Valuing coastal blue-green infrastructure:
Development of a dune system assessment methodology, Ōtautahi Christchurch, New Zealand.

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Abstract

With climate change causing an increased intensity and frequency of natural hazard events, coastal communities are realising the need for adequate adaptation to remain resilient. The limitations of traditional hard-engineered approaches as coastal protection are becoming more prevalent and evident. Recent scholarship emphasises the need for a paradigm shift towards incorporating nature into coastal adaptation, including sand dunes, salt marsh, and wetlands. Using coastal blue-green infrastructure (CBGI) as an adaption response provides a multitude of benefits that extend beyond coastal protection, though the complete CBGI values set is often not well understood or underrepresented. The low-lying delta city of Ōtautahi Christchurch, New Zealand, is at a critical point where a comprehensive approach to coastal adaption planning in a changing climate is being addressed for the first time. This process has started at a time when built infrastructure data is generally available and far more prioritised while CBGI data is relatively patchy to absent. In response, this study develops a methodology to assess the values of the New Brighton coastal sand dune system, a significant CBGI resource fringing the city's open coast.

A CBGI assessment methodology was developed through a global review of the history and different types of CBGI, while critically analysing the potential applicability of approaches to the New Brighton coastal sand dune system. A 'Nature's Contribution to People' approach was used to develop a set of appropriate valuation methods. This methodological development and selected assessment results for the New Brighton coastal sand dune system are then explained. Key findings are that sand dunes have a multitude of values with many of them requiring a contextual measurement approach. Despite the challenges of value determination, results clearly indicate that the New Brighton coastal sand dune system needs space for migration with climate change which currently does not exist due to urban development, and further plantings of native species, such as spinifex (*Spinifex sericeus*) and pīngao (*Ficinia spiralis*), to aid with the maintenance and enhancement of its ecology, aesthetic, and protection values.

This research is significant as it provides a baseline of the current dune system CBGI values for Ōtautahi, which can be used by the government and community to understand the benefits of existing CBGI as an adaptation response to climate change. It also highlights the work needed to recognise, value, enhance and further implement a nature based coastal protection approach at the core of coastal settlement climate change responses throughout New Zealand.

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3D	Three dimensional
AEP	Annual exceedance probability
AMSL	Average mean sea level
ARI	Average recurrence interval
BGI	Blue green infrastructure
BM	Black Maps
BMAP	Beach morphology analysis programme
BMP	Best management practices
CBGI	Coastal blue green infrastructure
CCC	Christchurch City Council
CO_2	Carbon dioxide
DOC	Department of Conservation
DEM	Digital elevation model
EBA	Ecosystem based approach
ECan	Environment Canterbury
EDRR	Ecosystem disaster risk reduction
EE	Ecological engineering
EPA	Environmental Protection Agency
GDP	Gross domestic product
GFP	Green flood protection
GI	Green infrastructure
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental panel on climate change
LID	Low Impact Development
LVD37	Lyttleton vertical datum 1937
MEA	*Millennium Ecosystem Assessment*
MSL	Mean sea level
NBI	Nature based infrastructure
NBS	Nature-based Solutions
NCP	Natures contribution to people
NIWA	National Institute of Water and Air
NNBF	Natural and nature-based features
NZ	Aotearoa New Zealand
NZCPS	New Zealand Coastal Policy Statement
RCP	Relative concentration pathway
RMA	Resource Management Act 1991
SLR	Sea level rise
SSP	Shared socio-economic pathway
SuDs	Sustainable urban drainage system
UAV	Unmanned aerial vehicle
UK	United Kingdom
USA	United States of America
USACE	United States Army Corps of Engineers
VLM	Vertical land motion
WSUD	Water sensitive urban design

Māori terminology

Ātua	"*Ancestor with continuing influence, god, demon, supernatural being, deity, ghost, object of superstitious regard, strange being*" (Ngata, 1993 p182)
Hapū	"*Pregnant, subtribe*" (Hamsworth & Awatere, 2013 p 284)
Ingoa Wāhi	"*Māori place names*" (Ngata, 1993 p 340).
Iwi	"*Tribe, bones*" (Hamsworth & Awatere, 2013 p 284)
Kai	*"Food*" (Ngata, 1993 p 161)
Kaitiakitanga	"The *act of guardianship*" (Matu, 1994 in Roberts et al., 1995 p12).
Kete	"*Woven bags*" (Herbet & Oliphant, 1991 p2)
Ki uta ki tai	Explains the overall Māori approach to resource management as "*a whole landscape approach, understanding and managing interconnected resources and ecosystems from the mountains to the sea*" (Harmsworth & Awatere, 2013 p275).
Mahinga kai	"*The places where natural resources were/ are obtained, the resources themselves and the practises and principles that guided how these resources were harvested and managed*" (Matapopere Charitable Trust, 2015 p7).
Mana	"*Authority and prestige*" (Walker, 2019 p2)
Manakitanga	Describes the ability of someone to fulfil the obligations of a host and "*extend hospitality and reciprocity"* (Matapopere Charitable Trust, 2015 p12).
Manuhiri	"*guest*" (Ngata, 1993 p190)
Mātauranga Māori	"*Māori knowledge*" (Walker et al., 2019 p2)
Mauri	"The *life force present in all things, both animate and inanimate"* (Royal, 2003, p. 47).
Pare	*"Headband*" (Herbet & Oliphant, 1991 p2)
Pōtae	"*Hat*" (Herbet & Oliphant, 1991 p2)
Rongoā	"R*emedy, medicine, treatment*" (Scheele et al., 2016 p9)
Tangata whenua	*"People of the land, connected to place (e.g., river) through a distinct whakapapa*" (Harmsworth & Awatere, 2013 p285)
Taonga	"*Treasured resources, a prized possession, precious resources, iconic species*, *etc*." (Hamsworth and Awatere, 2013 p284)
Taonga tuku iho	"*Intergenerational protection of highly valued taonga, passed on from one generation to the next, in a caring and respectful manner"* (Hamsworth & Awatere, 2013 p 275)
Te ao Māori	"*Māori world view*" (Hamsworth & Awatere, 2013 p 284)
Te taha hinengaro	"*Psychological health*" (Durie, 1982 np)
Te taha tinana	"*Physical health*" (Durie, 1982 np)
Te taha wairua	"*Spiritual health*" (Durie, 1982 np)
Te taha whānau	"*Family health*" (Durie, 1982 np)

Te Whare Tapa Whā	An indigenous framework signifying a meeting house which is a symbol used to illustrate the dimensions of well-being to Māori as seen in Figure 41 (Durie, 1982).
Tikanga Māori	"*Traditions and customs passed down through generations". *Tikinga Māori is about "*protocols and customs... and can vary between hapū and iwi"* (Nā, Maahanui Kurataiao Ltd, 2017 p9).
Tirangawaewae	*"Inherited rights and obligations associated with belonging to a place that claims those with Māori ancestry by virtue of all the above*" (Smith, 2004, p1)
Tūrangawaewae	Tūrangawaewae is someone's "*sense of place*" and identity (Scheele et al., 2016 p120.
Wāhi tapu	"P*laces link with death or ceremonies*" (Nā, Maahanui Kurataiao Ltd, 2017 p8).
Wāhi Toanga	"P*laces that are treasured or valued by manawhenua/ tangata whenua*" (Nā, Maahanui Kurataiao Ltd, 2017 p8).
Wai	*"Water"* (Ngata, 1993 p526)
Wai tai	"C*oastal water*" (Nā, Maahanui Kurataiao Ltd, 2017 p9).
Waiata	"*Song*" (Smith, 2004 p1)
Waikino	"*Polluted waters*" (Ngata, 2018 np)
Waimate	"*Stagnant, dead, or death-inducing waters*" (Ngata, 2018 np)
Waiora	"*Healthy water*" (Ngata, 2018 np)
Wairiki	"*Water that can heal*" (Ngata, 2018 np)
Wairuatanga	"*Spirituality*" (Patterson, 1992)
Waiunu	"*Drinking water*" (Ngata, 2018 np)
Waiwhakaika	"*Ceremonial water used for embedding knowledge*" (Ngata, 2018 np)
Whaikōrero	"*Oratory, oration, formal speech-making*" (Ngata, 1993 p 331)
Whakapapa	"C*onnection, lineage, or genealogy between humans and ecosystems and all flora and fauna*" (Harmsworth and Awatere, 2013 p275)
Whakatauki	"*Proverbs*" (Smith, 2004 p15)
Whānau	"*Family, extended family (incl. cousins, twice, thrice over, etc.)"* (Hamsworth & Awatere, 2013 p 284)
Whanaungatanga	"C*ommunity connectivity*", refers to "*how well whānau, hapū and iwi well-being and social prosperity is improved through their connection to, and interactions with, the natural environment*" (Scheele et al., 2016 p5).
Whāriki	*"Mat"* (Herbet & Oliphant, 1991 p2)
Whenua	"*Land*" (Herbet & Oliphant, 1991 p2)

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1 Introduction

This chapter begins with a thesis statement outlining the research gap and scope, followed by sections reviewing the climate change context and coastal adaptation options facing coastal communities today. This sets the scene for understanding the need to value Coastal Blue Green Infrastructure (CBGI) globally and, as the focus of this research, in Ōtautahi Christchurch. Finally, the thesis aim, and objectives are outlined along with the thesis structure.

1.1 Thesis statement

Climate change may be characterised as a 'wicked' problem, with significant and irreversible changes resulting globally (Incropera, 2016). Internationally, coastal communities are impacted by both acute and chronic stressors accompanying climate changes. Over 600 million people reside in coastal areas less than 10 m above sea level (United Nations, 2007). Settlement patterns combined with accelerated sea level rise (SLR), causes ecosystem loss, increased coastal erosion and inundation (Wong et al., 2014). Coastal communities need to have adequate adaptation and protection options to build resilience in the face of such challenges (United Nations, 2007).

Traditionally, many *minority world*[1] coastal communities such as Aotearoa New Zealand (NZ) have 'held the line' or shoreline position with the use of 'hard' coastal protection measures (e.g., sea walls, groynes, revetments). These structures attempt to build a barrier between hazards and coastal communities (Sutton-Grier et al., 2015) but over the last century research has identified their many flaws (French, 2001; Morris et al., 2018; Williams et al., 2016). While hard shoreline infrastructure may protect in the short term, over the long-term they can exacerbate coastal erosion, increase the likelihood of inundation disasters, and degrade or cause the loss of intertidal ecosystems via coastal squeeze. Dune, saltmarsh, and mangrove ecosystems are especially threatened (Nicholls et al., 2007). In a negative spiral, coastal ecosystem losses due to hard structures can increase community vulnerability to climate change (Barbier et al., 2011). Such adverse effects need to be recognised in coastal community hazard and climate change adaptation assessments.

New, more environmentally beneficial methods of coastal protection are emerging internationally (Karanikola et al., 2016), including Coastal Blue-Green Infrastructure (CBGI). CBGI is an approach to

[1] The term 'minority world' refers to countries and regions previously referred to as 'Western', 'developed' or 'Global North'. This term seeks to decolonise regional descriptors and to bring recognition that such places are in fact in the minority in terms of the world's populations, with areas previously referred to somewhat patronisingly as 'non-Western', 'developing world' or 'Global South' referred to as 'majority world' according to this terminology.

coastal protection that utilises nature-based amenities and processes to provide erosion and inundation protection while offering many co-benefits (Sutton-Grier et al., 2015). CBGI enhances the natural, social, and economic capital of a community, therefore, increasing resilience, with positive impacts reaching beyond those directly affected by flood protection (Saleh & Weinstein, 2016). A significant research gap exists in NZ's coastal adaptation space in terms of our lack of awareness and assessment of our CBGI resources and its value at local to national scales. Recognition of CBGI resources has the potential to underpin a paradigm shift in coastal management and community perspectives in NZ, towards more sustainable coastal adaptation.

This thesis sets out to raise awareness of the multitude of values that CBGI has here in NZ, specifically the values of the dune system in Ōtautahi. It begins by setting the scene for climate change adaptation in coastal environments.

1.2 Global effects of climate change on coastal environments and communities

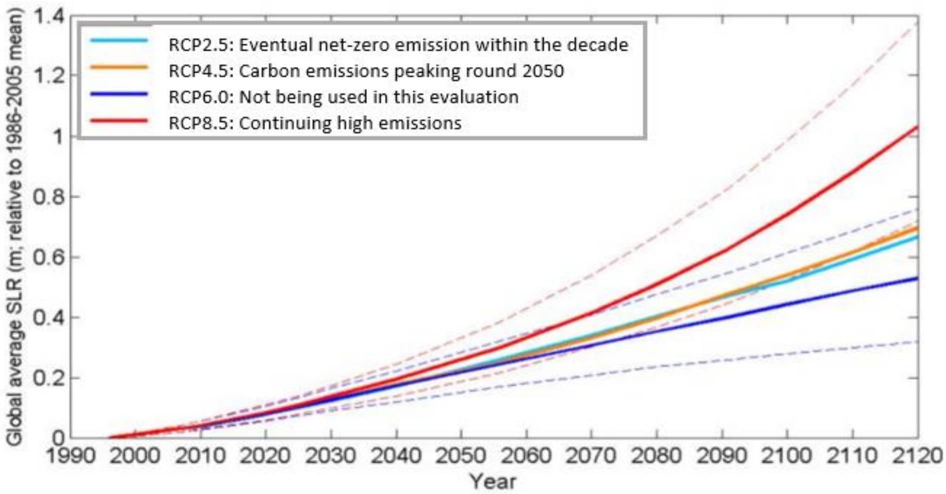
Climate change is a 'wicked' problem that is causing significant and irreversible changes to the world (Incropera, 2016). From 1880 to 2020 global temperatures have been warming at an average rate of 0.07°C per decade. Since the industrial era, beginning in 1760, humans have become the biggest driver of planetary change, with anthropogenically induced global warming accelerating to a rate of 0.18°C per decade (NOAA, 2020). The Intergovernmental Panel on Climate change (IPCC) 5th assessment revealed that the ocean has absorbed 93% of the increase in planetary heat (Rhein et al., 2013), with more recent IPCC studies indicating sea surface temperatures warmed on average by around 1°C between 1981 and 2017 (Allen et al., 2018). This acceleration in warming is predicted to significantly affect coastal areas globally through accelerated SLR, increased sea surface temperatures, larger storm surges and extreme wave events. Coastal areas are projected to also be affected by more intense and frequent tropical and ex-tropical cyclones and hurricanes, altered precipitation and runoff, changes in sediment supply, and increasing ocean acidification. These changes are likely to produce increased coastal erosion and increased frequencies and extents of coastal inundation, with effects varying at both local and regional scales (IPCC, 2014; Nicholls et al., 2007; Wong et al., 2014).

The extent of these climate change effects depends primarily on the cumulative quantity and types of greenhouse gasses that human activities emit. Due to uncertainties in future human activities, four scenarios or 'relative concentration pathways' (RCPs) have been modelled by the IPCC, corresponding to various development and population projections and their likely future greenhouse gas emission figures (Church et al., 2013). These RCPs include one mitigation pathway (RCP2.6) that requires the removal of some of the carbon dioxide currently in the atmosphere; two stabilisation pathways (RCP4.5 and RCP6.0), and a pathway (RCP8.5) that has been called ‘business as usual’, and which involves no reduction in the greenhouse gasses quantities that are emitted and thus very high greenhouse gas cumulative atmospheric concentrations by 2100 and beyond (IPCC, 2014; Stephens., 2015). These scenarios are used to project the effects of climate change, including on SLR, coastal erosion, and increased storminess (IPCC, 2014).

The global mean sea level (MSL) is projected to rise by 2100 between 0.29 to 0.59 m (RCP2.6 likely range) and 0.61 to 1.10 m (RCP8.5 likely range) compared to global MSL in 1986 to 2005 (Oppenheimer et al., 2019). Figure 1 illustrates the SLR projections under each scenario. Note the slow transfer of atmospheric heat into the oceans and melting responses of ice sheets mean that long time lags are involved between greenhouse gas emissions ceasing and new climate equilibriums establishing (Oppenheimer et al., 2019). Thus, thermal expansion of the oceans and ice sheet melting are projected to cause SLR for centuries, even under scenario RCP2.5 (Edwards et al., 2021). Ongoing SLR is, therefore, inevitable over historic timescales, with at least a global mean SLR of 0.29 to 0.59 m occurring by 2100 (Rhein et al., 2013).

Figure 1- Global average sea level rise (SLR) projection trajectories to 2120

Note: Projections are originally from the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report, as adapted by Stephens (2015, p17) and include the median projections (solid lines) for the Regional Concentration Pathways RCP2.6, RCP4.5, RCP6.0 and RCP8.5, plus their ‘likely ranges’ (dashed lines).



Globally, over 600 million people reside in coastal areas less than 10 m above sea level (United Nations, 2007). Human settlement patterns combine with accelerated SLR to produce ecosystem losses, increased coastal erosion and inundation leading to billions of dollars’ worth of damage to coastal communities (Wong et al., 2014). Like climate system responses, human development patterns also involve climate adaptation response lags, with living by the coast ever popular despite increasing hazards. It is predicted that by 2080 there will be up to 5 billion people residing in coastal areas (Nicholls et al., 2015). Climate change is going to have significant impacts on these coastal communities as coastal ecosystems become degraded further and coastal protection measures are stressed to their limits, with many eventually failing (Morris, 2018). Under scenario RCP8.5 by 2100, with an assumption of no coastal protection, more frequent and intense coastal inundation events alongside coastal erosion could threaten assets worth up to 20% of global Gross Domestic Product (GDP) and put an increased 48% of developed land at risk of episodic coastal flooding from a one in 100-year return period event (Kirezci et al., 2020). Such changes could uproot coastal communities, destroy livelihoods, and have significant negative impacts on coastal dwellers' mental health (Fisher et al., 2011). Substantial pressures would be placed on governmental organisations to financially support at-risk communities, with insurance prices escalating in particular in minority world (developed country) settlements. In response to these exacerbated stressors coastal retreat, whereby communities relocate their dwellings and infrastructure inland, will become a necessary response to climate change (Carey, 2020).

1.3 Coastal options for climate change adaptation

Globally coastal communities are going to be significantly impacted by the acute and chronic stressors that accompany climate change. These communities need to have adequate coastal protection and adaptation strategies to remain resilient to these challenges (Table 1) (United Nations, 2007). Six main categories of response types have been identified for coastal communities to ensure they remain resilient to climate change: no response, advance, protection, retreat, accommodation, and ecosystem-based adaptation which can provide more protection than retreat by itself (Figure 2).

Figure 2- Illustration of six main options for coastal adaptation to climate change.

Note: modified from Oppenheimer et al. (2019, p87).

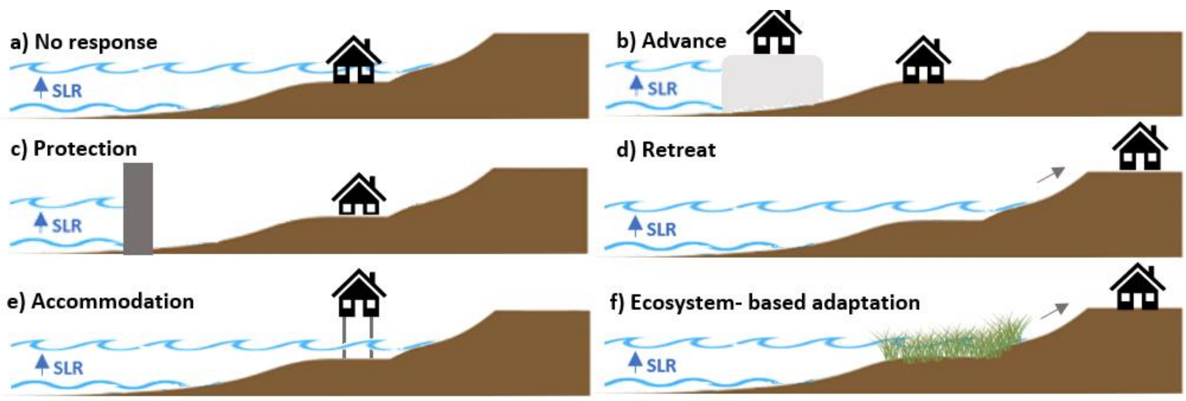


Table 1- Different approaches to coastal adaptation with their associated strengths and weaknesses.

Note: modified from Sutton-Grier et al. (2015, p141).

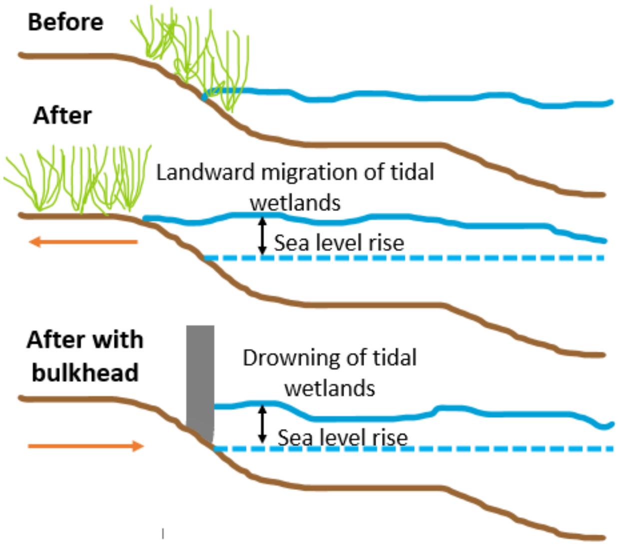
Type	Strengths	Weaknesses
Built (Revetments, groynes, levees, bulkheads, etc.)	• Significant expertise already exists on how to design, build and implement such approaches • Excellent understanding of how these approaches function and what level of protection will be provided by different types of structures built to specific engineering standards • Ready to withstand a storm event as soon as they are constructed	• Does not adapt to changing conditions such as the sea-level rise • Weakens with time and has a built-in lifetime • Can cause coastal habitat loss, significant erosion and have negative impacts on the ecosystem services provided by nearby coastal ecosystems • Can provide a false sense of security to communities leading to increased loss of life or property • May sustain more damage during small storm events than natural approaches • Only provides storm protection benefits when a storm is approaching; no co-benefits accrue in fair weather
Natural (Salt marsh, mangroves, beach renourishment, dune restoration or building, oyster and coral reefs, etc.)	• Provides many co-benefits in addition to coastal protection such as fishery habitat, water quality improvements, carbon sequestration and storage, and recreational use. These benefits are provided to coastal communities all the time, not just during storm events • In the case of ecosystem restoration, the ecosystem grows stronger with time as it becomes established • Has the potential to self-recover after a storm or forcing event • Can keep pace with sea-level rise • Can be cheaper to construct • Can survive smaller storms with less damage than built infrastructure and can self-repair	• Need to develop best practices for how to restore ecosystems (can be destroyed by diseases, consumers and disturbances) • Provides variable levels of coastal protection (non-linearity of the provisioning of coastal protection benefits) depending on the ecosystem, geography, season and also on the type and severity of the storm • Require more research to better understand how to estimate or predict the coastal protection provided • In the case of restored ecosystems, it can take a long time for ecosystems to get established and to provide the necessary level of coastal protection • Likely requires a substantial amount of space to implement natural approaches (such as ecosystem restoration or protection of existing ecosystems) which may not be possible • Minimal data available on the cost to benefit ratio for projects • Permitting for natural projects can be a more difficult process than for built projects • Growing but still limited expertise in the coastal planning and development community on which approaches to use where and when
Hybrid (Combination of built and natural such as salt marsh and seawalls or dune fencing)	• Capitalizes on best characteristics of built and natural • Allows for innovation in designing coastal protection systems • Provides some co-benefits besides coastal protection • Can provide a greater level of confidence than natural approaches alone • Can be used in areas where there is little space to implement natural approaches alone	• Little data on how well these systems perform to date • Does not provide all the same benefits that natural systems provide • Need more research to design the best hybrid systems • Growing but still limited expertise in the coastal planning and development community on which approaches to use where and when • Hybrid systems, due to the built part of them, can still have some negative impacts on coastal ecosystems • Little data on the cost to benefit ratio for projects • Permitting for hybrid projects can be a more difficult process than for built projects

Traditionally, many minority world coastal communities such as NZ have ‘held the line’ or shoreline position with the use of ‘hard’ coastal protection measures such as sea walls, groynes, and revetments. These structures act to build a barrier between hazards and coastal communities (Sutton-Grier et al., 2015) (Table 1). Hard coastal protection measures aim to ensure communities can maintain the shoreline position in the face of climate change effects. Over the last century research has identified many flaws with this type of approach (French, 2001; Morris et al., 2018; Williams et al., 2016). While hard shoreline infrastructure may protect coastal communities in the short term, they typically exacerbate beach erosion alongside and/or in a seaward direction, due to their truncation of natural sediment supplies to beach backshores (Sutton-Grier et al., 2015; Zhu, Linham & Nicholls, 2010). A study conducted by Brown & McLachlan (2002) indicated that artificial structures such as sea walls may be responsible for more than 80% of the losses from sedimentary shorelines worldwide.

Recent studies have identified that hard coastal infrastructure can also damage natural ecosystem services and coastal environment resources by causing coastal squeeze (Cooper et al., 2020). This is a phenomenon whereby the increasing populations residing by the coast put immense stress on coastal systems via the building of hard infrastructure in coastal areas to protect developments. Ecosystem degradation results with SLR and the inability of intertidal ecosystems to retreat inland across hardened shorelines, since high-water marks are fixed by infrastructure boundaries (Martinez, 2014). Essential coastal ecosystems and their associated services are thus lost (Figure 3). Dune as well as saltmarsh and mangrove coastal wetland ecosystems are especially threatened where they are sediment starved or constrained on their landward margin (Nicholls et al., 2007). Coastal ecosystem deterioration due to human activities is intense and increasing: 50% of salt marshes, 35% of mangroves, 30% of coral reefs, and 29% of seagrasses have either been lost or degraded worldwide (Barbier et al., 2011). Coastal squeeze affects numerous ecosystem services, causing impacts such as degraded fisheries, habitat loss, declining water quality, decreased coastal protection, and increased biological invasions. In a negative spiral, coastal squeeze induced degradation of ecosystem services can thus increase coastal community vulnerability to climate change (Barbier et al., 2011). Such adverse effects need to be accounted for in coastal community hazard and climate change adaptation option assessments.

Figure 3- Coastal squeeze.

Note: modified from Kennish et al. (2020, p158).



Other significant issues are associated with hard engineering coastal protection approaches. For example, such infrastructure can provide a false sense of security to coastal residents by creating a perception that development landward of coastal protection structures is safe from natural hazards (Sutton-Grier et al., 2015). This perception promotes increased coastal urbanisation and development. Unfortunately, such structures can fail and are expensive to maintain, thereby increasing community vulnerability to inundation and erosion over long timescales (Williams et al., 2016). Additionally, material like concrete used for these protection structures are not environmentally friendly, producing large volumes of greenhouse gas emissions, requiring large volumes of resources such as sand in their fabrication, and leaching pollutants into coastal environments (Sutton-Grier et al., 2015).

As disadvantages of hard engineering have become more widely documented, new and less environmentally destructive methods of coastal protection have emerged such as Coastal Blue-Green Infrastructure (CBGI). CBGI is an approach to coastal protection that utilises nature-based amenities and processes to provide coastal erosion and inundation protection, as well as offering a multitude of co-benefits to coastal communities (Sutton-Grier et al., 2015). CBGI can involve sand dune restoration or creation, beach renourishment, coastal wetlands, seagrass, mangroves, salt marshes, artificial reefs, and/or a combination of built and green infrastructure known as a hybrid approach (Cunniff & Schwartz, 2015). This natural or nature-based approach to coastal adaption has been implemented successfully internationally (Karanikola et al., 2016), with co-benefits including reducing multi-hazard vulnerability, enhanced water quality, improved biodiversity, benefiting well-being and community connections, providing habitats, carbon sequestration, increased tourism, economic benefits, and community amenity (Cunniff & Schwartz, 2015; Sutton-Grier et al., 2015) (Table 1). CBGI enhances the natural, social, and economic capital of a community, therefore, increasing resilience, with positive impacts reaching beyond those directly affected by flood protection (Saleh & Weinstein, 2016). Additionally, unlike sea walls, CBGI does not promote development within proximity to the coast as it generally takes up a larger area of space than 'hard' infrastructure, so CBGI does not increase the vulnerability of coastal urbanisation (Cunniff & Schwartz, 2015 & Zhu et al., 2010). While typically requiring more space to implement, CBGI can be far more cost-effective than hard engineering over the long-term since it can adapt to climate change and has self-repair mechanisms in response to many types of hazard event such as with storms (Gittman et al., 2014). CBGI is a more proactive and holistic approach to coastal protection, which is needed in the face of climate change (Williams & Micallef, 2009).

1.4 The need to value CBGI

Due to the benefits of CBGI which create a very high value coastal protection method, this approach is becoming more popular globally with a recent article published in 2020 indicating that approximately 35% of the global coastal communities now receive CBGI storm surge mitigation rather than the traditional hard engineering approach to coastal protection (Van Coppenolle & Temmerman, 2020). This is a significant proportion of global coastal communities that have now adopted a softer approach to coastal protection alongside or rather than the more traditional hard engineered approach. As the co-benefits of CBGI are felt by coastal communities, countries have begun to map and monitor the extent of CBGI to ensure that this resource is not depleted or destroyed, and its values are recognised. For example, the European Union has a system whereby it has defined Blue-Green Infrastructure (BGI) as "*A strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas*" (Medarova-Bergstrom et al., 2014, p. 21). The BGI definition is employed to map the extent of BGI, including CBGI, in Europe. Linkages can then be made between the value and extent of BGI, including CBGI. The BGI mapping strategy aims to prevent the loss of BGI in Europe and recognise the need to restore and promote BGI for its co-benefits to be felt. This mapping strategy ensures that the value of BGI is recognised and, thus, is protected and further development of BGI is advocated. This is a practice that could be implemented in all countries to help BGI, including CBGI, become a recognised, valued, and protected resource.

NZ, a country with one of the longest coastlines in the world of approximately 15,000 km and with more than 75% of the population residing within 10 km of the coast, is a nation that has ample CBGI, almost all of which has not had its value recognised or monitored (Colin et al., 2018). This CBGI includes coastal sand dunes, salt marsh, mangroves, seagrass, kelp, and wetlands. This lack of recognition, alongside population, agricultural and urban expansion has contributed to the significant degradation of these coastal ecosystems, as well the public having a general lack of understanding and awareness of all the values CBGI can and is bringing NZ (Bergin, 2011). CBGI monitoring techniques similar to the European Union mapping approach to assess the value of CBGI, mapping and evaluating the benefits of various CBGI in NZ, could promote recognition of the values of these coastal ecosystems and subsequently aid support and resources going towards protecting and enhancing these coastal environments. Recognition of CBGI resource extents and values could underpin a potential paradigm shift in thinking towards a more sustainable approach to coastal adaptation in NZ.

1.5 Case study- Ōtautahi, Christchurch, New Zealand

Ōtautahi, a coastal delta city with a population size of c. 400,000 residents (Statistics New Zealand, 2018), is located on the east coast of the South Island in NZ (Figure 4). Ōtautahi's Coastal Park [2] consists of both an open coastline and an estuarine system. This study will focus on a section of this city's open coastline comprising of the dynamic dune system located on New Brighton Spit.

New Brighton Spit first formed approximately 6000 years ago. During the quaternary there were large fluctuations in sea level which caused sedimentation in the coastal regions of Canterbury (Comfort, 1995). This sedimentation caused Canterbury coastline to prograde utilising coastal processes such as longshore drift which took sediment from the Waimakariri, Kowhai, and Ashley Rivers and deposited it along Pegasus Bay. Approximately, 68% of New Brighton's Spit sediment is from the Waimakariri River (NIWA, 2018). Sand sources for the spit also originate from other rivers, erosional sediment from other coastal areas, and continental shelves. New Brighton Spit is a dynamic coastal environment, accreting and eroding as sediment supply fluctuates alongside changes in frequency and intensity of storms, tectonic activity, and climate change (Hart, Marsden & Malcom, 2008). Sand availability can be reduced during long term storm surge repetitions due to high energy waves washing away sediment and the beach not having time to recover between each successive storm (this occurred in the 1970's). This causes degradation of New Brighton spit. Erosion also occurred during the Canterbury 2011 earthquake due to an abrupt rise in sea level (1.1m) that

[2] Coastal parks are a "*network of protected areas owned and managed by Christchurch City Council (CCC) on behalf of the community*" (Orchard, 2014 p84).

washed away a large portion of the Spit (Kelland, 2013). Today the spit is accreting with a positive sediment budget which is projected to remain in a surplus at least up until 2020, unless the climate change RCP8.5 scenario eventuates (NIWA, 2018).

New Brighton Spit ranges in elevation from approximately 5 to 13 m above MSL (Hart and Knight, 2009) and is an important coastal asset to the city and its communities (Duns, 1995; Carass 2020). The dune system provides recreational activities and ecological habitats as well as acting as a critical form of coastal defence by dissipating and reflecting wave energy offshore and away from the coastal communities located in the hinterland (Carass, 2020; Duarte et.al. 2013; Tonkin & Taylor 2021; Tonkin & Taylor 2021a). At various times in the past, this coastal sand dune system has been significantly degraded as a result of human activity and limited appreciation and knowledge of all the benefits and functioning the sand dune system can provide (Mr J., Roberts, CCC Coast Care Park Ranger pers. comm. 29/10/21). Though efforts over recent decades by the Christchurch City Council (CCC) park rangers have seen an increasing focus on enhancing the dune geomorphic and ecological resources while managing human use of this environment, in particular through native plantings and beach accessways. Like elsewhere in NZ (Hilton et al., 2006), the very significant historic degradation of the coastal sand dunes along Southern Pegasus Bay has led to a reduction in their cultural, ecological, and recreational amenity values. As coastal hazards become exacerbated with climate change, the coastal communities along the New Brighton coastline face increasing risks from inundation and erosion processes (Tonkin & Taylor, 2021). It is, therefore, essential that this coastal sand dune system is valued, protected, and enhanced to ensure that the existing benefits of the coastal sand dune system can continue to be enjoyed.

Figure 4- The New Brighton Dune system.

Note: The map on the left indicates where Ōtautahi and New Brighton Spit are located within New Zealand. The image on the right is looking north into Pegasus Bay and along a section of New Brighton Spit. The dune system is labelled and the urban development in the coastal hinterland of New Brighton is also visible. Adapted from Google images (2022).

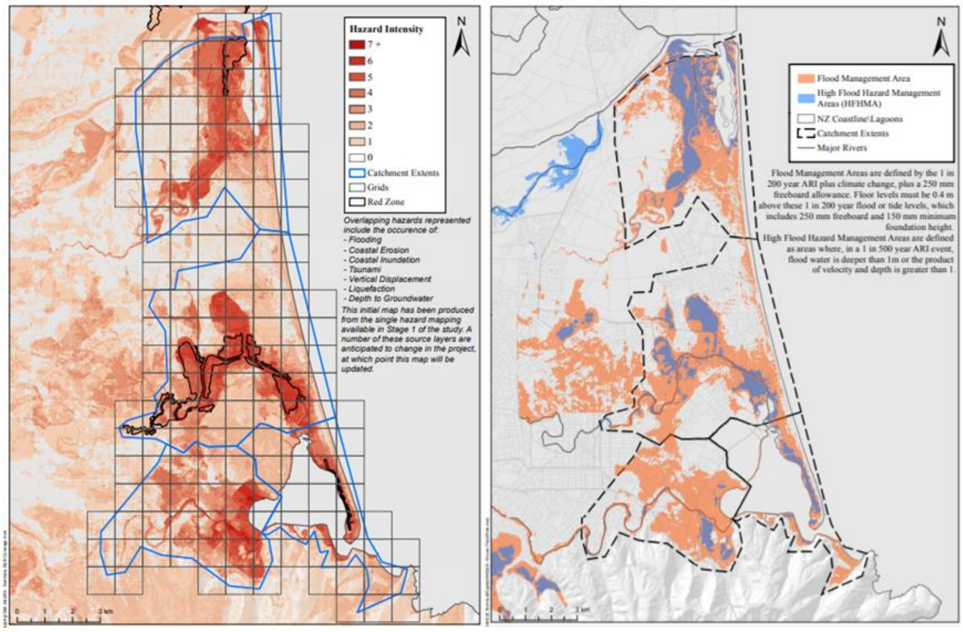
Impacts of climate change on Ōtautahi coastal environments

Ōtautahi is vulnerable to the impacts of atmospheric and coastal-ocean hazards such as SLR and erosion, in part because of its low-lying, low-gradient topography (Todd et al., 2017) (Figure 5). SLR has been occurring over the 20th Century on average at 1.7 ± 0.1 mm/year in NZ and is forecast to accelerate to 2.0 ± 0.15 mm/year due to climate change. Ōtautahi's seaboard has also been subsiding at 0.2 mm/ year during the quaternary period, with the 2010/ 2011 Canterbury Earthquake Sequence causing subsidence of 0.5 to 1 m in some areas of the Ōtautahi flood plain (Hughes, 2015; Wellmen, 1979). Due to the combination of SLR and ongoing land subsidence, it is projected a total SLR of 0.30 to 0.41 m will occur in Ōtautahi by 2065 (Hannah and Bell, 2012; Tonkin & Taylor, 2021).

Alongside SLR, the El Niño-Southern Oscillation is predicted to intensify, with La Niña conditions causing significant erosion in coastal areas of NZ (Barnard et al., 2015; Smith & Benson, 2001; Stephens, 2015; & Ummenhofer & England, 2007). In Ōtautahi, climate change may result in coastal inundation extending across a larger area of hinterland due to increased storminess and SLR combined with extreme high tides, storm surges and/ or large waves (Todd et al., 2017; Tonkin & Taylor 2021). This is predicted to put 1000 properties at risk of coastal erosion and may result in 25,000 properties being exposed to coastal flooding in Ōtautahi in the next 100 years (CCC, 2020a).

Figure 5- Flooding and multi-hazards in the Christchurch City District.

Note: (left) spatial location and concentration of flood related hazards (between 1 and 7+ hazards as indicated by the strength of the red colouring), and (right) projected coastal suburb flood management areas for 2065 with High Flood Management Areas highlighted in blue and Flood Management Areas highlighted in orange (from Todd et al. 2017, p127 and 153).



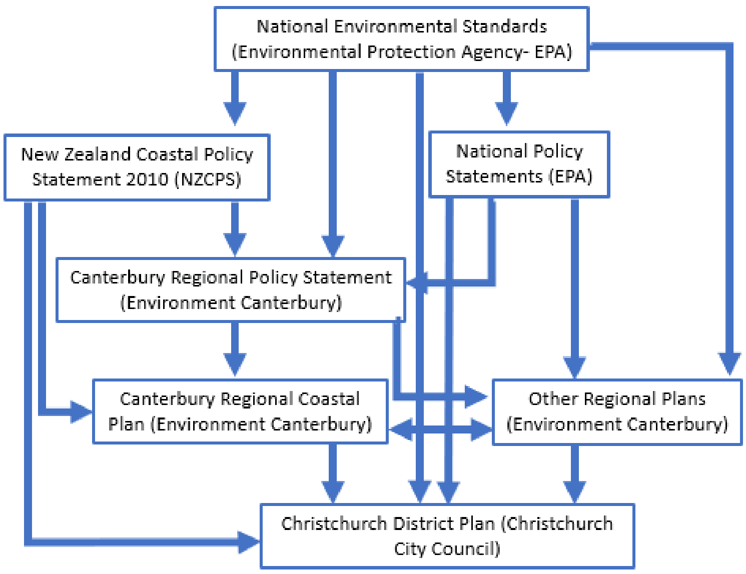
Policy and coastal adaptation in Ōtautahi

The 2065 predicted flood management area for the Ōtautahi city coastal suburbs is shown in Figure 5, highlighting the particular vulnerability of these areas in future flooding due to SLR (Todd et al., 2017). This map, along with Tonkin and Taylor (2021) coastal hazard assessment predictions, suggests that climate change will significantly impact Ōtautahi coastal environments within the next century. Coastal adaptation responses need to be implemented proactively to ensure coastal communities can adapt adequately to climate change (DOC, 2010).

The need for climate change hazard assessment and coastal adaptation planning is recognised in various plans and policies at a national and local level in NZ and Ōtautahi (Tonkin & Taylor, 2017) (Figure 6). There are numerous statutory documents overseeing management of the coastal area in Ōtautahi, with the main one being the New Zealand Coastal Policy Statement 2010 (NZCPS) (DOC, 2010). NZCPS Objective 5 ensures that coastal hazard risks, taking into account climate change, are managed by "*locating new development away from areas prone to such risks, considering responses, including managed retreat, for existing development in this situation and protecting or restoring natural defences to coastal hazards*" (DOC, 2010, p.10). This objective is also reflected in the Canterbury Regional Policy Statement (2013) and the Regional Coastal Environment Plan for the Canterbury Region (2005) (Tonkin & Taylor, 2017).

Figure 6- Diagram explaining the relationship between the national, regional, and local policy that impacts Ōtautahi coastal environments

Note: modified from (Tonkin and Taylor, 2017).



The need to value CBGI in Ōtautahi Christchurch

Despite NZ's statutory documents promoting the use of CBGI as an adaptation approach, Ōtautahi has followed the historic global trend with traditional coastal adaption approaches typically being hard engineering (Rouse et al., 2017). This dependency on hard infrastructure to provide coastal protection and facilitate climate change adaptation has created a biased perspective amongst residents in Ōtautahi that 'hard' engineering is the only reliable method for coastal protection. Both Ōtautahi communities and coastal managers have not yet fully recognised that many coastal environments are already partly protected by CBGI (M. Anderson, CCC Planner, *pers. comm.*, March 3, 2021). For example, there are sand dunes on New Brighton Spit and in Clifton Bay and saltmarsh in areas of the Avon-Heathcote and Brooklands Lagoon estuaries. However, there are significant monitoring and research gaps concerning recognition of the coastal protection resource and amenity of these CBGI.

CCC is aware of the pressing need for further innovative coastal adaptation options and is currently undertaking a coastal adaptation planning programme called '*Coastal Futures*'. CCC's programme aims to gain an understanding of how Ōtautahi communities want to adapt to climate change induced coastal erosion, coastal inundation, and rising groundwater (CCC, 2020a). Community consultation commenced in August 2021 whereby community engagement with vulnerable coastal communities aimed to decide what type of coastal protection each community would prefer. However, if the value of CBGI is not recognised in Ōtautahi, it is unlikely new CBGI will be implemented as the community and stakeholders will not be aware of CBGI coastal protection value and extended co-benefits. Further, if the existing CBGI resources are not quantified and changes monitored, then the implementation of other 'coastal protection' measures could lead to the degradation or loss of CBGI resources. To avoid such maladaptive measures, an inventory is needed to assess the extent and current value of CBGI in Ōtautahi. This inventory could mirror research conducted in the EU that quantified the value of BGI and hence promoted its protection and further implementation in the European Union. This dune based CBGI research, conducted for the purpose of aiding adaption to climate change in Ōtautahi, NZ, will provide valuable guidance to authorities, such as the CCC, to ensure that a shift in thinking towards more sustainable coastal protection options can occur.

1.6 Research aim and objectives

This research aims to investigate the value of the CBGI of the New Brighton coastal sand dune system that exists in Ōtautahi. To achieve this overarching aim, the research has been broken down into four main objectives, each with associated research steps, as follows:

1. Define the concept of CBGI
    - Investigate the historical context of the term CBGI, providing perspective as to why the development of the terminology 'CBGI' is required for the purpose of this research and in the coastal space.
    - Provide a clear definition of CBGI that describes its purposes of natural and nature-based coastal hazard mitigation, plus co-benefits.
2. Identify the potential range of CBGI values
    - Identify the different types of CBGI with a focus on sand dune CBGI adaptation options used globally and summarise the strengths and weaknesses of each approach
    - Discuss why CBGI is preferred to hard engineering in coastal sand beach environments adapting to climate change.
3. Create a CBGI evaluation methodology applicable to local sand dunes
    - Identify different approaches to valuing CBGI and their associated strengths and weaknesses.
    - Select an appropriate framework in which CBGI can be valued for its coastal protection value.
    - Create a methodology by assessing international case studies and undertaking interviews with specialists that can be used to specifically measure and rank the 'value' of the New Brighton sand dune system.
4. Quantify the benefits of the New Brighton sand dune system, with a focus on its ability to provide coastal protection plus co-benefits.
    - Undertake fieldwork using an unpiloted aerial vehicle (UAV) to gather data to create a three-dimensional (3D) ortho-mosaiced image of three study sites within the New Brighton sand dune system.
    - Use this 3D ortho-mosaiced model, alongside interviews with specialists on CBGI, to apply the method developed in Objective 3 to determine the various values of the coastal dune system, with a particular focus on the coastal protection values.
    - Attribute data based CBGI quantified benefit scores to the three different study sites.
    - Discuss from these results ways to improve or enhance the method used to obtain the CBGI values of the New Brighton coastal sand dune system alongside what the results indicate regarding how the value of the New Brighton coastal sand dune system could be enhanced.

1.7 Thesis structure

As this thesis concerns the development of both conceptual and practically applicable definitions for use in an assessment methodology, it includes several literature analyses in order to develop a practical and applicable CBGI definition and an approach to valuing CBGI appropriate for use in NZ's regulatory and cultural context, followed by a case study application of the approach developed to demonstrate its usefulness in a specific coastal dune setting. The structure of this thesis is explained in Table 2.

Table 2- Structure of thesis

Chapter number	Chapter name	Chapter purpose and scope
1	Introduction	Chapter 1 provided the background and rationale for the research gap, identified the research aim and objectives, and broadly outlined the approach to addressing the aim and objectives.
2	Defining CBGI	This chapter critically analysed literature to produce an applied definition of CBGI that communicates its primary purpose of providing coastal protection. The chapter then reviewed the various types of CBGI that exist in dune system settings, including case studies of CBGI and further sections on the limitations of a hard engineered approach to coastal protection on sand beaches. The chapter finished by describing the CBGI of the New Brighton coastal sand dune system.
3	Methodology	Chapter 3 explains the overarching methodology employed to practically complete the CBGI baseline assessment of the regulatory, material and nonmaterial benefits of the New Brighton dune system.
4	Different approaches to valuing CBGI	Chapter 4 assesses potential approaches that could be used to measure the value of the CBGI of the New Brighton coastal sand dune system. It provides rationale on why the NCP approach to valuing nature was chosen and how this approach will be undertaken.
5	Assessment of regulatory dune system benefits	Chapter 5 describes what the regulatory benefits of the New Brighton coastal sand dune system are, how they were assessed, the results from the assessment and any limitations to using this approach and what further research could be done moving forwards.
6	Assessment of nonmaterial dune system benefits	Chapter 6 describes what the nonmaterial benefits of the New Brighton coastal sand dune system are, how they could be assessed, any results from the assessments that could be undertaken and any limitations to using this approach and what further research could be done moving forwards.
7	Discussion and conclusion	Chapter 7 discusses the thesis results and relates them back to the aim of this thesis of developing a CBGI dune system assessment value methodology. It then concludes this thesis by outlining the overall findings and where they sit in the field of CBGI research with limitations and opportunities for further research described.

2 Defining CBGI

This chapter summarises and critically analyses appropriate literature to produce a clear definition of CBGI that relates to the primary purpose of providing coastal protection. The purpose of this is to provide an applied definition of CBGI that can be used to classify CBGI confidently and consistently in NZ coastal settings such as the New Brighton dune system. After a clear definition has been established, the chapter then reports on a review of the various types of CBGI adaptation options that exist in sand beach and dune system settings, that is coastal settings which are relatable to the New Brighton dune system.

2.1 Blue-Green Infrastructure

CBGI is a term that has not been used much in peer-reviewed literature. After an extensive search of academic literature databases, it can be concluded that no published literature accessible therein has used these keywords together before to explain what this research refers to as CBGI. Therefore, it is important the concept is analysed and placed in the context of existing terminologies, with potential differences and overlaps acknowledged (Nesshöver et al., 2017). This section investigates the history of how the terminology surrounding CBGI has developed over time and assesses ambiguities in these concepts, making a clear argument for why the new term CBGI is required for assessing natural infrastructure values in a Ōtautahi coastal setting. Finally, a clear and concise practical definition of CBGI is provided, which is then employed in subsequent research steps.

As the term CBGI has not yet been adopted in coastal literature, the first step undertaken in the process of developing a definition was an assessment of closely aligned terminology. The concept that CBGI builds upon is BGI. Due to the numerous benefits BGI provides, and various historical purposes for BGI, there is ample international literature that offers differing definitions of this term depending on the primary purpose of the BGI in its local setting and the positionality of the researcher (Morris et al., 2018). For example, engineers, biologists, coastal scientists, freshwater scientists, and geographers can have different perspectives on what BGI is, and its main purpose. These various perspectives have resulted in conceptual ambiguity and inclusion of a wide range of infrastructure, the majority of which does not primarily ‘protect’ coasts (Nesshöver et al., 2017). The first section of this literature review aims to assess the development of the term BGI over time, building an argument as to why this term today is interchangeable with many other terms, the confusion surrounding this terminology, and the need for a new concept which has a clearer focus on natural infrastructure in coastal environments.

Using BGI to adapt to climate change and manage water systems sustainably has historically focussed on inland freshwater systems, with coastal area applications only developing and increasing in popularity more recently (Evans et al., 2019). A literature review conducted by Ruangpen et al. (2020), which had the purpose of understanding the research area surrounding nature-based solutions and their ability to provide hydro-meteorological risk reduction, provided insight into the lack of coastal focus in current BGI terminology use. The authors undertook a comprehensive review of literature, utilising the databases of Scopus and Web of Science in their studies. Initially, 1650 articles were selected for review. However, following the discarding of articles that did not focus on nature-based solutions having the primary purpose of risk reduction or which did not contain key terminology such as 'hydrology', 'coastal', or 'risk', there were 146 articles that were critically analysed in full. Of the articles analysed, only 6% of them included the capabilities of BGI to reduce coastal flooding, while 82% focussed on the capacity of BGI to reduce urban flooding and 12% had an unclear focus on either terrestrial or coastal environments (Ruangpen et al., 2020). This literature review raised the concern that BGI, although having ample potential to be utilised in coastal environments to provide coastal protection, had not been employed to anywhere near its full potential in this space in the past.

The bias in the concept of BGI towards terrestrial freshwater systems is supported by a multitude of recently published papers and reports. Another example of the lack of research that indicated that BGI can be utilised in coastal environments is an article published in the *International Journal of Environment and Sustainability* (Ghofrani et al., 2017). This paper provided what was described as a 'thorough' review of information on the impact of BGI on environments, particularly on water resources and vegetation. The authors reviewed the development of BGI internationally. However, despite this article being written in 2017, well after the first CBGI had been implemented, this article did not discuss that BGI could include coastal infrastructure.

Adding to the significant lack of recognition of BGI in coastal environments, there are multiple examples of scholarship on BGI where coastal environments are not included or are only briefly mentioned. In a report called *'Adaptation to climate change using green and blue infrastructure'*, a database of case studies written by researchers from the University of Manchester (2010), 15 case studies of BGI infrastructure were investigated. This study had the purpose of exploring different mechanisms in which urban areas can adapt to climate change in a green or blue way. Of the 15 case studies, only one included CBGI, analysing how restoring wetlands in New Orleans can mitigate climate change impacts from SLR and increased storminess. It is positive that one example was focused on coastal environments, however, when this is compared to the dire situation numerous global coastal ecosystems are in, and the obvious need for more CBGI to help coastal settlements and communities adapt to climate change, this seems insufficient and unrepresentative of the potential role of BGI in different environments.

In another literature review conducted to understand how BGI had been used in developing countries such as Africa, Asia and Latin America, Valente de Macedo et al. (2021) comprehensively assessed 283 abstracts published from 2015 to 2019. The only CBGI mentioned were mangroves, making up 0.3% of the BGI types studied (Valente de Macedo et al., 2021). However, Valente de Macedo et al.'s (2021) definition of BGI did not include or consider coastal environments as places where BGI could exist and function. The mangroves mentioned were located in inland urban wetlands utilised for stormwater runoff purposes (Valente de Macedo et al., 2021). This highlights past focus on freshwater systems for BGI and raises the question if this terminology is appropriate in the coastal space. The following section examines the emergence of the BGI terminology and its limited use in coastal settings.

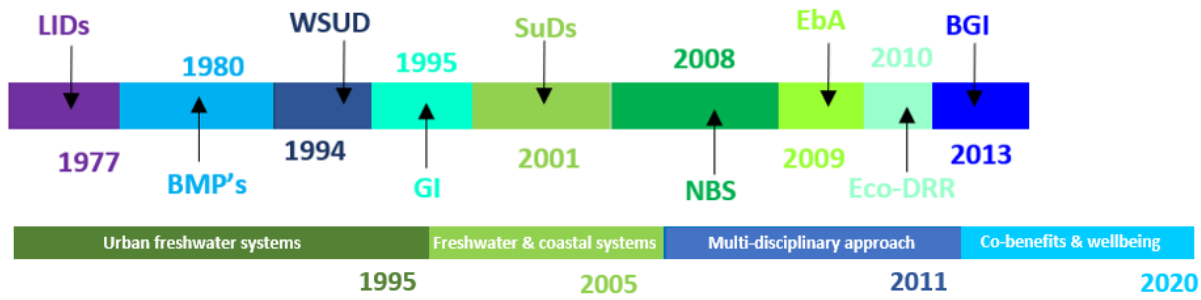
2.2 Development of the term BGI

The term BGI is relatively new, however, the historical concept of using nature for human benefit dates as early as the Edo era (1603- 1868) in Japan (Monteiro et al., 2020). For example, the Japanese used windbreak trees or *yashikirin* to protect their homes from strong winds as well as using ring dikes or *waju zutsumi* which were areas of farming in the lowlands that aimed to provide protection against flooding (Ministry of the Environment, 2016). The first reported studies of using natural infrastructure rather than 'hard' or 'grey' (traditional) engineering approaches appear to have been undertaken in the 1960s in America. The United States Army Corps of Engineers (USACE) reported salt marshes effectively attenuating wave energy during a storm in Louisiana (USACE, 1963). Following this study mangroves were hypothesised to help protect coastal environments in Bangladesh (Fosberg & Chapman, 1971). However, these natural infrastructures had no terminology to explain them and their value beyond solely coastal protection was not yet recognised.

When assessing the development of the term BGI, it is clear to see why there has been a focus on inland systems. The original terminology of this term such as Low Impact Development (LID), Water Sensitive Urban Design (WSUD), Best Management Practises (BMP) and Green Infrastructure (GI) are exclusive to inland environments and only since 1995 has BGI also included coastal infrastructure. The term BGI has developed from several terms and concepts which largely have been used interchangeably (Ruangpen et al., 2020). Terms that overlap with BGI include Sustainable urban drainage (SuDs), Nature-based Solutions (NBS), Ecosystem based approach (EBA), and Ecosystem Disaster Risk Reduction (Eco-DRR). Figure 7 displays these terms and the dates they originated as well as the overlying research focus of the time (Ruangpen et al., 2020). It is important to note that all these terms have their roots in the deep ecology and sustainability movements popularised in the 20th Century as partly a response to the proliferation of hard engineering, however, examination of these deeper roots is beyond the scope of the search for a term that is suitable for use in the present research.

Figure 7- Dates that the interchangeable BGI terms originated in published literature.

Note: modified from Ruangpen et al. (2020, p245). Low Impact Development (LID), Water Sensitive Urban Design (WSUD), Best Management Practises (BMP) and Green Infrastructure (GI) are exclusive to inland environments and only since 1995 has BGI also included coastal infrastructure. Terms that overlap with BGI include Sustainable urban drainage (SuDs), Nature-based Solutions (NBS), Ecosystem based approach (EBA), and Ecosystem Disaster Risk Reduction (Eco-DRR).



The dates these terms originated highlights the different research emphasis of that historical time period. From the 1970s to the early 2000s there was largely a focus on more sustainable and multipurpose freshwater management in urban areas. At this time the research was mainly conducted by stormwater engineers and the co-benefits and parallel values of these more natural approaches to stormwater management were not recognised. The changes to the BGI concept and its potential in various environments gained broader attention after the Indian Ocean Tsunami in 2004 and Hurricane Katrina in 2005, when the protective and buffering role of saltmarsh and mangroves became apparent (Chatenoux & Peduzzi, 2007 & Harada; Imamura, 2005; Olwig et al., 2007). More importantly, the consequences of these ecosystems being degraded were noted. The timing of these events coincided with the publication of the Millennium Ecosystem Assessment (MEA). This assessment raised significant concerns for the state of the world's natural environment and linked coastal ecosystems and the services they provide, such as sediment retention and wave attenuation, to benefiting coastal communities via erosion prevention and reduced coastal inundation risk (MEA, 2005).The convergence of large-scale disasters and international frameworks resulted in major increases in the research field of interdisciplinary solutions to complex problems that society and science were beginning to face more intensely and frequently (Brandt et al., 2013; Monteiro & Antunes, 2020).

Nature and nature-based solutions to environmental stressors and disasters became a topic with a growing body of scientific evidence, for example suggesting that indicated storm water run-off and terrestrial flooding were best managed by BGI and that coastal habitats could attenuate waves, secure sediments, and reduce storm surge, with natural infrastructure providing more durable protection in smaller storm surges (Moriss et al., 2018; Narayan et al., 2018). Subsequently researchers developed techniques in which nature could be restored or implemented to protect communities. Research was conducted on BGI such as mangrove and saltmarsh conservation, oyster restoration, instalment of sills to facilitate saltmarsh recruitment, seagrass and mangrove transplantations, and coral reef planting and inland wetlands, green roofs and bioswales (Saleh & Weinstein, 2016). Globally, nature-based infrastructure use and appreciation expanded in many countries like Belgium, the Netherlands, and the United States of America (USA), employing a 'build with nature' approach to managing water (CPRA, 2012; Temmerman & Kirwan, 2015; van Slobbe et al., 2013). Canada, Europe, the USA and the United Kingdom (UK) began to emphasise the importance of BGI in urban planning and terrestrial flood protection (Temmerman & Kirwan, 2015). In 2015, the United States (US) administration issued an *Office of Management and Budget Memo* that directed federal agencies to incorporate the value of ecosystem services and 'green infrastructure' into decision making and planning (Donovan et al., 2015). Meanwhile, the European Union's *Biodiversity Strategy* encouraged the implementation and protection of green infrastructure as an investment priority for sustainable growth in 2020: this strategy advises that natural processes become an inherent part of spatial planning (European Union (EU), 2020).

The BGI concept is still evolving, more recently shifting in focus towards appreciating the co-benefits BGI can provide society with, highlighting why natural infrastructure can be a better alternative to built infrastructure alone. Now, partly as a result of stresses related to pandemics (COVID19), research is emerging on the mental well-being benefits of green and blue spaces (Twohig-Bennett & Jones, 2019). The present research aims to contribute to yet another development in the evolution of the BGI space to be more inclusive of coastal environments.

2.3 Relationship between BGI terminology and CBGI

This section critically analyses the different definitions used interchangeably with BGI today, exploring if they are suitable for the purpose of this research. To understand the ambiguous relationship between BGI and analogue concepts, Table 3 was constructed to clarify the definitions of the interchangeable terms used while critiquing their suitability for use in coastal spaces. As indicated in the quotes, the development of the term BGI stems from historically inconsistent research agendas, with different emphasis across different sectors and disciplines. Thus, a broad range of BGI terminology has been used interchangeably (Chatzimentor et al., 2020), like soft engineering (Chapman & Underwood, 2011), natured-based infrastructure (Bridges et al., 2015), nature-based coastal defence (Nesshover et al., 2017), nature-based solutions (NBS), green/ blue infrastructure (Mayer-Pinto et al., 2017), living shorelines (Bilkovic et al., 2016) and building with nature (De Vriend, Van Koningsveld, & Aarninkhof, 2014). These broad framings have resulted in significant conceptual flexibility and, potentially, a risk of missing opportunities to implement, restore or manage BGI resource in a robust manner (Waylen et al., 2014). To suit the purpose of this research the definition utilised to define BGI needs to reflect the primary purpose of coastal protection. From Table 3 none of the analogue terms are ideally suited to the purpose of valuing CBGI in an Ōtautahi coastal setting. However, these terms share helpful similarities: they resonate with the overarching purpose of utilising and harnessing nature whether it be explicitly, or to complement/ as an alternative to built infrastructure, to provide amenity to people (Nesshover et al., 2017), an overarching concept which will be drawn upon in the next section to form a definition of CBGI appropriate for this study.

Table 3- Definitions of interchangeable terms used to describe BGI and critique of their suitability for use in coastal spaces.

Definition	Is this terminology appropriate to use in the coastal space?
Blue-green infrastructure (BGI) *"An interconnected network of natural and designed landscape components, including water bodies and green and open spaces, which provide multiple functions such as: (i) water storage for irrigation and industry use, (ii) flood control, (iii) wetland areas for wildlife habitat or water purification, among many others"* (Ghofrani et al., 2017, p.1).	The IPCC, the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES), and the European Commission (EC, 2013) use this terminology to describe essential NBS for urban environments for adaptation to climate change and resiliency agendas (Bazaz et al., 2018; Ghofrani et al., 2017). However, BGI does not address the primary purpose of BGI as coastal protection.
Green infrastructure (GI) *"The creative combination of natural and artificial (green, grey, and blue) structures intended to achieve specific resilience goals (e.g., flood/drought management, public health, etc.) with broad public support and attention to the principle of appropriate technology"* (Zuninga et al., 2020, p. 711).	The purpose of GI does not exclusively have to be for sustainably managing water, whereas BGI always includes sustainably managing water resources. Such examples of green infrastructure include green spaces to reduce the urban heat island effect and parks for enhancing recreation and well-being in urban areas (Karanikola et al., 2017). This definition is not suitable to use in a coastal setting since it focuses on terrestrial environments.
Nature-based solutions (NBS) *"(i) NBSs that address a better use of natural or protected ecosystems (no or minimal intervention), (ii) NBSs for sustainability and multi-functionality of managed ecosystems, and (iii) NBSs for the design and the management of new ecosystems, which is more representative of the definition given by the European Commission"* (Ruangpen et al., 2020 p.1).	The term NBS is an umbrella term and is so ambiguous that Ruangpan et al. (2020) argue its usage can be classified according to three different purposes. NBS, subsequently, has the potential to incorporate a significant variety of BGI. Therefore, NBS are more inclusive of natural coastal infrastructure than BGI and GI definitions. Further descriptions of NBS range from broad to specific concepts, depending on the purpose of the scholarship involved.
NBS Kabisch et al.'s (2016) and Cohen-Shacham et al. (2019) research indicated that NBS involved working with natural ecosystems to overcome societal challenges. While Nesshover et al. (2017) research describes NBS's as having the purpose of promoting nature as a means for providing solutions to climate mitigation and adaptation challenges.	Broad definitions like NBS can prove to be inappropriate when trying to manage resources as they can leave too much flexibility in what is valued and managed. This leads to poor management practices and can cause further degradation of coastal ecosystems (Nessover et al., 2017). A comprehensive formulation with specific terminology, which is what CBGI aspires to be, would help to stimulate discussion and innovation, and facilitate communication among the communities of science, policy, and practice in the coastal realm (e.g., Brand and Jax, 2007).
NBS *"A sustainable, self-sufficient and cost-effective strategy to mitigate coastal flood and erosion hazards. Nature-based solutions are based on the conservation, restoration or creation of coastal ecosystems… for their capacity to reduce the inland propagation of storm surges, to reduce wind waves and shoreline erosion, and to adapt to sea level rise by sedimentation"* (Van Coppenolle & Temmerman, 2020, p.1).	This definition communicates that NBS must have a high coastal protection value with examples of NBS provided including wetland, salt marsh, and mangrove restoration. CBGI, however, may include infrastructure that is not solely natural ecosystems, therefore, this definition is inappropriate. Additionally this definition does not recognise dunes as NBS. It is clear that the diversified concept of NBS has a different research emphasis in different disciplinary areas (Ying et al., 2021). This is not ideal, as a term needs to be used consistently across the literature to confirm its validity and successful replication (Ying et al., 2021).

Ecosystem-based adaptation (EBA) "*EBA uses biodiversity and ecosystem services in an overall adaptation strategy. It includes the sustainable management, conservation, and restoration of ecosystems to provide services that help people adapt to the adverse effects of climate change*" (Convention on Biological Diversity, 2009, p. 6).	This definition appears to be very similar to NBS, with some researchers describing it as a subset of NBS (Ruangpen et al., 2018). Due to its similarities to NBS, it has the same downfalls and again is too broad to utilise successfully for the purpose of this research.
Green flood protection (GFP) "*GFP is an upcoming approach in coastal protection knowledge and policy. The central notion of this multifunctional concept is that natural processes, nature development and the dynamics of ecosystems are taken into account in realising flood protection*" (Janssen et al., 2014, p.1).	This is a definition that aligns with the principles of CBGI, however, it does not clearly define what it includes and excludes. Therefore, there could be significant confusion surrounding what types of coastal infrastructure is included in this definition.
Nature-based infrastructure (NBI) "*Natural features are created through the action of physical, geological, biological and chemical processes over time. While NBI, in contrast, are created by human design, engineering, and construction (in concert with natural processes) to provide specific services such as coastal risk reduction and other ecosystem services*" (Bridges et al., 2015, p.6).	This definition of NBI has the potential to be utilised in coastal environments, however, it is not exclusive to this location. Therefore, it does not truly reflect the purpose of this research.
Ecological engineering (EE) "*Engineering to solve problems, or to create amenities or rewards for society, in a manner that appears more natural, or which may provide more natural habitat for species other than people*" (Chapman & Underwood, 2011, p. 304).	EE combines engineering principles with ecological processes to reduce environmental impacts from built infrastructure (Chapman & Underwood, 2011). This explanation of EE is not suitable as CBGI aims to contain natural infrastructure which has not been engineered but still provides value to people.
Soft engineering "*Obstructions to tidal flow are removed, therefore, allowing the water to find and develop its own natural shore, with associated habitats*" (Chapman & Underwood, 2011, p.304).	This definition was gathered from the literature that has an overlying focus on coastal environments. It reflects BGI as having a purpose in a coastal environment, however, is not inclusive of numerous types of CBGI.
Living shorelines "*Harnessing coastal habitats, such as wetlands, which have a natural capacity to stabilise the shore, restore or conserve habitat, and maintain coastal processes*" (Bilkovic et al., 2016, p.1)	Living shorelines are a more proactive approach to coastal protection and provide further inspiration of NBS being utilised in a coastal space.
Blue infrastructure "*Refers to the coastal and near shore habitats that provide the physical matrix for ecological functions, which in-turn provide important services and ecological benefits to society*" (Edwards et al., 2012, p.1).	This is a useful definition to build the concept of CBGI off as it provides inspiration that BGI can be used successfully in coastal environments. However, it is not appropriate for the purpose of this research in their current form as it does not accommodate hybrid approaches to coastal protection.

2.4 CBGI definition

Critical analysis of recently published literature has provided a clear indication that research in the CBGI is limited. Ruangpen et al. (2020) identifies the ability of green infrastructure to reduce hydro-meteorological risk in coastal environments as an area that needs further research. There is inherent ambiguity due to the complicated history and volume of interchangeable terms that describe BGI. To have the best success in managing natural environments a definition should be based on a well-balanced, clear, widely accepted, and implementable set of key principles (Ying et al., 2021). For this to occur in coastal environments, a new term must be created to provide clarity so natural, and nature based coastal infrastructure can be adequately valued and monitored in a way that can be replicated by other researchers. It is essential that the term created has a clear focus on coastal environments, therefore, paving the way for BGI to become more established in this space. Creating this term could create a paradigm shift in thinking that BGI can be utilised successfully in coastal environments to protect coastal communities. Consequently, once recognition is gained, the goal would be for further implementation of BGI in coastal environments, resulting in coastal communities that are protected in a more sustainable way that fosters resilience to climate change.

As well as CBGI having a focus on coastal environments, the definition must also describe its main purpose of mitigating coastal hazards such as coastal erosion and inundation. This is to ensure, unlike previous definitions, that the primary focus of CBGI is coastal protection as opposed to its opponents. The term CBGI must also acknowledge that infrastructure can be natural (e.g., natural dune system), or nature- based with a built component (e.g., dune contouring), and whilst CBGI's primary purpose is to provide coastal protection, it is recognised that there are significant additional benefits of maintaining, conserving or introducing new ecosystems to coastal environments to help coastal communities adapt to climate change.

The definition proposed for the terminology of CBGI will draw upon the previous literature, taking the focus which resonated throughout all the definitions, that CBGI must work with nature. To put this concept in a NZ context, terminology utilised in the *NZCPS 2010* will be incorporated into the definition. This may help the definition to become operationalised into policy in NZ as, once the value of CBGI is identified, it will become a resource that policymakers will recognise as needing to be protected. The language that will be carried across from the NZCPS will be:

- **Areas of ecological significance** are defined as areas "*of significant indigenous vegetation or a significant habitat of indigenous fauna is an area or habitat whose protection contributes to the maintenance of indigenous biological diversity at the Ecological District level*" (Davis et al., 2016, p.4).

- **Natural character** as defined by Froude, Rennie & Bornman, (2010 p339) *"Natural character occurs along a continuum. The natural character of a 'site' at any scale is the degree to which it:*
    - *is part of nature, particularly indigenous nature*
    - *is free from the effects of human constructions and non-indigenous 'biological artefacts'*
    - *exhibits fidelity to the geomorphology, hydrology, and biological structure, composition, and pattern of the reference conditions chosen*
    - *exhibits ecological and physical processes comparable with reference conditions Human perceptions and experiences of a 'site's' natural character are a product of the 'site's' biophysical attributes, each individual's sensory acuity, and a wide variety of personal and cultural filters."*

Therefore, for the purpose of this research CBGI can be practically defined as:

> ***Coastal blue green infrastructure (CBGI)*** *describes natural, or nature-based coastal features which have a primary function of protecting people and/or places they value from coastal hazards, whilst also providing co-benefits for environmental, cultural, social and other purposes. CBGI occurs or can be established via the conservation, restoration, or creation of coastal ecosystems. CBGI acts to maintain and/or enhance the natural character of the coastal environment, as well as protect, manage, and extend coastal areas of ecological significance. It can be used alone or in addition to built infrastructure as a hybrid approach to coastal protection.*

2.5 Potential coastal adaption options for enhancing the CBGI of coastal dune environments

Natural CBGI innately acts to provide coastal protection while providing amenities to the community, however, climate change is threatening the integrity of these environments (Everard et al., 2010). Based on the above practical definition for CBGI, different types of CBGI adaptation options can be identified (Table 4) and analysed and the benefits of using CBGI for coastal protection can be quantified. Once these benefits (or lack of benefits) have been determined this thesis recommends investigating sustainable coastal adaption options for further conservation or alternative interventions to enhance these existing natural CBGI. Subsequently, the CBGI of, for example, the New Brighton coastal sand dune system can remain a sustainable approach to coastal protection in the future.

Table 4- Different benefits associated with different types of CBGI found globally

Note: Adapted from Barbier et al., 2011; Bridges et al., 2021; Bulleri & Chapman, 2010; Cunnif & Swartz, 2015; Everard Jones & Watts, 2010; Gallego-Fernández, Sánchez & Ley 2011; Morris et al., 2021; Marois & Mits.

Benefit	Wave attentuation	Inundation prevention	Erosion prevention	Self recover after storm events	Adapts with SLR	Carbon sequestrian	Nutrient cycling/ water purification	Cultural	Tourism/ education	Recreation	Wildlife mantience/ biodiversity	Aesthetic	Low cost
CBGI type													
Mangroves	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Saltmarsh	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
Seagrass	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
Shellfish reef	✓		✓		✓		✓	✓	✓		✓		✓
Coral reef	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Vegetated dune restoration		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Vegetated dune creation		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Beach renourishment		✓	✓						✓	✓			✓
Wetland restoration	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Wetland creation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Conservation of the CBGI of the New Brighton sand dune system means ensuring the vegetation cover of dunes is not reduced or damaged and that the dunes are repaired naturally following blowouts or periods of erosion, using techniques that can aid the natural repair of these dunes by reducing trampling and manipulating the deposition rates of sand (Hesp, 2000). It is also important the natural CBGI of the sand beach in front of these dunes is managed and maintained sustainably, therefore, promoting a healthy beach system that can dynamically act as a CBGI (French, 2001).

Both the natural CBGI of the beach and dune system can be conserved through people management (Mr J., Roberts, CCC Coast Care Park Ranger pers. comm. 29/10/21). This includes implementing informative signs on the importance of beaches and how these can be protected, citizen science such as CoastSnap where members of the public help to monitor changes in the coastal environment over time by taking photographs from a predetermined location (Pahlen, 2021) and as described in this upcoming section of this thesis, more physical conservation approaches such as; restored revegetated dunes, vegetated dune creation, beach renourishment, sand fences and vegetated dunes, sand dune thatching and resistant core vegetated sand dunes (Bridges et al., 2021; Barbier et al., 2011; French, 2001 & Nordstrom, 2018).

Interventions that can help to protect coastal dune environments can also be built interventions such as sea walls, groynes, and revetments (French, 2001). However, these typically do not enhance dune systems' ability to self-repair, nor do they have many benefits beyond coastal protection (Hesp, 2000; Bridges, 2021). The next section of this thesis aims to outline the different coastal adaptation options for protecting these natural CBGI, highlighting through case studies that the best options to enhance these natural dune environments are CBGI coastal adaption approaches rather than the traditional approach to protecting coastal communities by engineered infrastructures.

Table 5 displays a summary of the benefits of each CBGI approach to coastal adaption that is related to coastal sand dunes, highlighting the benefits of the different CBGI approaches to sand dune restoration and conservation as well as the coastal protection or risk reduction elements involved with each approach. All these processes aim to not obstruct the natural dune forming processes but rather to conserve the dune ecosystem, therefore, maximising its self-repair capacities.

Table 5- Benefits and risk reduction performance of coastal sand dune related CBGI.

Note: the first part of this table summarises benefits (Cunnif & Swartz, 2015; Gallego-Fermandez, Sachez & Ley, 2011; Nordstorm et al., 2000; Russel, Shultzitiski & Setty, 2009), while the second part of the table summarises coastal protection or 'risk reduction performance' benefits (Cunnif & Swartz, 2015; Gallego-Fermandez, Sachez & Ley, 2011; Nordstorm et al., 2000; Russel, Shultzitiski & Setty, 2009) of different types of CBGI relating to coastal sand dunes.

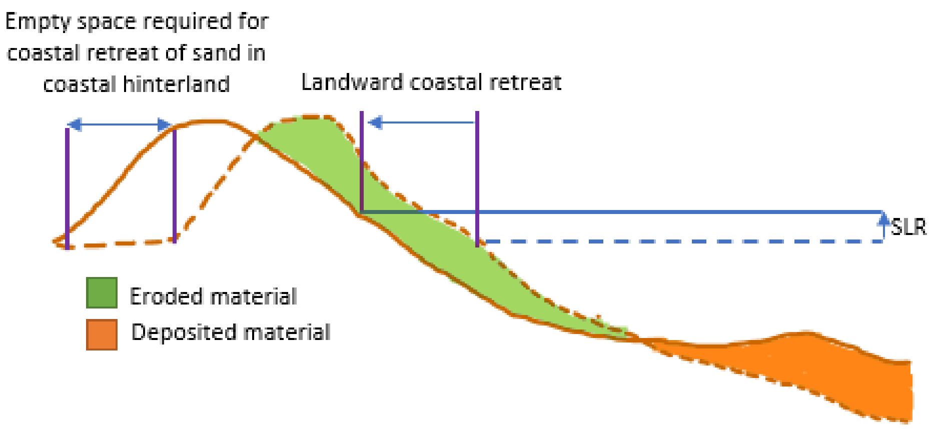
Benefit	Adapts with SLR	Carbon sequestrian	Nutrient cycling/ water purification	Cultural	Tourism/ education	Recreation	Wildlife mantience/ biodiversity	Aesthetic	Low cost
Type of sand dune CBGI									
Vegetated dune restoration	✓	✓	✓	✓	✓	✓	✓	✓	✓
Vegetated dune creation	✓	✓	✓	✓	✓	✓	✓	✓	✓
Beach renourishment				✓	✓	✓	✓	✓	
Hybrid									
Sand fences and vegetated dunes		✓	✓	✓	✓	✓	✓	✓	✓
Sand dune thatching		✓	✓		✓		✓	✓	✓
Resistant core vegetated sand dunes		✓	✓	✓	✓	✓	✓	✓	✓

Risk reduction performance	Redue effects of coastal erosion/ shoreline stabilisation	Nuisance floods (high tides with SLR)	Short wave attentuation (stabilise sediment)	Reduce force and height of medium waves	Storm surge (low frequency extreme events)
Type of sand dune CBGI					
Vegetated dune restoration	✓	✓	✓	✓	✓
Vegetated dune creation	✓	✓	✓	✓	✓
Beach renourishment	✓	✓	✓	✓	
Hybrid					
Sand fences and vegetated dunes	✓	✓	✓	✓	✓
Sand dune thatching	✓	✓	✓	✓	✓
Resistant core vegetated sand dunes	✓	✓	✓	✓	✓

In general, as highlighted in Tables 4 and 5, CBGI adaptation options have numerous benefits to communities. However, the major drawback of CBGI approaches are that CBGI requires significantly more space than hard engineering (Sutton-Grier et al., 2015). A stable and efficient CBGI once implemented, requires space in the hinterland to migrate into with SLR or during storm-induced erosion events (Sutton-Grier et al., 2015). For example, coastal sand dunes require space behind the existing dune ridge to colonise and remain functional under SLR (Jenks, 2018) (Figure 8).

Figure 8- The space requirements of sand dunes with sea level rise.

Note: this diagram illustrates how climate change induced sea level rise can cause dune system transgression, necessitating coastal hinterland space to allow for dune migration, thereby allowing the dunes to continue to provide coastal protection (adapted from Walker et al., 2017 p228).



Furthermore, migration, colonisation, succession, and recovery take time, resulting in reduced coastal protection in between storm events and other major disturbances (Narayan et al., 2016). An example of CBGI taking time to establish is vegetated sand dunes. Once the vegetation is planted it can typically take up to 5 years for it to become fully established and have the ability to withstand and recover from storm events (Jenks, 2018). The vegetation takes time to establish itself as when it is young, its roots are not deep, and it has yet to grow stolon's that trap and stabilise sand dune sediment. Large storms may therefore damage, wash away or bury newly planted vegetation. With time the vegetation grows deeper roots and stolon's and becomes more resilient to coastal storm events as well as acting to accrete a reservoir of sand which helps to prevent erosion. Coastal communities are vulnerable to flooding whilst the sand dune becomes established (Sutton-Grier et al., 2015). Therefore, the best approach to implementing CBGI is to be proactive and to establish it in coastal environments before they reach a critical level of coastal hazards whereby the only safe option is coastal retreat.

Furthermore, older established coastal sand dune vegetation, may also require time to recover between storm events (Bergin, 2011). Aeolian sediment supply is needed alongside established sand binding vegetation for the dunes to efficiently trap this sediment and re-establish the form of a healthy coastal sand dune between storm events. If there are frequent and intense storm events the ability of sand dune vegetation to prevent coastal erosion may be lowered as it does not have the capacity to recover quickly enough between storm events. Significant erosion events may occur during these periods (Dahm & Jenks, 2005).

Further limitations of CBGI coastal adaptation approaches are a lack of community support and poor understanding from both experts and the public on the potential benefits of CBGI compared to hard engineering (Barbier, 2011). In the past, in coastal environments where surveys have been conducted, it has been noted that coastal communities distrust the capacity of CBGI to provide adequate coastal protection (Thorne et al., 2018 & Simons, 2017). People generally prefer hard engineered approaches to protect their coastal assets, rather than retreating (uncompensated) from the coastline to make space for CBGI (Morris et al., 2018). What the community often lacks in understanding is the negative effects of the hard engineered coastal protection infrastructure and the awareness of the false sense of security engineered coastal protection structures generally bring people residing in the coastal hinterland (Sutton-Grier et al., 2015). In addition to this lack of understanding in the public realm, further analysis of literature indicated that there is limited technical expertise, especially in NZ, on how to implement CBGI and protecting and modelling how effective it would be at providing adequate coastal protection in different environments (Britton & NIWA, 2011; Rouse et al., 2017).

Despite these weaknesses, when comparing CBGI values to those of hard engineering it is clear that CBGI adaption approaches are well beyond hard engineering in terms of its ability to provide co-benefits to remaining coastal communities while also not degrading the coastal environment (Sutton-Grier et al., 2015), though the loss of some housing must be recognised as a significant challenge for communities facing housing crises (such as in NZ) where CBGI maintenance or expansion necessitates inland migration. Some of the co-benefits that CBGI can provide were listed in Table 4 and the local benefits of the CBGI of coastal sand dune systems will be explored in detail in the results section of this thesis. Next, the benefits and weaknesses of hard engineered approaches to coastal protection will be explored, thus, highlighting the gap between the extensive benefits of CBGI adaption approaches to protecting the natural CBGI of dunes and the limited benefits of hard-engineered structures as a form of coastal protection.

Hard-engineered approaches associated with sandy beaches include sea walls, revetments, groynes and breakwaters. The benefits of a hard-engineered approach to coastal protection are limited (Table 6) (Sutton-Grier et al., 2015). This is because engineered approaches to coastal protection in sandy beach environments typically do not act to protect coastal ecosystems, they act to degrade them through processes such as coastal squeeze (French, 2001). Therefore, it is important to note that when assessing which type of coastal infrastructure is suitable for a particular location, the negative impacts on the CBGI of the natural ecosystem (and missed benefits) from hard engineered structures are accounted for (Curniff & Swartz, 2015).

Table 6- Co-benefits of hard engineering approaches to coastal protection.

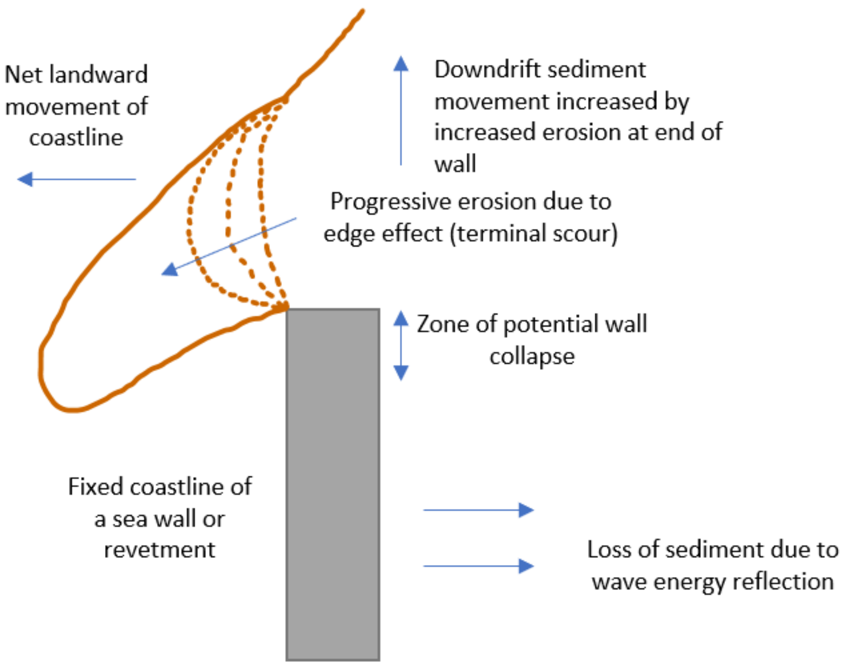
Note: adapted from Cunnif & Swartz (2015, p29).

Benefit	Adapts with SLR	Carbon sequestrian	Nutrient cycling	Cultural	Tourism/ education	Recreation	Wildlife mantience/ biodiversity	Aesthetic
Hard engineering								
Sea wall/ revetment					✓	✓		
Groyne					✓	✓		
Breakwater					✓			

Furthermore, although hard engineered approaches may appear to prevent coastal erosion in front of the engineered structure the horizontal erosion is often translated to vertical erosion and, consequently, beach lowering occurs (French, 2001). This means with time you lose your high tide beach and, potentially, the recreational and tourism value that the beach may have (Cunnif & Swartz, 2015). Additionally, hard engineered structures must end somewhere and where they do, they often cause edge effects. Edge effects (Figure 9) occur where a structure ends, and erosion is exacerbated surrounding the ends of the structure (Boateng, & Bray, 2007 p7). This can cause significant problems to coastal ecosystems (naturally occurring CBGI) and coastal amenities/ infrastructure located near the ends of a hard engineered coastal protection structure.

Figure 9- Diagram explaining what happens at the edges of hard/ engineered structures when they are implemented on sandy beaches

Note: modified from Boateng, & Bray, (2007 p7)



The positives of hard engineering for coastal protection are that there is a lot of expertise on the best practice regarding construction, and the suitability of the location for implementation (Sutton-Grier et al., 2015). The ability of hard engineered infrastructure to provide coastal protection from coastal inundation and erosion is easier to predict, measure and quantify than it is for CBGI due to the linearity of structures and the multiple years of studying the effects of hard engineered coastal protection structures already conducted (French, 2001). Additionally, unlike most types of CBGI, once constructed the hard engineered coastal infrastructure can withstand a storm immediately and does not need time to develop its coastal protection ability. However, these structures weaken over time (Sutton-Grier et a., 2015) cannot self-repair in-between storm events, do not adapt to SLR and can be expensive to maintain and repair (Cunnif & Swartz, 2015). Hard engineered structures may promote an unsustainable way to protect coastal assets both in terms of their financial viability and the number of resources required to maintain the integrity of the infrastructure (Barbier, 2011; Morris et al., 2018; Sutton-Grier et al., 2015). Furthermore, limited benefits are felt from the structure until there is a storm event whereas the co-benefits of CBGI are there all the time (Sutton-Grier et al., 2015). Having said this these built structures can be utilised alongside natural approaches to coastal protection to create a hybrid approach to coastal protection. However, in most cases related to the CBGI of sand dunes, this is not as successful as a CBGI approach to dune management. This is because the built infrastructure will always act to prevent the natural migration of the dune system with SLR, therefore causing coastal squeeze (Sutton-Grier et al., 2015 & Nordstrom, 2018).

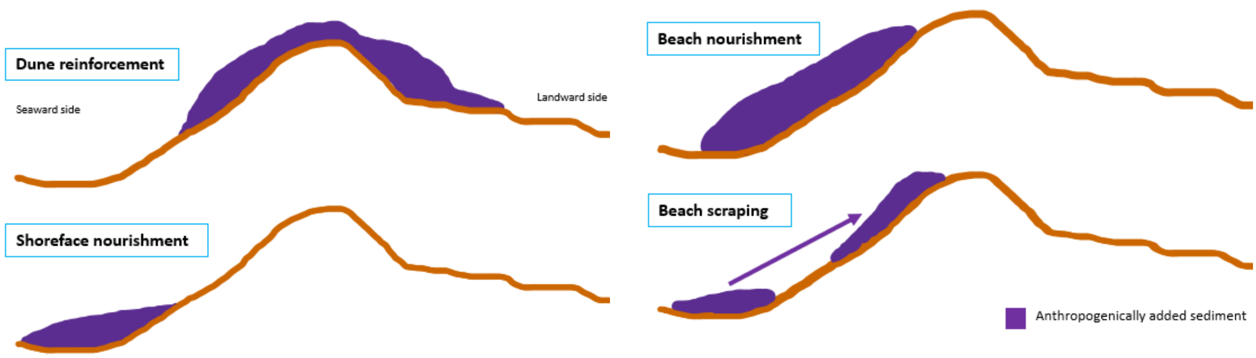
This thesis has now clearly outlined that despite the limitations of CBGI coastal adaption options, they have a significant array of benefits when compared to a hard engineered approach to coastal protection in conserving the CBGI of sandy beach environments. Therefore, sandy beach CBGI coastal adaption options that could potentially act to enhance or conserve dune systems will now be investigated further, with the strengths and weaknesses of each approach explored in more detail with national and global case studies investigated, thus, providing more information on what each approach is, where it is suitable to implement and the benefits and limitations of each approach to CBGI in dune environments.

2.6 Beach renourishment

Beach renourishment is a type of CBGI coastal adaption that adds or redistributes sediments on foreshores, beaches, or dunes to maintain or advance the shoreline position (Linham & Nicholls, 2010). There are numerous approaches to beach renourishment: dune reinforcements, beach renourishments, shoreface nourishments and beach scraping (Figure 10). Sediment can be supplied from external sites or through local beach replenishment (French, 2001). Dune reinforcements occur when sediment are added from an external source which provides the dune system with added protection against breaching during storms (Nordstrom & Arens, 1998). Beach nourishments occur when sand is placed as high as possible on the beach with the primary purpose of obtaining a recreational beach. While shoreface nourishments occur when nearshore berms or mounds are constructed from dredged material (van Rijn, 2011). Shoreline nourishment is usually carried out on dissipative, sandy beaches but it can also be conducted on mixed sand and gravel or cobble beaches (Linham & Nicholls, 2010).

Figure 10- Options of beach nourishment

Note: modified from van Rijn, (2011 p6).



In addition to these four approaches to beach nourishment there are also different approaches to coastal nourishment which determine where and how the sediment is collected from and supplied too. The first is artificial nourishment; this approach involves the introduction of sediment to a beach or offshore sediment depository that supplies the beach from a collection site outside of the beach's coastal compartment (Linham & Nicholls, 2010). Secondly, there is beach replenishment which utilises local sand as the sediment supply and the third is beach scraping or recontouring. Beach scraping is done by mechanically redistributing sediment within a beach, that is without changing the net volume of local sediments in the coastal cell (Wells & McNinch, 1991). It is important to note that beach nourishment is not commonly combined with dune plantings as frequent replenishment of the sediment and heavy machinery would bury and hinder young vegetation growth (French, 2001).

The added and/or redistributed sediments reduce erosion by providing a temporary buffer zone, allowing waves to run up and dissipate energy and can, if successful, temporarily reverse sediment deficits (French, 2001; Linham & Nicholls, 2010). It is important to understand that beach nourishment does not stop the process of erosion it merely minimises the negative impacts of erosion by adding sediment to the system.

Sand nourishment of beaches widens the beach which protects both coastal communities and coastal infrastructure (Pinto et al., 2018). Adding sand to the beach can reclaim the high tide beach and this can increase the recreational amenity of the beach for beach users. This benefits the land value of nearby properties and can increase economic growth through tourism and recreation (Cunnif & Swartz, 2015; French, 2001). Beach nourishment also retains the natural aesthetics of the beach (Scottish National Heritage, 2000) and may provide ecological benefits by establishing habitats for seabirds and insects or promoting dune vegetation growth in environments that do not require frequent replenishment of sand which would cause vegetation burial (Cunnif & Swatz, 2015). It is also deemed a more environmentally friendly approach than sea walls or other hard protection methods which may be located on sandy beaches as sand is a natural product (Barbier, 2011). Adding sediment to one beach may also benefit neighbouring beaches through existing coastal processes such as longshore drift which naturally acts to redistribute coastal sediment (Linham & Nicholls, 2010). Occasionally, sediment for nourishment of a particular beach of high amenity is taken from a beach of lowered amenity value, therefore increasing erosion on this beach. Beach nourishment can be combined with other types of coastal protection, like dune plantings, to increase sand stability (Cunnif & Swatz, 2015).

However, sand nourishment often requires repetitive sand additions (Box 1) to replace sediment that is continually washed away (Linham & Nicholls, 2010). Regular maintenance also restricts access to the beach while it is occurring and if large quantities of sand are needed this may bury wildlife or negatively impact native species in this coastal environment (Climate-ADAPT, 2015 & Linham & Nicholls, 2010). Additionally for beach nourishment to be successful it must utilise sediment that is compatible with the existing beach sediment and contains no significant pollution (French, 2001). For sand nourishment to be cost-effective, it is best if there is nearby dredging capacity or an alternative source of sand (Cunnif & Swartz, 2015), otherwise transporting sediment can be very expensive and unsustainable. Overall, sand nourishment is not stopping erosion but is typical as a temporary solution to reduce erosion.

Box 1. Case study of sand nourishment- Orewa Beach, New Zealand

An example of sand nourishment from NZ is Orewa, North of Auckland on the east coast (Figure 11). Orewa Beach is a moderate to low wave energy, wide sandy bay with fine sediment, subjected to large spring tides, storm surges and SLR, with accelerated erosion since the 1970s. The immediate coastal hinterland of Orewa Beach is heavily developed with residential properties and roading infrastructure. To protect this infrastructure from coastal erosion sand replenishment occurs annually, normally before the busy summer season, unless there are unexpectedly severe erosion events during the year which require immediate sand replacement (Healy, Kirk & Lange, 1990).

Figure 11- Location of Orewa beach on the east coast of the north island displaying the beach and the coastal erosion issues

Note: The map (left) displays the location of Orewa Beach, while the images to the right (top) show Orewa Beach development within close proximity to the coast and below this the severe coastal erosion issues. The bottom central image displays diggers working to add sediment to the eroding Orewa Beach (Google Earth Version 7.3.2.5776 (2019) (Orewa, 36.5866° S, 174.6867° E) [Online]. Available through https://earth.google.com/web/@-43.53588351,172.72323047,3.53715676a,11837.98001097d,35y,0h,0t,0r [19/05/2022] and (Stuff.co.nz, 17.01.2018).

Depending on the severity of erosion two types of sand nourishment occur at Orewa. The first one costs ca. $100,000 per nourishment with Auckland City Council paying and is hoped to only be undertaken annually. This involves placing sediment obtained from the estuary in front of the highly developed coastal hinterland along Orewa Beach. However, due to frequent and intense storm events this sand nourishment often needs topping up after erosion events (Auckland Council, 2018). Sand is also collected from the sand trapped by the groyne at the southern end of the beach and mechanically deposited in areas of erosion, typically central to the bay (Figure 11). This costs ca. $12,000. In 2018, this had to occur five times in the financial year. Sand fences have also been erected to ensure people and vehicles do not trample this deposited sand (Auckland Council, 2018).

The Hibiscus coast where Orewa is located attracts over 15,000 tourists every summer and it is considered important that there is a beach for the recreational and tourism amenity to support the local economy of Orewa. Sand nourishment is the best option determined by the council, for maintaining this amenity and protecting the coastal development as the implementation of a sea wall could lead to beach erosion in front of the built structure. Residents are not particularly supportive of this approach to coastal protection as they believe it does not work due to the sediment being washed away during storm events, it is too expensive, and the sand deposited gets blown into their properties which they have to manually remove frequently (Auckland Council, 2018). This highlights the importance of educating the public on the strengths and weaknesses of each approach to coastal protection.

2.7 Dune planting

The second CBGI coastal adaptation option for the CBGI of dunes that will be investigated is dune planting. Coastal sand dune planting can occur on both the front and back dune, however, for the primary purpose of preventing coastal erosion the most effective place to undertake sand dune planting is on the frontal dune with sand binding plants (Scottish National Heritage, 2000). Planting on the frontal dune initially helps to reduce the windspeeds across the surface of the dune, trapping windblown sediment (Climate-ADAPT, 2015). As the plants grow, they stabilise the sediment leading to sand dune accretion. Sand dune plants can encourage dune recovery in between storm events. However, select species must be chosen that can flourish in the harsh conditions of the dune environment and be tolerant to environmental stressors such as salt spray, high winds, frequent burying events or trampling by humans or animals (Verhoeven et al., 2014). In NZ, these plants are generally the native spinifex (*Spinifex sericeus*) or pīngao (*Ficinia spiralis*) (Jenks & Bergin, 2005). Once these plants have aged past 5 years and have developed sufficient roots and stolon's they can typically withstand or recover from storm events (Mr P., Borcherds, CCC Coast Care Park Ranger pers. comm. 12/10/21).

Sand dune planting is a low-cost and low maintenance coastal protection practice (Climate-ADAPT, 2015; Linham & Nicholls, 2010). It benefits the aesthetics/ tourism value of the beach and improves the ecological value of the coastal environment (Barbier et al., 2011). Community planting days can be held which can enhance community connectivity (Jenks & Bergin, 2005). At these events, people are also educated on the benefits of the vegetation, reducing the likelihood of vegetation damage by the public (Mr J., Roberts, CCC Coast Care Park Ranger pers. comm. 29/10/21). Sand dune vegetation sequester carbon, which mitigate the greenhouse effects and climate changes (Alongi, 2012; Bonito et al., 2017; Drius et al., 2019; Yang & Tang et al., 2019). In NZ, coastal sand dune vegetation can have high cultural value if pīngao and spinifex are used for replanting as these plants are taonga and sources of mahinga kai to Māori (Bergin, 2011).

Planting sand dune vegetation can be more successful when done in conjunction with other coastal protection techniques such as fencing or thatching as described in section 2.5 (Linham & Nicholls, 2010). Such techniques ensure the plants are more protected while they are young and too vulnerable to withstand stressors. Unfortunately, limitations exist in the public perception of the efficacy of this approach to coastal protection. Members of the public have reported their expectations that coastal sand dunes will function as a solid wall. However, sand dunes are designed to be dynamic and fluctuate with storms which means they potentially migrate inland over time (Mr J., Roberts, CCC Coast Care Park Ranger pers. comm. 29/10/21).

Box 2. Case study of sand dune plantings- Papamoa East, New Zealand

An example of coastal sand dune plantings as an approach to CBGI with the primary purpose of providing coastal protection is Papamoa East. Papamoa East is located between Mount Maunganui and Maketu on the Bay of Plenty coast in the North Island of NZ (Figure 12). Coastal subdivision in Papamoa East has been implemented in places that are vulnerable to coastal hazards due to their proximity to the coast. For example, in areas along Papamoa East the coastal sand dune width has been reduced approximately 14 m from 1903- 1994 m to a current width of 15-20m as a result of these high value properties being constructed. However, with climate change there is predicted to be 40-50 m of coastal erosion in the next 50 years, therefore, these buildings could be destroyed (Gibb, 1996).

Figure 12- Location of Papamoa East, NZ, displaying the close proximity of coastal development to the coast, the coastal erosion on the coastal sand dunes in front of these areas of residential development and how dune plantings have successfully restored the dune system in Papamoa East

Note: The map (left) displays where Papamoa East is located while the images on the right show how close development is to the coast (top) and the resulting coastal erosion (bottom). The central bottom image shows the restored coastal sand dune system in Papamoa East established by a Community Coast Care group and replanting of native sand binding vegetation, such as spinifex and pīngao (Bayleys, 2021; Baynews, 22.09.2022; Google Earth Version 7.3.2.5776 (2019) (Papamoa East, 37.7330° S, 176.2983° E) [Online]. Available through https://earth.google.com/web/@-43.53588351,172.72323047,3.53715676a,11837.98001097d,35y,0h,0t,0r [10/05/2022] & Te Ara, 1997).

In 1958 the coastal sand dune system in Papamoa East was bulldozed and the dune system had not recovered in the 1990s where the frontal dune remained degraded and eroding. In response to this severe degradation a Coast care programme was set up by local residents in the 1990s to restore the dune system to provide coastal protection for the houses (Dahm & Jenks, 2005).

This Coastcare programme remain active, with continued restoration and fertilization to ensure extensive cover of native sand binding vegetation on the foredune, such as spinifex and pīngao. Dune accessways have also been installed to ensure sensitive and young vegetation were not trampled by humans. This work of restoring the native vegetation alongside the application of adequate fertiliser and creation of beach accessways has resulted in a seaward coastal sand dune advancement of 10-15m between 1998 and 2004. The resulting dune is a native vegetated gently sloping dune that is much wider and subsequently has a much higher ability to provide adequate coastal protection (Figure 12) (Jenks & Brake, 2001).

This case study highlights that coastal sand dune revegetation can increase coastal protection and add co-benefits such as community connection, recreational spaces, and elevated biodiversity.

2.8 Sand dune fencing

Sand dune fencing is another CBGI coastal adaptation approach to protecting the CBGI of dunes that includes utilising fences to trap sand and control beach access, to keep people off sand dune vegetation restoration areas. Dune fencing, with the primary purpose of encouraging foredune deposition of sediment, is constructed along the seaward face of the foredune (Jenks & Bergin, 2005). Fencing reduces surface wind velocity and as a result sediment and/or organic matter is deposited in this area. Although sand dune fences may not prevent severe erosion from storm waves, fences can provide a modest barrier against smaller waves and reduce the erosion potential of waves near the limit of uprush (Scottish National Heritage, 2000). Fences are typically constructed of wood, however, building materials may vary between sites (Bergin & Bergin, 2011). Fencing is more successful on low sloping coastal sand dunes with relatively stable sand dunes (Scottish National Heritage, 2000). Once fences are installed, they are typically monitored bi-annually for maintenance and potential repairs (Jenks & Bergin, 2005). The cost of fencing, native plantings and the maintenance of these in NZ equates to only 1-10% of the costs of a hard engineered approach to coastal protection (Dahm et al., 2005). Therefore, sand dune fencing provides a cost-effective approach to CBGI that can promote significant amounts of sediment to be deposited and thus an effective coastal protection approach (Linham & Nicholls, 2010).

Dune fencing can also be used along access ways and surrounding vegetated dune areas (Figure 13) to reduce public trampling. The protection of dune vegetation promotes sediment deposition and sediment stabilising (Jenks & Bergin, 2005) creating or maintaining a sustainable coastal protection infrastructure.

Figure 13- Sand dune fencing in Ria Formosa, Portugal and Waihi, New Zealand

Note: The two common purposes of coastal sand dune fencing from left to right are displayed with coastal sand dune fencing in Portugal with the purpose of trapping sand and protecting the coastal sand dune system from trampling by people and vehicles (Adriadapt European Union, 2022) and coastal sand dune fencing in Waihi, New Zealand which has the purpose of providing an accessway to the beach while protecting the coastal sand dune vegetation (Thompson, 2022)

Coastal sand dune fencing located along the front of the foredune with the primary purpose of sediment deposition can be multifunctional as it can also act to protect coastal sand dune vegetation from trampling (Jenks & Bergin, 2005; Scottish National Heritage, 2000). As dune fencing located in front of the dune for the primary purpose of sediment deposition is unlikely to succeed if erosion is severe (Scottish National Heritage, 2000), coastal sand dune fencing is typically used in conjunction with other restorative techniques such as sand dune planting (Bergin & Bergin, 2011). This means young plantings have additional protection from anthropogenic damage while they are young and vulnerable and thus have a higher chance of flourishing (Jenks & Bergin, 2005).

The success of the coastal sand dune fencing located in front of the coastal foredune is dependent on numerous complex coastal processes. However, a general prediction of its success can be determined by the void to solid ratio of the fence (i.e., the percentage space between the solid fence materials is ideally 30-50%), the availability of aerial sediment, the amount of vegetation present to stabilise trapped sediment and the frequency and intensity of wave attack (RISC-KIT, n.d). The success of sand dune fencing can be enhanced by planting dune vegetation on the beach to establish new foredunes (Scottish National Heritage, 2000).

Sand dune fencing is a low-cost option that increases accretion rates of coastal sand dunes (Bergin & Bergin, 2011). Fencing not only promotes sediment deposition on the sand dune it also protects the coastal sand dune vegetation and is, therefore, a multipurpose infrastructure (Bergin & Bergin, 2011). The dune fences can also extend the protected dune habitat beyond the toe of the embryo dune as the fences are typically located some distance in front of this embryo toe. Therefore, this area is protected and thus dune accretion strengthened (Bergin & Bergin, 2011; Scottish National Heritage, 2000). Although regular maintenance of sand dune fences is required the nature of this work is low cost and non-intensive as it typically involves removing organic debris trapped in the fences and repairing fence damages (Climate-ADAPT, 2015).

The limitations of sand dune fences are that they can be visually intrusive as the fence and trapped litter affect the aesthetic of the beach (Scottish National Heritage, 2000). Fences also reduce beach access and can hinder the natural dispersal of organisms. On popular beaches access to beaches can be made at regular intervals to avoid members of the public walking over the fence or knocking it down to gain access to the beach (Bergin & Bergin, 2011). Educational signs on the purpose of sand fences may be required to increase public valuation and minimise vandalism. Dune fences also contain wires and sometimes plastic which can be a nuisance if the fences get damaged (Climate-ADAPT, 2015).

Box 3. Case studies of sand dune fencing- Ria Formosa, Portugal and Whitiroa Beach, New Zealand

An example of sand dune rehabilitation using fencing is Ria Formosa on the southern coast of Portugal. Residential development and tourism have caused severe degradation of this dune system (RISC-KIT, n.d). In 2000 an elevated wooden pathway 1500m long was constructed as well as 6700 m of sand fences (Figure 14). The fence has aided dune rehabilitation via sand trapping and deposition with the sand dune system accreting 10m and growing 1.3 m in height over the past 15 years of monitoring (RISC-KIT, n.d). The pathway also contributed to the restoration of this dune system as it minimised the usage of wild paths through the sand dune system which had caused degradation of the dune vegetation and destabilisation of the sediment.

Figure 14- Restoration of native dune vegetation from fencing in Ria Formosa (RISC-KIT, n.d.)

Note: (left) restoration project shown with accessways protection dune vegetation and (right) native dune vegetation flourishing as a result.

The implementation of this fencing has allowed the natural coastal vegetation to now be the dominating species of this ecosystem (Figure 14) (RISC-KIT, n.d). The public reported that before the restoration of the dune system, frequent overtopping events occurred during storms or high tide events. However, now these have stopped occurring and it is predicted that if the fences and pathway are looked after this dune system will remain rehabilitated for the coming decades (RISC-KIT, n.d). Further benefits of this include recreational amenities, as the pathways mean it is now easier to access sites for activities . The ecological value of the dune system has been enhanced as the natural vegetation is now flourishing providing habitat for species, sequestering carbon, stabilising the dune system and enhancing the aesthetics of the coastal sand dune system (RISC-KIT, n.d). The initial costs of the project were around €1,250,000 paid for by local authorities. If maintenance is needed, it was expected to be done by local house owners and fishermen who utilised the dune system for their benefit (RISC-KIT, n.d).

An example from NZ of coastal sand dune restoration using coastal sand dune fencing is Whitiroa Beach, located on the East Coast of the North Island of NZ. This beach is a medium-coarse sand beach backed by a single frontal dune which is approximately 5-7 m high. The beach has no significant sediment input and over years of offshore sand extraction and trampling of the coastal sand dune system, the beach was evaluated to be significantly eroded in the 1990s (Dahm et al., 1993). It was predicted that Whitiroa beach had a hazard zone that extended 40-60 m inshore (Environment Waikato, 1992). To minimise the extent of this hazard zone and reclaim a healthy dune system, nearby sand extraction was stopped and sand dune accessways, plantings and fencing undertaken. The implementation of this took 4-5 years of community working bees[3] and included the installation of 20,000 sand binding species, 12 board accessways, fencing, signage, and the clearance of coastal sand dune weeds such as boneseed, coastal wattle, and pampas (Dahm & Jenks, 2005). These dune management practices have been successful as a dense cover of sand binding vegetation is now established. The cost of this project was estimated to be $3.50/ m2 inclusive of all costs (facilitators, plants, materials, etc) (Dahm & Jenks, 2005).

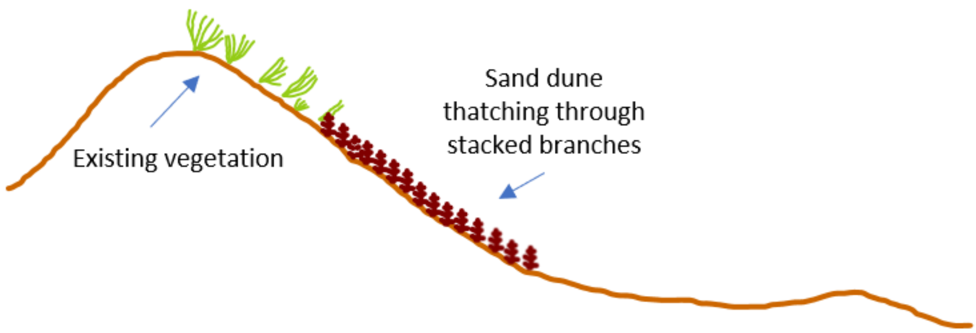
[3] In NZ vernacular a working bee is an event, typically lasting a day or less, when a community of interested people volunteer their work to achieve a common project. Working bees are often used in NZ for outdoor clean ups such as annual tidying of school grounds or construction of new garden beds, beach rubbish collections or for new plantings in common areas such as in parks, wetland and/or dunes.

2.9 Sand dune thatching

Sand dune thatching can also be utilised as a CBGI approach to aiding the protection and restoration of coastal sand dunes. Thatching aims to cover exposed coastal sand dunes with plant debris to stabilise sand, protect dune vegetation, and increase sand accretion (Figure 15) (Climate-ADAPT, 2015). Input of organic material can be done mechanically or manually and favours the development of sand dune vegetation and reduce surface wind speeds on the dune face, subsequently, causing the deposition of sediment (RISC-KIT, n.d; Scottish National Heritage, 2000). Dune Thatching is a low-cost method, and materials are generally biodegradable, that do not damage the original sand dune. Dune thatching costs approximately $200 - $4000/ 100m in length inclusive of maintenance (Scottish National Heritage, 2000). Total costs for thatching depend on labour, material sources, the extent of works, the need for ongoing management and the cost of ancillary works. However, if materials are sourced locally, they are generally low cost and maintenance does not require high skilled labour (Climate-ADAPT, 2015).

Figure 15- Diagram explaining one approach to sand dune thatching

Note: modified from Climate-ADAPT, (2015)



The limitations of this approach are that thatching will not work effectively if coastal erosion is severe due to frequent or intense wave attacks (Scottish National Heritage, 2000). Additionally, thatching is sometimes vandalized and/or used for bonfires and is susceptible to disturbances and destruction from storms. The labour required for maintenance can therefore be intensive and frequent (Climate-ADAPT, 2015). Sand dune thatching may also promote growth of invasive sand dune vegetation which outcompetes naturally existing sand dune vegetation in nutrient-rich environments (Scottish National Heritage, 2000) and may negatively impact the aesthetic quality and prevent recreational activities such as the dunes being home to footpaths for recreational users (Scottish National Heritage, 2000).

2.10 Resistant core sand dunes

Resistant core sand dunes are another type of CBGI coastal adaptation for the CBGI of sandy beaches. Engineered resistant core dunes is a hybrid approach where the core of the dune is made of an erosion resistant material. This approach mimics the function and appearance of the natural landform form of a coastal sand dune; however, the dune remains in a stable position (Nordstrom, 2018). The core of the sand dunes is typically made from geotextiles, gabions, clay and or rock/concrete (Figure 16) (Basco, 1999; Feagin, 2005; van den Berg et al., 1993 & Wamsley et al., 2011). These different core elements have different strengths and weaknesses where the core chosen should be determined based on local beach conditions (Nordstrom, 2018).

Figure 16- Different core materials of resistant dunes as seen along the New Jersey coastline.
Note: modified from Nordstrom (2018, p229 & 232).

Resistant coastal sand dunes with cores made of geotextiles can be relatively environmentally friendly. However, if these cores are exposed to UV, they can be damaged and degrade rapidly (Feagin, 2005). Gabion baskets are metal cages full of cobbles that provide a cheap, easy, and durable option as a sand dune resistant core. If exposed, the gabion baskets may undergo instantaneous storm damage by leaking cobbles from their baskets (van den Berg et al., 1993). Clay cores are rarely used, with little published research on this approach. However, clay cores are relatively cheap and utilise a natural material, though the clay cores can erode during storms (Wamsley et al., 2011). Rock and concrete cores are more durable, though the latter are less environmentally friendly because of chemicals used in the process of making concrete (Norsdtrom, 2018).

Concrete or rock cores of sand dunes typically develop around seawalls or hard engineered structures that are buried on a sandy beach after a storm event (Basco, 1999). Many natural processes such as short-term migration of swash bars or longer-term migration of inlet shoals aided by cutting of new channels or breaches in barrier islands updraft may promote the onshore deposition of sediment. This subsequently widens the beach, thus, promoting aeolian deposition of sediment and potentially acting to bury the concrete or rock structure that exists there (FitzGerald et al., 1978). With climate change and the added component of SLR, this process is not as common as it used to be with beach lowering typically occurring in the front of hard engineered structures on sandy beaches. However, each beach has its own influences on the sediment budget and there may be some locations with consistent sediment supply where this is a functional approach to coastal protection (Nordstrom, 2018).

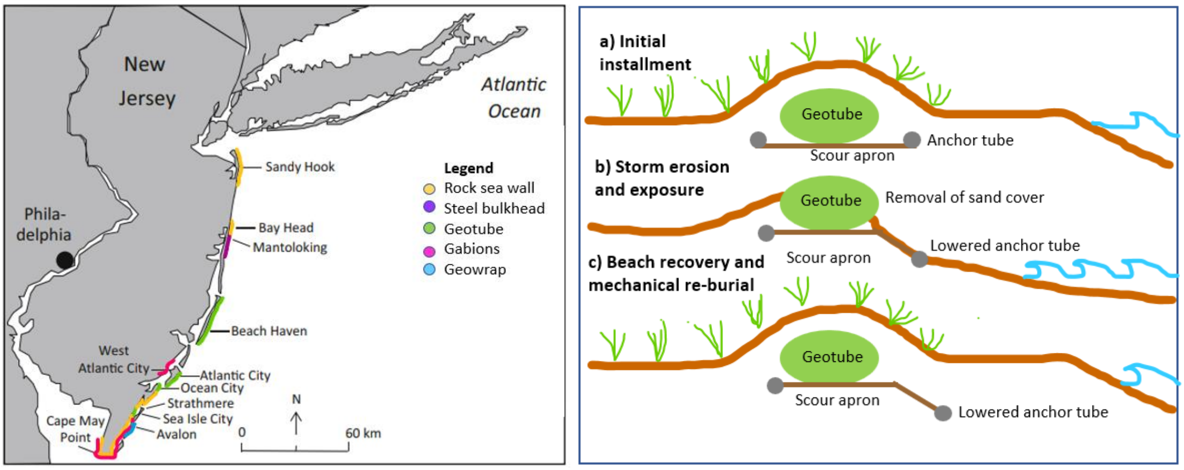
The benefits of using resistant cores for coastal protection are that these engineered dunes mimic coastal sand dunes with their co-benefits (Nordstrom, 2018) (Table 5). One of the limitations of this approach is that resistant cores need regular monitoring and maintenance to ensure they are not exposed for long periods of time to damage from the coastal environment. Implementing an engineered structure in a natural coastal environment has the potential to have negative impacts on the ecological value of the area. The creation of coastal sand dunes may impact coastal residents or visitors' views of the ocean and cause sand to be blown onto coastal amenities. Additionally, one of the benefits of natural sand dunes is that if there is enough empty space in the coastal hinterland then they can migrate inland with climate change thereby providing coastal protection but also working with the natural dynamic nature of coastlines. However, if the sand dune has a hard core, it is effectively acting like a seawall, in that it cuts off the sediment supply of the coastal hinterland, reducing the ability of sand dunes to migrate inland. With SLR and increasing intensity and frequency of storms it will become increasingly challenging to keep the engineered cores covered in sediment. Options to manage this include beach renourishment, however, this approach to coastal protection requires regular maintenance and monitoring on erosional coasts (Nordstrom, 2018).

Box 4. Case study of coastal sand dunes with resistant cores- New Jersey, United States of America

A case study area which has multiple types of engineered coastal dunes with resistant cores, like geotubes, gabions and burial of existing structure coastal sand dunes, is New Jersey, America (Figure 17). Geotubes are installed here by cutting trenches for the geotubes and stockpiling the excavated material on the seaward side of the trench to provide temporary protection against coastal hazards. Geotubes are then placed in the trenches by placing the bags first and then filling them with sand and water slurry. They can be secured in place with anchors (Kessler, 2008). Geotube sizes can vary substantially, however, the geotubes placed in Atlantic City were 1.8 m high, 3.7 m wide and 1.92 km long (Kessler, 2008). The process of installing a geotube and the subsequent succession is schematised in Figure 17. Often, after installation, a storm event can erode the artificial sand covering the geotube. However, when the beach system begins to accrete again after the storm the geotube is recovered. Although this process lowers the anchor apron, some coastal protection remains on the beach as the geotube is not washed away and recovery post-storm is faster because there is a structure to block the sand from blowing further inland (Nordstorm, 2018).

Figure 17- Resistant core coastal sand dunes in New Jersey.

Note: map of the different types of resistant core dunes (left) and diagram of the lifetime of a geotube coastal sand dune protection method (adapted from Nordstrom (2018, p230-231).



Gabions have been placed in Atlantic city and Cape May point and are covered by sand and transplanted sand binding vegetation (US Army Corps Engineers, 1981). Gabions are steel meshed baskets full of rocks. These gabions have maintained their sand cover and have so far managed to provide adequate coastal protection to local communities (Nordstorm, 2018).

Dune nourishment projects are also being conducted in New Jersey whereby dunes are being created that extend 0.3 m above the height of the existing hard engineered structures of the walls or revetments (US Army Corps of Engineers Philadelphia District, 2016). This burial creates a slope of sand on the seaward side of the structure which prevent the lowering of the beach in front of the hard engineered structure due to coastal erosion.

2.11 Ōtautahi coastal CBGI overview

In Ōtautahi, NZ, there are numerous types of CBGI that are protecting the city from the coastal hazards of coastal erosion and coastal inundation (Orchard, 2020). Many of these structures are not recognised CBGIs and resources to protecting, maintaining, and enhancing them is therefore limited. One of the main types of CBGI present in Ōtautahi is the New Brighton sand dune system as seen in Figure 18.

Figure 18- Extent of the New Brighton sand dune system with the benefits of fencing for native vegetation displayed.

Note: The map on the left which identifies the extent of the dune system is adapted from Google Earth Version 7.3.2.5776 (2019) (New Brighton Spit, 43.5079° S, 172.7226° E) [Online]. Available through https://earth.google.com/web/@-43.53588351,172.72323047,3.53715676a,11837.98001097d,35y,0h,0t,0r [11/04/2022] while the image on the right shows plantings are by the Christchurch City Council Coast Care team being protected by purposeful fencing (Thompson, 2022)

In New Brighton, the CCC Coast care team plant spinifex, and a selection of native sand binding vegetation annually along the coastal foredune. There are also accessways and fencing implemented to help protect these native plantings as seen in Figure 18. The objectives are to increase coastal sand dunes resilience and recovery between storm events, enhance the ecological and aesthetic value, and ensure that the communities residing in the hinterland are protected from coastal hazards such as storm surges, SLR and coastal erosion (Bergin, Kimberley & Ede, 1999; Bergin, 2008).

The plantings of native sand binding vegetation on the New Brighton Coastal sand dune system were initiated in the 1990s as a Coast Care program was formed by the CCC in collaboration with the Forestry Research Institute (CCC, 1995). A total of 12 trial sites were established along Ōtautahi's open coast with native sand binding plants instead of the introduced marram grass and ice plant that had been planted in the past to prevent coastal erosion (Bergin, Herbert, White & 1996). The sites have been monitored to assess if the native sand binding species of spinifex, pīngao and sand tussock had a higher coastal protection value by causing the coastal sand dune system to prograde more efficiently than the introduced plant species (Bergin, 2008).

This monitoring indicated that on average the native plantings had caused the formation of an incipient foredune that extended 10 m seaward compared to the existing steepened marram grass-dominated dune face. These incipient foredunes typically accumulated sand to a height of 1.2 m (Bergin, 2008). These native vegetated foredunes have withstood several years of storms and dune erosion and are still providing adequate coastal protection to the New Brighton coastal community. In comparison, areas where introduced species were planted have eroded with no incipient foredune present (Bergin, 2008). This trial suggests that the native sand binding vegetation of spinifex are effective at preventing coastal erosion and promoting the accretion of sediment.

The Coast Care program remains ongoing, involving numerous community members and agencies including the Southshore Coast Care and South Brighton Coast Care groups. To ensure the coastal sand dune system can adapt to the increasing acute and chronic stressors of climate change more dune plantings with native sand binding species are planned (Mr J., Roberts, CCC Coast Care Park Ranger pers. comm. 29/10/21) although required funding is still lacking. Future funding and resources may be easier to secure if the public supports the New Brighton coastal sand dune system as a valuable coastal protection structure and recognises the multiple co-benefits it provides. Sand dunes provide more than just coastal protection in Ōtautahi. They provide a multitude of social, recreational, and ecological benefits (Barbier et al., 2011 & Everard et al., 2010). This research, therefore, aims to develop a methodology to evaluate the New Brighton coastal sand dune system.

Chapter 2 has given us the background rationale and clear description of the definition for CBGI. This definition was then employed to recognise the various benefits of CBGI and the associated CBGI coastal adaption options for coastal dune environments. The strengths and weaknesses of beach renourishment, dune planting, fencing, and thatching as well as resistant core dunes were explored through international case studies. The chapter finished by using the CBGI definition to describe the CBGI of the New Brighton coastal sand dune system, the study site for this thesis, and explaining how this CBGI is currently being conserved, alongside highlighting some of the benefits of this CBGI.

3 Methodology

To gain an understanding of the CBGI benefits of the New Brighton dune system in Ōtautahi, information and data were gathered from a mixed method approach including literature reviews, field and imagery mapping exercises and expert interviews. The use of multiple, different methods helps to provide different kinds of data and to overcome the limitations of each individual method (Creswell, 2014). The following chapter explains these methods in relation to how each helped address the four objectives of this research and how they combine to offer a new, contextual approach to valuing dune system CBGI. This methodology overview chapter is complemented by method investigation reviews and descriptive sections in the approach development and testing Chapters 5 and 6.

In the following sections, a literature review of national and international literature is employed to address the first three research objectives while the fourth research objective required interviews, fieldwork, and a literature review to be undertaken to adequately address it.

3.1 Literature review

To achieve objectives 1 and 2, which have already been addressed in Chapters 1 and 2 of this thesis, literature was sourced from the University of Canterbury library website, Google Scholar, and Scopus. This literature included international and local papers that had been peer-reviewed or authored by a government organisation, with all literature reviewed aiming to focus on recent works (published post 1990). Therefore, the literature reviewed for this research had a focus on quality and up-to-date materials (Snyder, 2019, Green, Johnson, & Adams, 2006). As the development of the term CBGI (i.e., Objective 1, completed in Chapter 2) originated from numerous different terms which spanned multidisciplinary study environments, many different key search terms were used in that literature review. These diverse terms were included by using key search words such as: *green infrastructure, blue infrastructure, soft engineering, green engineering, blue/ green infrastructure, nature-based solutions and ecosystem engineering*.

Once a clear definition of CBGI was developed, identifying the potential range of CBGI values (Objective 2) could be investigated as there were clear criteria for what CBGI included and excluded. To this end, research was found by searching the phrases and combinations of the phrases such as: *benefits of blue-green coastal infrastructure, values of coastal soft engineering,* and *limitations of coastal green infrastructures.* Searching both the benefits and limitations of CBGI ensured that literature selection bias was limited as different perspectives were being investigated, critically analysed, and accounted for. To ensure the values were relevant in New Brighton, research was also conducted on underlying site-specific values of the New Brighton community and coastal dune environments. A multitude of literature was also analysed to determine an appropriate methodology that could be utilised to measure these benefits. Table 7 summarises a selection of this literature examined.

Table 7- Literature critically analysed to identify the potential range of CBGI benefits that could be measured in the New Brighton dune system and the approach used to measure these benefits (Objective 3)

Type of BGCI	Literature available
Sand dunes	Barbier et al., 2011; Bergin, 2008; Dahm & Jenks, 2005; Drius et al., 2019; Everard et al., 2010; Cunniff & Schwartz, 2015; Gallego-Fermandez, Sachez & Ley, 2011; Harris et al., 2020; Morris et al., 2018; Nordstorm et al., 2000; Orchard, 2014; Russel, Shultzitiski & Setty, 2009; Sutton-Grier et al., 2015; Zhu et al., 2010
Beach renourishment	Cunniff & Schwartz, 2015; Reguero et al., 2018; Shibutani et al., 2016; Zhu et al., 2010
Hybrid	Morris et al., 2018; Schoonees et al., 2019; Sutton-Grier et al, 2015; Zhu et al., 2010
Methods used to value nature	Bridges et al., 2021; Dewsbury et al., 2016; Díaz et al., 2018; Kadykalo et al., 2019; Morris et al., 2021; Pascual et al., 2017; Anderson et al., 2019; McKenzie et al., 2021
Local values at New Brighton	Carrass, 2021; McNabb, 2020; Orchard 2021 and interviews.

When undertaking a literature review, selection bias can occur due to the positionality of the researcher having inherent opinions on the topic being researched (Drucker, Fleming & Chan, 2016). When opinions are involved or 'facts' determined are influenced by measurement choices, it is thus important that peer-reviewed literature is included from multiple perspectives so that opinions and approaches can be critically analysed. This can reduce biases arising from the positionality of the researcher. Methodologies employed in previous work should be critically analysed in particular to reduce the chance of replicating inherent researcher biases (Drucker, Fleming & Chan, 2016).

Once CBGI values were identified, literature was also employed to assess how these values could be quantified in a New Brighton dune system context. This is introduced in section 3.4 of this methodology and addressed fully in Chapter 4 of this thesis. Keyword searches were conducted for research involved: *valuing nature*, *ecological services*, and *nature's contributions to people*. In numerous cases this literature was not primarily focussed on valuing CBGI, with limited scholarship being available in this area. Additional literature searches were focussed on including materials recognising Māori values and/or those of the New Brighton community. The Māori values were determined through research authored by people of indigenous culture and year the literature was published was not taken into consideration. It was important to research both the benefits and limitations of different approaches to valuing nature, including, and extending beyond the geographic discipline of this researcher, to reduce selection biases (McDonagh et al., 2013; Creswell, 2014). As a part of the analysis process, identified literature was summarised and tabulated in a spreadsheet including data on the title, year, authors, key points, methodology and figures, tables and numbers or terminology deemed to have significant information value towards achieving the objectives of this research. Extracted data were used to analyse the literature's approach, key points, and arguments.

3.2 Field data gathering and analysis

Once a method for evaluating the values of the CBGI of the New Brighton dune system was identified (Objective 3), fieldwork could be undertaken to gather the necessary local data to quantify the CBGI value of the New Brighton dune system (i.e., Objective 4). Three sites along the New Brighton dune system were investigated (Figure 19). These study sites overlap with sites included in the Environment Canterbury (ECan) network of 56 monitored Canterbury beach profiles, with records dating back to 1990 at twice-yearly intervals, documenting changes in beach profile attributes (Bergin, 2008). The three dune area sites investigated each spanned 100 m of dune system (50 m along the shore either side of an ECan profile) and were chosen because they included different vegetation covers, dune shapes and sizes, and were located adjacent to differing levels of property and infrastructure development. The coordinates of the ECan profile monitoring sites at the centre of each of the examined dune areas were supplied by ECan in shapefile format and mapped in ArcGIS 10.8.1, as well as overlaid on 2021 aerial imagery. Dune width and vegetation cover characteristics were broadly reviewed using the Google earth satellite imagery. In combination with UAV imagery gathered in the field (method explained below), the review of the satellite and field imagery, as recommended by Carvalho et al. (2020), provided a broadscale check that the three study areas selected were reasonably representative of the wider New Brighton coastal sand dune system.

On 22nd September 2021, a sunny clear day with light winds (Figure 20), a DJI Matrice 200 UAV with a DJI X4S mounted camera was used to gather digital terrain points and aerial images of the three study sites. The UAV imagery was referenced to local geodetic points which were sourced from the LINZ Geodetic database with 16 cm horizontal accuracy. The UAV was pre-programmed to fly a specific flight path at 100 m altitude covering 50 m each side along the shore from the ECan transects, with the cross-beach dimensions covering out to the water line in a seaward direction and to the limit of the full dune system extent inland. This flight path provided high resolution digital images, with pixel sizes of 2.19 cm^2.

Figure 19- Location of the three study sites on New Brighton Spit

Note: map constructed using QGIS (QGIS Development Team, 2020).

A Trimble global navigation satellite system (GNSS) survey tool (Figure 20) was used to aid ground truthing of the vegetation types. This ground truthing technique was undertaken to aid in the identification of vegetation species captured in the UAV images during post-processing, therefore, helping to determine the ecological characteristics of each study site. The GNSS was calibrated using a base station connected to a local geodetic point at each site. The GNSS rover was then carried on foot across the dunes to gather points atop of specific vegetation types (e.g., marram grass (*Ammophila arenaria*), spinifex, and pīngao, cabbage tree (ti kouka tree, *Cordyline australis*), karo (*Pittosporum crassifolium*) and coastal daisey (*Erigeron glaucus*). Points were recorded in the NZ Transverse Mercator 2000 coordinate system, with attribute data added on vegetation type.

Figure 20 – Field equipment employed in this research

Note: this image, taken during fieldwork and showing the clear sunny conditions experienced, pictures the UAV base (towards the right), the DJI Matrice 200 AUV (centre) and the GNS Trimble used for ground truthing the UAV imagery (left corner).

Agisoft, a photogrammetric program (Khalaf & Akram, 2020) that utilises a computer vision algorithm to process 3D images, was employed to analyse the UAV images gathered for each study site. That is, common points among photos gathered from various angles were detected and processed to calculate the depths of structures shown on the ground (Khalaf & Akram, 2020). The Agisoft workflow tab undertook this by creating an orthomosaiced image and a digital elevation model (DEM) for each study site via four steps (align photos, build a dense cloud, build a mesh, and build texture) and two secondary steps (build a DEM and build an orthomosaiced image). To align the UAV images gathered insitu (step 1), this programme searched for common pixels in adjacent images, and then made an automated assumption on the position of the camera. Next, for step 2, dense cloud building occurred whereby a cloud of points was gathered from the UAV imagery in 3D space. Once these points were loaded in *Agisoft*, mesh building occurred (step 3) by linking the groups of neighbouring points into triagonal faces to produce a mesh overlay. This process enabled information on the texture of the sand dunes to be analysed (step 4), using image data points and 3D mesh overlay points. Next, the first secondary step was completed, and a DEM was constructed based on the raw imagery, textural information and mesh data. Lastly, the second secondary step was undertaken, and an orthomosacied image was created, with the resulting output being a 3D image of each dune study area at 2.19cm^2 resolution. The same process was applied to each study site, producing three 100m-wide (i.e., longshore beach length) 3D orthomosaiced models of the New Brighton sand dune system, ready to be assessed using the CBGI value assessment methodology created in this research (Objective 3).

3.3 Expert interviews

Finally, experts on coastal sand dunes and their benefits in Ōtautahi were interviewed to aid understanding of the local values of the New Brighton dune system. In combination with the earlier described literature reviews, this enabled development of a comprehensive methodology to assess both the context-specific and general values of the dune system, as advocated in Natures Contribution to People (NCP) approaches, which are explained and evaluated by comparison with other valuation approaches in Chapter 4 of this thesis and introduced in Section 3.4 of this methodology. Expert interviews-provide qualitative primary data gathered via open and closed questions in structured or non-structured interviews (Creswell, 2014 & Hay, 2016). The structure of the interviews conducted in this research depended on interviewee expertise, with the experts being interviewed listed in Table 8.

Table 8- List of interviewees, their positions, and relevant expertise for this research project

Name	Position	Relevant area of expertise
Derek Todd	Principal coastal and hazard scientist, Jacobs	Coastal science in New Zealand.
Maiki Anderson	Coastal planner and Advisor, CCC	Community viewpoints on CBGI in Ōtautahi as well as insight into the CCC's work surrounding CBGI as a climate change adaptation strategy.
Justin Cope	Principal Science Advisor - Natural Hazards, Environment Canterbury	Local understanding of values, coastal processes, and knowledge of viability of CBGI on the New Brighton Spit.
Greg Bennet	Waimakariri DC and Coastal Restoration Trust	Māori values of dune systems as well as community perspective on CBGI in NZ.
Dr Shane Orchard	Dune restoration project lead- Clifton Beach	Different types of sand dune vegetation and their effectiveness on New Brighton Spit as well as knowledge on impacts of climate change on New Brighton.
Jason Roberts & Pieter Borcherds	Coast care, CCC	Practical local knowledge of the values of the dune system and coastal geomorphology. As well as extensive knowledge of coastal sand dune vegetation and how these influence the ability of a coastal sand dune in New Brighton provide coastal protection.
David Bergin	Director of Environmental Restoration Ltd	Benefits of dune systems in NZ alongside experience in valuing nature in NZ as well as extensive knowledge on vegetation and how dunes work.
Dr Hannah Buckley	Head of School | School of Science at Auckland University of Technology	Field techniques on gathering sand dune data and knowledge on the ecological value of the New Brighton sand dune system.
Dr Teresa Konlechner	Senior Ecologist, Wildland Consultants Ltd	Knowledge on coastal vegetation in Ōtautahi and the values of dune systems to the community.
Tom Simons-Smith	Principal Advisor Coastal Adaptation, CCC	Knowledge on the research gap surrounding CBGI in Ōtautahi.

The Māori perspective on the value of the New Brighton coastal sand dune system was also a topic for which an interview approach was planned. Before any Māori participants were to be approached for interviewing, collaboration was undertaken with Te Waka Pākākano in an attempt to ensure that appropriate interviewees could be selected and that any interviews would be conducted in a culturally respectful manner. A Māori ethics process was completed (Appendix A), and collaboration was occurring between Te Waka Pākākano and Mana whenua to determine suitable interviewees. However, this collaboration did not result in any suitable interviewees being identified, and it was decided that Te Waka Pākākano did not have any suitable contacts that would be able to address this research topic adequately. Attempted contact with CCC cultural advisors was also unsuccessful.

In response, further collaboration occurred with other members of Te Waka Pākākano - a Māori resources librarian who helped the researcher locate indigenous literature relevant to this topic. This literature is what forms the basis for determining the te ao Māori perspective on the New Brighton dune system in this present research. The librarian recommended the use of broad literature from indigenous authors that sometimes may come in the form of stories, suggesting if relevant literature could not be located in the Māori worldview, other indigenous cultures would hold similar values from all over the world and to utilise this. Appropriate literature was found in a Māori context, however, not specifically relevant to coastal sand dune environments. Therefore, interpretations were made from advice from Te Waka Pākākano that these values were relevant in a coastal space. However, due to the limitation of not being able to interview Māori, and the pakeha background of this thesis researcher, further research in this space *by* or *working with* indigenous scholars and community members is recommended as a next step for deepening the Aotearoa cultural understandings of CBGI begun here.

3.4 Selecting a dune CBGI valuation framework

This section outlines the valuation framework of CBGI benefits that is employed in this study to assess the values of the New Brighton dune system, using an NCP-informed approach, with values grouped into regulatory, material, and nonmaterial categories (Table 9).

Table 9- Three NCP categories of benefits assessed for the New Brighton sand dune system

Note: for the three dune study areas, the benefits listed in Table 9 were assigned a 1 to 3 ranking level, with levels defined as, poor value (1), moderate value (2), or high value (3) present.

Regulatory	Nonmaterial	Material
Coastal protection value	Aesthetics value	Monetary value
Ecological value	Sense of place value	
Carbon sequestration value	Recreational value	
	Touristic value	
	Educational value	
	Well-being value	

According to the NCP paradigm, which will be explained in detail in the results section of this thesis, cultural values are intertwined into each human value assessed (a contextual approach), with international through to national and literature on coastal dune systems and sandy beaches also being employed (a generalised approach). Where possible, quantitative individual benefit valuation measurements were applied to the field sites. However, the lack of existing quantitative measurement methodologies, combined with time and resource constraints encountered during this research, as well as questions regarding the appropriateness of quantifying some kinds of benefits, mean that the quantitative field site focused measurements were only undertaken for the analysis of certain benefits, namely coastal protection, carbon sequestration, ecological, and recreational. It is also important to note that within these measured values there are components of the dune system which are measured multiple times as they contribute to multiple values, therefore, an overall value of the dune system was not measured.

Chapter 3 has explained that the four objectives for this thesis were addressed via a mix of qualitative and quantitative research techniques as recommended by Creswell (2014). Moving forwards these research techniques will be implemented to create an evaluation methodology through the NCP approach to valuing nature with the benefits of the sand dune split up into regulatory, material, and non-material benefits categories. The next three results chapters examine and explain the significance of this approach to valuing nature discussing each NCP category benefit to people and the environment, and how each value can be measured.

4 Different approaches to valuing CBGI benefits

This chapter reviews and discusses different approaches to valuing CBGI, before selecting NCP as an appropriate approach to apply to the evaluation of the New Brighton coastal sand dune system, Ōtautahi.

4.1 The value of CBGI

Evaluating the benefits of nature for people is a contentious topic with diverse opinions. Some researchers advocate for giving nature value, while others imply that valuing nature is flawed with inconsistences arising when assessing natures' values from different perspectives (Getzner, Spash & Stagl, 2005; 2004). However, all decision and policy making involves value judgements. Providing stakeholders and decision makers with a value estimate of nature may facilitate rational decision making. Costanza & Folke (1997, p50) state that "*we cannot avoid the valuation issue because as long as we are forced to make choices, we are doing valuation".* This nature-value-realisation is becoming more accepted globally as our coastal ecosystems are being rapidly degraded due to human activity. If nature is not valued, habitat destruction for perceived human benefits may accelerate (Bar et al., 2016). Therefore, giving nature a measurable transparent value promotes recognition of nature and the benefits it provides (Barbier et al., 2011; Medarova-Bergstrom et al., 2014).

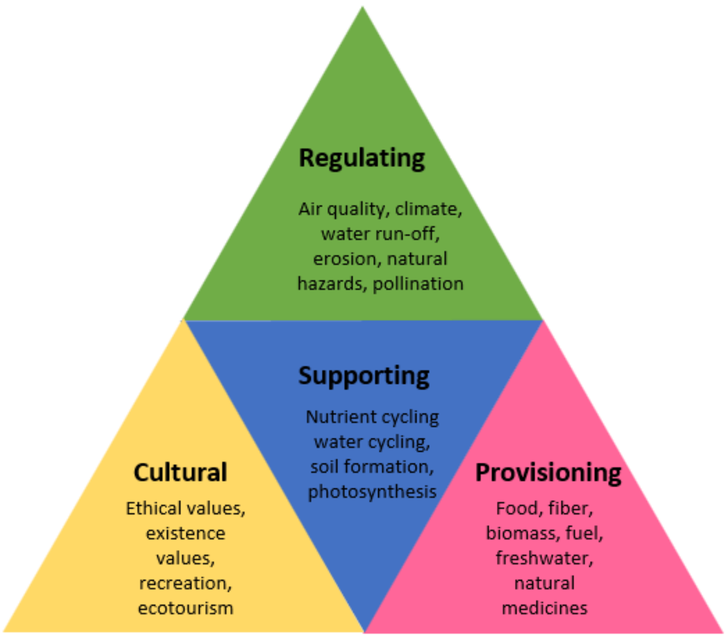
The New Brighton dune system has been significantly altered for perceived human benefit. In 1995, a consent was granted by ECan to CCC to recontour and lower the North New Brighton dune system to 8 m above mean sea level (AMSL), with 8000 cubic metres of sand removed from the dune system in 2000 (Sinclair, 2000). The purpose of this was to enhance the sea view for coastal dwellers in New Brighton. With SLR and climate change exacerbating coastal hazards, it is important that dune systems are protected and restored (Bridges et al., 2021). For the dune system to be protected, its multiples values to people should be understood and demonstrated (Bar et al., 2016). When the value of living systems like our dunes are recognised, it can catalyse community and stakeholder action to further enhance its protection and restoration (Thorne et al., 2018).

The next section explores two approaches to valuing nature: 'ecosystem services' and 'natures contributions to people'. One of these methodologies, the natures contribution to people (NCP) method, chosen because of its emphasis on a contextual approach to valuing nature, is then applied to valuing the New Brighton sand dunes in a way that could underpin and facilitate these dunes' future protection, restoration, and enhancement.

4.2 Ecosystem services

A common methodology in which nature is conceptualised, measured, and later valued in natural scientific discourse is related to the 'ecosystem service' concept (Costanza et al., 2017). The ecosystem service concept arose because society depends on healthy functioning ecosystems, and economic valuations of nature-associated services needed to be developed to promote sustainable ecosystems. The *Millennium Ecosystem Assessment* (MEA, 2005, p.40) define these services as "*benefits people obtain from ecosystems*"; implying that the benefits can be measured and valued. From an economic viewpoint, the services and goods that benefit humans can be classified into regulating, supporting, provisioning and cultural benefits (Figure 21), (MEA, 2005). The term 'ecosystem service' has been used frequently to assess direct and indirect contributions from nature to society and well-being (Costanza et al., 2017).

Figure 21- Diagram summarising ecosystem services that benefit humans.
Note: adapted from MEA (2005 piv).



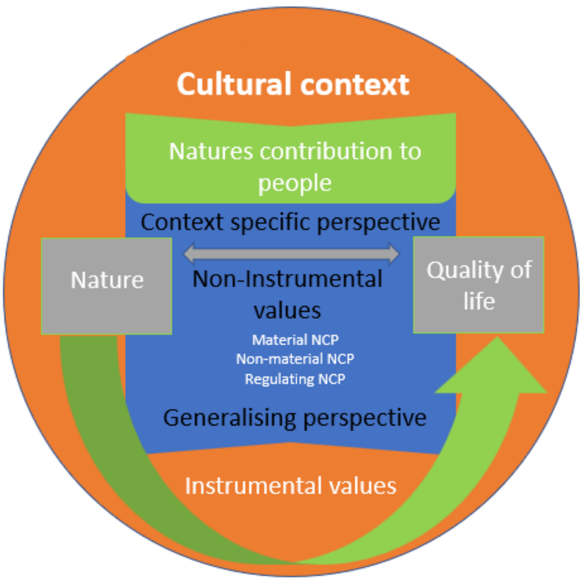
Historically, there has been a significant lack of research into valuation of cultural services (Martin et al., 2016). Recent studies have analysed ecosystem service approaches to valuing CBGI, and it has been recognised that these approaches mainly focus on the ecological and economic services of nature and lack a social science or indigenous understanding of the benefits of nature (Díaz et al., 2018 & Martin et al., 2016). For example, the ecosystem services approach to valuing nature is split up into regulating, provisioning, supporting, and cultural services, with the economic value of the ecosystem perceived more important than the (sub) categories (MEA, 2005). This approach does not recognise that culture affects all aspects of the relationship people have with nature (Barbier et al., 2011). As a result of culture being represented by a single, separate category of the valuation, stakeholders and minority group views are typically marginalised when this approach is applied to assessing the benefits of CBGI. Identifying a diversity of values from different stakeholders and individuals may be challenging, but not doing so can undermine the robustness of CBGI values and produce unsustainable outcomes (Pascual et al., 2017).

As indicated, culture underlies all interactions humans have with nature and ecosystems. Hence scepticism of the term 'ecosystem services' has arisen, as social inequities in the ecosystem services approach pose challenges for assessing nature benefits in fair and inclusive ways (Kadykalo et al., 2019). Research has shown that the way nature values are perceived can be starkly different depending on assessors' ontologies and cultural background (Kadykalo et al., 2019 & Pascual et al., 2017). Nature values should be conceptualised to accommodate the different relationships with nature held in different cultures (Díaz et al., 2018). Consequently, although CBGI ecosystem service assessments have been helpful in promoting the value of CBGI, this approach has historically been overlooked that culture is part of all ecosystem services. New nature valuation methods may be needed to better recognise the importance of cultural benefits.

4.3 Natures Contribution to People (NCPs)

An alternative approach to measuring the value nature provides to people NCP was introduced in 2017 by the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) (Figure 22). NCP can be defined as "*all the positive contributions, losses or detriments, that people obtain from nature"* thereby emphasizing both beneficial and harmful effects of nature on people's quality of life (Pascual et al. 2017, p. 9).

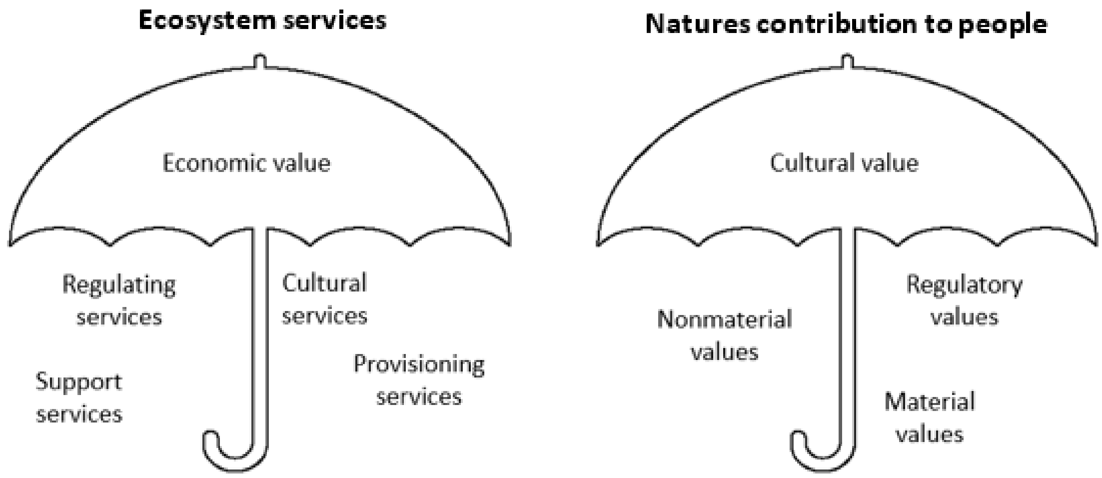
Figure 22- Diagram explaining the conceptual approach of Nature's Contributions to People' (NCP)
Note: this method is used to evaluate the value of natural ecosystems (Elllis et al., 2019 p89).



NCP differ from ecosystem services because NCP recognise the central role that culture plays in defining all links between people and nature. NCP also actively emphasises the role of indigenous and local knowledge in understanding nature's contribution to people (Chaplin-Kramer et al., 2019). The NCP approach promotes social equity and inclusion, as well as allowing the benefits of nature to be assessed in both universal and context-specific manners (Costanza et al., 2017). NCP can be measured via three categories: material, nonmaterial and regulatory, based on their contribution to people's quality of life (Pascual et al., 2017). The cultural value of nature is incorporated as an integral component of all categories. This approach differs from ecosystem services, which confines and isolates the cultural benefits of nature to one category (Chan et al., 2012). Figure 23 displays the differences between the two approaches.

Figure 23- Differences between the 'ecosystem services' and 'natures contribution to people (NCPs)' approaches to valuing the benefits of nature.

Note: the ecosystem services approach to measuring the value of nature is shown on the left. This approach is overseen and measured from an economic perspective with the cultural services that ecosystems provide being confined to one small compartment of analysis. On the right, the NCP approach to valuing nature places culture across all aspects of assessing the value of nature, enabling a contextual assessment of the value of nature. Source: authors own.



NCP incorporates two different ways of viewing nature: at one extreme, nature and humans are considered distinct entities (generalising perspective) and at the other extreme humans and non-humans are interwoven and deeply connected in reciprocal obligations (context-specific perspective) (Diaz et al., 2018). These two perspectives are often seen as end members of the one continuum (Díaz et al., 2018b). Although the generalised perspective is utilised in the ecosystem services approach to valuing the benefits of nature (Kadykalo et al., 2019), NCP goes beyond this by also incorporating context-specific perspectives. Context-specific knowledge can be incorporated, such as the unique local or cultural worldviews communities have and their applicability to certain socio-ecological settings (Peterson et al., 2018). These views have limitations because they may not transfer universally and may miss relationships between nature and people that the ecosystem services approach could highlight. Thus, the NCP approach has adapted a hybridisation between the context-specific and generalised ways of valuing nature (Pascual et al., 2017).

In the case of NZ, Māori culture is a significant part of our heritage, however, due to colonisation, the Māori worldview has been marginalised and decisions surrounding the value of nature to people have been inequitable (Wheaton et al., 2018). To ensure Māori culture is included throughout all aspects of the assessment of the value of the New Brighton sand dune system the NCP approach to valuing CBGI is adopted here. However, before the benefits to humans of the CBGI of the New Brighton coastal sand dune system can be assessed, the Māori worldview must be explored to provide a contextual understanding of the study area.

4.3.1 Aotearoa New Zealand's culture

NZ's natural environment is often described as "*part of our cultural identity"* and as being essential to its residents' well-being (Brown et al., 2015; Upton, OECD Environment Director, 2017, p.2). Human knowledge systems, religions, cultures, languages, amenity services and social interactions are all influenced by our ecosystems (Millennium Ecosystem Assessment, 2005). Natural ecosystems have inspired drama, songs, dance, fashion, and design for as long as humans have existed, with our NZ way of life being shaped by our ecosystems (PCE, 2002).

Sand dunes are a key ecosystem of cultural value in NZ. Numerous indigenous flora are found on dunes. Sandy beaches have helped to shape our individuality as a country and are a key asset in terms of tourism and culture (Collin & Kearns, 2018). Coastal environments have developed this strong connection to the coast through *whakapapa*, or in a sense of reverence for the land/seascape due to repeated visits to the beach. Many New Zealanders view "*the beach is the essence of the Kiwi dream*" (Collin and Kearns, 2018 p436), and that easy access to the coast is "*a national birth right*" (Phillips, 2007 np). Unfortunately, dune systems have been degraded via human development, cattle grazing, forestry, and coastal erosion and hence this societal fabric built from the health of our coastal environments, could weaken (Dahm et al., 2005, Ministry of statistic New Zealand, 2019). Therefore, it is important for NZ's cultural identity to recognise the cultural value of dunes to improve dune restoration projects across NZ.

4.3.2 Māori perspectives on ecosystems

The cultural values of ecosystems in NZ are difficult to measure due to the complex and intertwined relationship with people and the many direct and indirect benefits of these ecosystems (Small, Munday & Durance, 2017). For the purpose of this research, te ao Māori perspectives were explored in order to assess the cultural values of the sand dune ecosystem, using the literature of indigenous scholars. This attempt at understanding te ao Māori perspectives on dunes is limited not only because it is conducted by a non-indigenous scholar but also due to the text-based approach taken. As such it should be considered a first exploration, with future research needed to refine this aspect of the values approach developed here.

Traditional Māori worldviews are holistic and with a deep spiritual connection to nature with "*clear links between healthy ecosystems (with greater life-supporting capacity) and people's cultural and spiritual well-being*" (Harmsworth & Awatere, 2013 p1). This belief is captured in the term 'Whakapapa' which describes "*the heart of Māori identity and connection to place*" (Matapopere Charitable Trust, 2015 p4), with Whakapapa "*being embedded in the landscape and inherent to understanding the relationship between Māori and the natural world*" (Matapopere Charitable Trust, 2015 p5). Spirituality, self-awareness, and self-respect grow from the relationship between Māori and the whenua (land) which includes coastal land (C; Harmsworth & Awatere, 2013; Scheele et al., 2016; Wheaton et al., 2021; Walker et al. 2019). Māori well-being is "*interdependent on ecosystems and ecosystem services*" (Harmsworth & Awatere 2013 p. 274). To maintain well-being, it is important "*that people care for ecosystems (manaaki whenua) so that ecosystems can care for people (manaaki tangata)"* (Dymond et al. 2014 para. 20). This perspective implies that a loss or degradation of ecosystems in NZ such as coastal sand dunes will result in a loss of well-being (Wheaton et al., 2021), with the Māori proverb stating "*Ka ora te whenua, ka ora te tāngata - When the land is well we are well*" (Aimers et al., 2021). This perspective can be implemented to the New Brighton coastal sand dune ecosystem.

To further understand the Māori worldview and how this relates to dunes in NZ, some further key concepts are listed below in Table 10 which relate to the Māori perspective on the natural world as described by indigenous scholars or research working with indigenous scholars. The key concepts help us understand the relationship Māori have with the land (including coastal) and how important it is to maintain healthy ecosystems (including dune). The following Māori proverb supports the worldview that if healthy ecosystems are not maintained, well-being will be depleted (Scheele et al., 2016; Wheaton et al., 2021; Walker et al. 2019)- "*Ko ahau te taiao, ko te taiao, ko ahau – The ecosystem defines my quality of life (Ngāti Wai and Ngāti Whatua)"* (Harmsworth & Awatere, 2013 p1).

The Māori concepts listed in Table 10 were integral components from local research exploring the cultural values of NZ ecosystems: examples include valuing non-timber aspects of native forests, and the cultural value of Raekura/ Redcliff's school and park, with input from Te Ngāi Tūāhuri Rūnanga (Aimers, Bergin & Horgan, 2021; Maahanui Kurataiao Ltd, 2017). Although these case studies are not directly related to the New Brighton coastal sand dune system, the concepts provided can aid the initial exploration of how sand dunes could be appropriately valued from a Māori worldview (though further research with or by indigenous scholars is also recommended beyond this thesis).

Table 10- Key concepts from a Māori world view that can be used in this research to again an understanding of the cultural value of the New Brighton coastal sand dune system

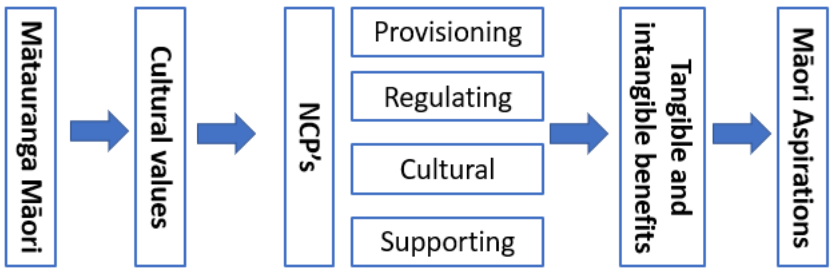
Concept	Description
Tangata whenua	Tangata whenua refers to "*people of the land, connected to place (e.g., river) through a distinct whakapapa*" (Harmsworth & Awatere, 2013 p285)
Mauri	Mauri is "*the life force present in all things, both animate and inanimate"* (Royal, 2003, p. 47). Natural features such as water, forests and air and the life supported by them all have Mauri (Aimers et al., 2021; Matapopere Charitable Trust, 2015; Yates et al., 2019).
Whakapapa	Whakapapa explains "*connection, lineage, or genealogy between humans and ecosystems and all flora and fauna*" (Harmsworth and Awatere, 2013 p275). It is given credit for the creation of the earth and universe (Matapopere Charitable Trust, 2015; Sceele et al., 2016; Walker et al., 2019).
Kaitiakitanga	Kaitiakitanga roughly translates to "*the act of guardianship*" (Matu, 1994 in Roberts et al., 1995 p12). It describes the position of tangata whenua as temporary guardians of the environment (Harmsworth & Awatere, 2013; Marsden & Henare, 1992). It emphasizes the importance of the responsibility we have of maintaining the health of the natural world for future generations. Kaitiakitanga is based on whakapapa as a cultural bridge between Māori and their offspring in the environment (Aimers et al., 2021 & Walker et al., 2019).
Mahinga kai	Mahinga kai "*encompasses the places where natural resources were/ are obtained, the resources themselves and the practises and principles that guided how these resources were harvested and managed*" (Matapopere Charitable Trust, 2015 p7). Mahinga kai could be birds or fish taken for food or harakeke or pīngao used for weaving (Matapopere Charitable Trust, 2015; Scheele et al., 2016; Maahanui Kurataiao Ltd, 2017; Walker et al., 2019).
Rongoā	Rongoā is a "*remedy, medicine, treatment*" (Scheele et al., 2016 p9)
Manakitanga	Manakitanga describes the ability of someone to fulfil the obligations of a host and "*extend hospitality and reciprocity"* (Matapopere Charitable Trust, 2015 p12).
Whanaungatanga	Whanaungatanga (community connectivity), refers to "*how well whānau, hapū and iwi well-being and social prosperity is improved through their connection to, and interactions with, the natural environment*" (Scheele et al., 2016 p5). For example, access and abundance of rongoā (Māori medicine), and mahinga kai positively influences whanaungatanga. Another part of whanaugatanga is manakitanga (Scheele et al., 2016; Matapopere Charitable Trust, 2015 p7).
Tūrangawaewae	Tūrangawaewae is someone's "*sense of place*" and identity (Scheele et al., 2016 p12). It elicits how whānau, hapū and iwi well-being is reflected in their natural environment (Aimers et al., 2021; Scheele et al. 2016; Ministry for the Environment & Stats NZ 2019).
Tikanga Māori	Tikanga Māori are "*traditions and customs passed down through generations".* Tikinga Māori is about "*protocols and customs.. and can vary between hapū and iwi"* (Nā, Maahanui Kurataiao Ltd, 2017 p9).

Ki uta ki tai	Ki uta ki tai explains the overall Māori approach to resource management as "*a whole-of-landscape approach, understanding and managing interconnected resources and ecosystems from the mountains to the sea*" (Harmsworth & Awatere, 2013 p275). Ki uta ki tai includes "*whakapapa, traditions, and acknowledges the inherent link between the environment, those that inhabit it and other elements that constitute and interact with it*" (Nā, Maahanui Kurataiao Ltd, 2017 p8).
Ingoa Wāhi	Ingoa Wāhi are Māori place names (Matapopere Charitable Trust, 2015; Walker et al., 2019). Māori place names "*exemplify the relationship Māori have with the landscape (whakapapa)"* (Nā, Maahanui Kurataiao Ltd, 2017 p8)
Wāhi Toanga/ tapu	Wāhi Toanga may include "*places that are treasured or valued by manawhenua/ tangata whenua*" (Nā, Maahanui Kurataiao Ltd, 2017 p8). These areas are regarded as the footsteps of ancestors (Ministry for the Environment & Stats NZ, 2019 & Walker et al., 2019). Wāhi tapu refer to "*places link with death or ceremonies*" (Nā, Maahanui Kurataiao Ltd, 2017 p8).
Wai tai	Wai tai –"*coastal water*" (Nā, Maahanui Kurataiao Ltd, 2017 p9). The approach of Kaitiakitangi and ki uta ki tai implies that activities affecting coastal water needs to be considered. If the health of wai tai is affected this can have impacts on the mauri of Tangaroa and on the abundance of mahinga kai (Nā, Maahanui Kurataiao Ltd, 2017; Walker et al., 2019).
Taonga species	Taonga species are native flora and fauna of special cultural significance and importance to indigenous people (Aimers et al., 2021; Matapopere Charitable Trust, 2015; Walker et al., 2019). In the present day Taonga species are treasured because they "*link to whakapapa and traditions as well as being a food source*" (if in abundance) (Nā, Maahanui Kurataiao Ltd, 2017 p9).

These key concepts will be incorporated throughout the NCP assessment of the New Brighton dune system as seen in Figure 24 to give it a context-specific approach, therefore, honouring the NCP approach to valuing ecosystems.

Figure 24 - Diagram explaining the overlying impact of Mātauranga Māori on measuring NCPs values of the New Brighton coastal sand dune system

Note: adapted from Harmsworth & Awatere (2013 p284).



4.3.3 Generalised benefits of CBGI

As well as exploring Māori culture to gain a context-specific perspective of CBGI values, within the NCP lens it is also important to employ a generalised approach to valuing CBGI. To address the general values of the New Brighton sand dune system CBGI, global case studies assessed in the earlier literature review of this thesis are employed to understand general CBGI co-benefits. These include ecological value; coastal protection; carbon sequestration; aesthetic value; sense of place; tourism, education, and recreational value; well-being value; monetary value as categorised in Table 9 of the methodology section of this thesis.

As argued in this chapter the NCP approach to valuing nature is the most appropriate for the purpose of valuing the New Brighton sand dune system. This is because culture plays a role in all the values of the sand dune system that will be measured. Therefore, this approach is contextually appropriate with the Māori worldview being incorporated, with the central belief being that the value of the dune system to humans is heavily dependent on the health of the dunes ecosystem. Moving forwards this NCP approach to valuing nature will be implemented to measure the various values of the New Brighton coastal sand dune system.

5 Assessment of dune system CBGI regulatory benefits

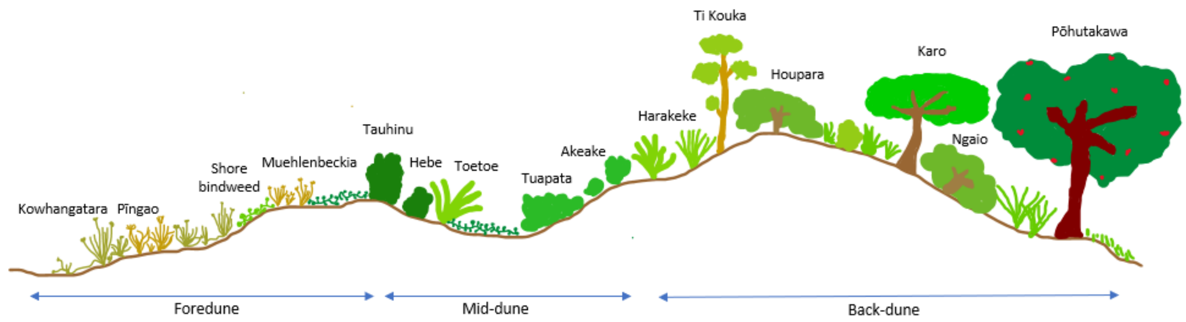
This chapter is divided into in two parts. The first part explores understandings and potential evaluation methods for a suite of regulatory benefits provided by dune system CBGI in NZ as outlined in Table 9, namely the ecological, coastal protection and carbon sequestration values. In the second part, a subset of the evaluation methods developed are applied to the New Brighton dune system CBGI, and the regulatory values of this system are discussed.

5.1 Ecological benefits

NZ coastal sand dunes can be areas of rich ecological biodiversity fostering both a variety of rare and indigenous psammophilic (sand dwelling) specialised flora and fauna (Figure 25). However, they have been identified as one of NZ's most critically endangered environments, occupying less than 30% of their original area with that remaining being highly modified or degraded (Hilton et al. 2000). These sand dunes are also understudied and, consequently, their ecological value has not been adequately quantified, a factor which potentially contributes to their degradation (Hesp, 200; Jamieson, 2008).

Figure 25 - Typical zonation of native coastal sand dune vegetation in New Zealand

Note: adapted from Auckland Council (n.d. p1).



Coastal sand dune vegetation comprises a sequence of terrestrial plant species adapted to the multiple condition gradients occurring from seaward to landward across backshore environments and beyond (Figure 25) (Hesp, 2000). Key environmental stressors that vary along the cross-shore gradient include sand mobility, deposition/ burial rates and events, and the frequency and degree of salt spray, with corresponding variation in soil development and microbial activity. Three generally distinct coastal sand dune zones are recognised: fore, mid, and back dunes (Walker et al., 2007). Changes in species assemblages between zones can be abrupt or gradual (Dahm, 2017).

The foredune zone is the most seaward zone, and typically consists of sand trapping species like spinifex and pīngao (Figure 26 and 28) (Dahm, 2017). These species have adapted to rapid and variable sand movement and exposure to salt spray and wind, and can expand horizontally to colonise sand, and grow upward and seaward following burial events (Bergin, 2011 & DOC, 2005). The traits of foredune vegetation (detailed below) highlight these species' critical roles in dune building and repair after storm events, plus their importance in preventing erosion (Verhoeven et al., 2014).

In the mid- dune zone ground cover species exist and the environment is more stable with less sand movement and burial (Dahm, 2017). Thus, the sand building vegetation typically transitions to a more diverse vegetation community composed of sedges, vines, herbaceous vegetation, and low woody plants. These plants are slower growing and more stable than the foredune sand binding species (Bergin, Bergin & Dahm, 2014). Common native examples of these plants include harakeke (*Phormium tenax*), akeake (*Dodonaea viscosa*), taupata (*Coprosma repens*), toetoe (*Austroderia*), hebe (*Veronica speciosa*), and pohuehue (Muehlenbeckia astonii) as seen in Figure 25.

Finally, the back dune zone typically consists of more woody vegetation and trees. This zone is most stable and least exposed to salt water, wind and moving sand (Bergin et al., 2014). Common native woody species found in this area are ngaio (*Myoporum laetum*), karo (*Pittosporum crassifolium*), pohutakawa (*Metrosideros excelsa*), sand kanuka (Kunzea ericoides) and coastal five finger (*Pseudopanax lessonii - houpara*) (Bay of Plenty Regional Council, n.d; Bergin, 2011). Currently in NZ, these areas are commonly degraded or destroyed due to human development in the coastal area. However, the original width and nature of this back dune zone would have likely varied significantly (Dahm, 2017).

The following subsection Boxes 5 and 6 examine the characteristics and benefits of key selected NZ dune plant species. The key species of pīngao and spinifex are explored in further detail as these native species bring a vast array of benefits to the New Brighton dune system and, therefore, are significant contributors to the overall value of the dune system.

Box 5. Pīngao, golden sand sedge

Pīngao (pīkao, golden sand sedge, or *Ficinia spiralis*), is an endemic sand-binding plant inhabiting active sand dunes (Scheele & Sweetapple, n.d). It is a stout, grass-like plant approximately 0.3-0.9 m tall and is part of the sedge family (Figure 26). Pīngao can spread and reproduce vegetatively (with stolons) and sexually (with seeds). Vegetative reproduction occurs when Pīngao spread over sand dunes by extending thick and tough stolons that creep along the sand surface until they end up buried by shifting sand (DOC, 2005). Roughly textured tough leaves appear in dense tufts spaced along the stolons on short, upright, well-spaced tillers. The width, length, strength, and colour of leaves vary among pīngao populations but are typically green to yellow, with hints of orange. Some southern populations of pīngao do not produce extensive stolons and mainly occur as dense and patchy tussock-like plants (Bergin, 2011). Pīngao reproduces sexually in spring, when dark brown flowers appear on the culm (upper stem) and are interspersed with leaf-like bracts. The dark brown shiny seeds ripen and fall in early summer and are transported by the wind and sea (DOC, 2005).

Figure 26 - Pīngao (pīkao, golden sand sedge, or Ficinia spiralis)

Note: images illustrate pīngao in its natural environment on a mobile NZ sandy foredune (left), the plant's dark brown seedhead (middle), and a close up of the plant's stolon habit (right), allowing pīngao to effectively trap and stabilise sand (Adapted from Bergin, 2011).

Pīngao is commonly a vital part of healthy NZ sand dune ecosystems, as an effective sand binder (DOC, 2005). This species typically grows on the seaward side of coastal foredunes and is capable of growing lower to the shoreline than many other sand binder species found in NZ. Pre-European settlement pīngao was widely distributed and abundant on sandy coasts throughout NZ but its extent is now confined to small patches and the plant is classified as endangered (Jaimeson, 2008).

Pīngao populations began to decline with burning, trampling, and grazing by domestic stock and animals introduced by European settlers, including possums, goats, sheep and rabbits. This decline was exacerbated by the introduction of competitive plant species like marram grass (*Ammophila arenaria*) and lupin (*Lupinus aboreus*) (Bergin et al., 1997; Gadgil et al., 1999). These plants were first planted throughout NZ in the early 1900s for dune stabilisation for their aggressive (plant and dune) growth habits, and rapid spreading tendencies. Today, coastal development, damage from motor vehicle, quadbike, horse and pedestrian traffic, sand mining, and overharvesting for weaving continue to cause decline in pīngao (DOC, 2005).

In response to pīngao decline, restoration efforts have been undertaken throughout NZ. Restoration is typically done by gathering seeds in summer, and growing them in nurseries, before planting the established plants into dune systems from autumn to spring (DOC, 2005). In the nursery the plants are seeded in autumn, it then takes a further 9 to 15 months for the new plants to reach 40 to 50 cm, with a root collar diameter of 5 to 10 mm (Bergin, 2011). These new plants are then introduced to the dunes in potting containers, accompanied by a broadcast application of urea or fast-release nitrogen fertilisers at 200 kg/ha (Bergin, 2011). Typically, pīngao are planted in clumps spaced about 20 to 50 cm apart and thrive in exposed empty sandy environments (Bergin & Herbert 1998).

Pīngao has often been planted in the New Brighton dune system behind dunes in small gardens and alongside boardwalks for the visual amenity of the public and to introduce the plants into a local outdoor, coast-proximal environment before they are moved to the foredune for coastal protection purposes (Bergin, Herbet & White, 1996; Mr P. Borcherds, CCC Coast Care Park Ranger, *pers. comm.* 16/6/21). Pīngao does not recover as quickly as spinifex between storm events and, therefore, spinifex is the most popular plant used in the New Brighton dune vegetation recovery programme.

Pīngao has numerous benefits, for example, this plant can colonise and inhabit dynamic low sand dunes (Figure 27) (DOC, 2005). These dunes provide erosion and inundation protection as well as being aesthetically pleasing. The slope angles of pīngao dominated dunes (c.15° slopes) are gentler than those of dunes dominated by marram (c.45° slopes), with gentler sloped dunes potentially more stable against wave attack and less prone to collapse (Jenks, 2018).

Figure 27 - Foredune slope of NZ coastal sand dunes

Note: foredune slopes depend on vegetation type, with NZ native vegetated sand dunes having gentler slopes (left) than typical of introduced vegetation foredunes (right) (adapted from Jenks, 2018 p637).

Due to its dynamic stolons, pīngao supports areas of high biodiversity as the available habitats and niches create a constantly changing landscape mosaic. Many species living in pīngao habitat are endemic and relatively rare and/or threatened, with examples including birds such as the NZ pitpit (pihoihoi, *Anthus novaeseelandiae*), dotterel (tūturiwhatu, *Charadrius obscurus*) (Bergin, 2011 & DOC, 2005). Other habitat dwellers include the threatened katipō spider (katipō, *Latrodectus katipo*) which translates to 'night stinger', *Pericoptus truncatus*, the striped lax beetle larvae (mumutaua, *Thelyphassa lineata*), the wolf spider (*Anoteropsis litoralis*) as well as *Tmetolophota phaula,* a native moth which feeds on the plant (Jaimeson, 2008). Clearly, pīngao creates a rich ecological niche for endemic species and is, thus, a plant of very high ecological value in NZ.

Pīngao also has significant cultural value and is considered taonga (treasure) as one of four key native plants used by tangata whenua (indigenous 'people of the land' in NZ) for weaving. As the only native fibre that does not require colour alteration after drying, pīngao is used to make kete (woven bags) and pōtae (hats), whāriki (mats), pare (headbands), belts, raincapes as well as for decorative weaving (Herbet & Oliphant, 1991). The young shoots can be steamed and eaten and, in the past, were used as bindings for injuries. Pīngao also supports the lifecycle of the increasingly rare toheroa shellfish (*Paphies ventricosa)* by providing shelter for the toheroa spat when they wash up into the dune vegetation during a big high tide. The pīngao then keeps these pēpi (babies) safe until spring when the pīngao seed heads are blown down into the foreshore where the tide collects the young toheroa shellfish (Ross et al., 2018). Therefore, pīngao is a valuable mahinga kai and rongoā resource for Māori (Bergin, 2011).

Box 6. Kōwhangatara, spinifex

Spinifex (Kōwhangatara, *Spinifex sericeus* R.Br. silvery sand grass) is also a key indigenous sand binding plant found throughout most of the North Island and down to Ōtautahi (its southern range limit) on the foredunes (Bergin, 2011). Spinifex, like Pīngao, is a stout perennial grass with tough creeping stolons. Leaves grow from the stolons which are typically 5 to 10 mm wide and up to 38 cm long. Stolons can grow up to 20 m long with internodes up to 38 cm long (Bergin, 2011). These nodes produce upright, green silvery leaves as well as adventitious roots. These roots occur at intervals of 10-15 cm and eventually take root in the sand to form a discrete plant that is independent of its original stolon (Bergin, 2011, see Figure 28).

Figure 28 - Spinifex (Kōwhangatara, Spinifex sericeus R.Br. silvery sand grass)

Note: pictures show the seeds of a male (left side) and female (right side) of the kōwhangatara plant (left image), and kōwhangatara plants in their natural habitat (right image), a highly mobile NZ coastal foredune, where stolons can be seen actively trapping and stabilising sand, thus acting to prevent coastal erosion (adapted from Bergin, 2011).

Spinifex is a dioecious plant, that is the female and male flowers are born on separate plants (Maze & Whalley et al., 1990). The male flower appears from October to November while the female flower appears from January to early March when pollination occurs (Bergin et al., 1999). Male flowers are about 5 cm long, located on short branches, while female flowers are 30 cm diameter spherical seed heads (Bergin, 2011). Male and female plants should be spaced at 3 m or less apart for effective pollination, with prevailing October wind patterns also influencing pollination rates (Maze & Whalley et al., 1990).

The distribution of spinifex throughout NZ has been significantly influenced by human activity. Initially, dune vegetation was burnt by the European settlers, followed by the introduction of domestic and wild grazing animals by European settlers (Partridge, 1992). Compared to pīngao, spinifex is less palatable, though it is grazed by wild animals such as rabbits and deer. A significant threat to spinifex populations is the floral smut disease *Ustilago spinificis* (Kirby, 1988), a highly infectious disease that destroys seed heads and consequently affects spinifex reproduction. However, similar to pīngao, the introduction of lupin and marram grass as well as coastal development and human activities such as walking (trampling), biking and anthropogenic climate changes and associated effects such as accelerated SLR, are still causing the decline of spinifex today (Bergin, 2011). As a result of human pressures, the species range has contracted largely towards the north, with the last naturally occurring spinifex plant in Ōtautahi documented in 1944 (Simpson, 1974).

As a result of the decline and spinifex's exceptional sand binding characteristics, restoration is occurring in many parts of NZ (Bergin & Kimberly, 1999; Jamieson, 2010). For example, seeds are collected from spinifex plantations in Marlborough, grown in nurseries for 2 years until mature enough to withstand the stressors of the coastal environment, then planted in Ōtautahi's sandy foredunes that are vulnerable to coastal erosion. They are planted in planting cups, approximately 50 cm apart with a fertiliser cap to aid the establishment of the plant, typically in winter when more moisture is available (Bergin, 2011; Mr P. Borcherds, CCC Coast Care Park Ranger, pers. comm. 16/06/21).

Spinifex provides high coastal protection value as a strong sand stabilising plant. It is dominant on the seaward face of foredunes as it can colonise raw sand with its deep roots and high tolerance to prolonged dryness, salt spray, strong winds, and high light intensities (Verhoeven, Buckley & Curran, 2014). The upright shoots reduce surface wind velocities, thus causing sand deposition and burial of leaves and stems. The shoots then grow and effectively work to re-establish the Spinifex plant on the new sand surface (Hesp, 1991 & Bergin, 2011). Subsequently, sand dunes are developed. Spinifex can rebuild dunes after storm events, with the rapidly growing runners trailing over erosion scarps (Hesp, 1989). This encourages the build-up of wind-transported sand along erosion scarps, and, over time, development of shallow-angle dune faces typical of spinifex profiles (Jenks, 2018).

Like pīngao, spinifex is of Māori cultural significance for weaving. Spinifex is a mahinga kai resource, enabling Māori to maintain tikinga (customary practices) (Patrick, 2002). Spinifex is also considered taonga because it reduces dune and thus sand beach erosion. Additionally, spinifex supports the lifecycle of the toheroa shellfish in the same way as pīngao (Ross et al., 2018). Spinifex vegetation also provides an optimal home for katipō spiders (Beentjes et al., 2006 & Patrick, 2002).

Coastal sand dune vegetation succession

Coastal sand dunes often undergo directional/successional changes in species composition (Dahm, 2017). On dunes, succession refers to directional (non-seasonal) changes in plant communities following a disturbance. For example, in primary succession, pioneer species (like spinifex) initially colonise sand after a significant disturbance, and through processes such as vegetative sand-binding, organic matter deposition, and other autogenic changes a 'climax community' is eventually formed. A climax community occurs when the dune is in dynamic equilibrium with the environment (Jaimeson, 2008; Jenks, 2018). It is important to note that human activity and climate change have, and will continue to, significantly impact coastal sand dune vegetation succession (Dahm, 2017).

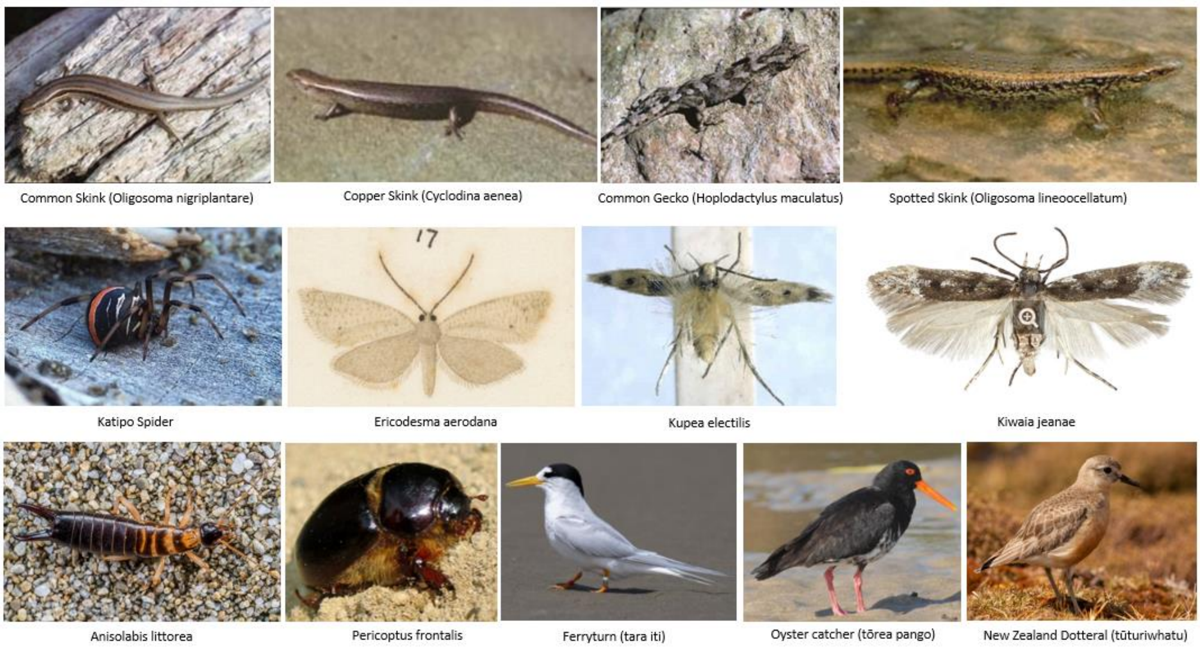
A classic example of human activity influencing natural sand dune succession is the planting of exotic species in response to enhanced coastal erosion after the existing sand dune vegetation was burnt, trampled, or destroyed by humans or introduced pests back in the 1960s (Jaimeson, 2008). The vegetation species planted included marram grass and the South African ice plant (*Carpobrotus edulis)*. Due to the extensive introduction of these plants, they have become dominant species on the New Brighton spit. However, in 1991 sand restoration began to be undertaken with native species (Jaimeson, 2008), partly because of the new RMA 1991 which stated that the 'natural character' of coastal sand dunes was an important resource that needed to be protected. It was also realised that marram grass had significant geomorphological and ecological limitations in relation to restoration, as mentioned above regarding slope gradients. Additionally, marram has a lower ecological value than native species it competes with such as spinifex and pīngao (Jaimeson, 2008). Therefore, marram grass can degrade the ecological value of the coastal dune system and hence is no longer planted for coastal protection, instead native species are planted.

NZ dune fauna

Coastal sand dunes in NZ are inhabited by native and rare invertebrates, lizards, spiders, moths, and beetles, as well as providing nesting sites for seabirds (Figure 29) (Jaimeson, 2008). These invertebrates include the flagship species of the katipo spider (*Latrodectus katipō* & *L. atritus*), moths *Ericodesma aerodana*, *Kupea electilis*, and *Kiwaia jeanae* (Patrick & Dugdale, 2000) and *Anisolabis littorea*, and sand scarab beetles (*Pericoptus frontalis*) (Brockie, 1957). Lizard species found in dunes vary regionally, but include the common gecko (*Hoplodactylus maculatus*), a common skink (*Oligosoma nigriplantare polychroma*), spotted skink (*O. lineoocellatum*), brown skink (*O. zealandicum*), and copper skink (*Cyclodina aenea*) (Milne & Sawyer 2002). Tuatara have also been found in dunes (Walls 1998). Seabirds use the dunes to nest or forage with the rarest bird in NZ, the Fairy Tern nesting here. Other seabirds which use the dunes as habitats are the NZ oystercatcher, the banded dotterel, northern NZ dotterel, red-billed gulls, black-billed gulls, pitpit and variable oystercatchers (Jenks, 2018). All these native faunas add to the ecological value of coastal sand dunes in NZ.

Figure 29- Native fauna found in New Zealand coastal sand dune systems

Note: images sourced from: Auckland War Memorial Museum (n.d.); DOC (2003; n.d.); Hegg (n.d.); Hudson (n.d.); Jewell (n.d.); Markin (2021); Reese (2021); Te Waihora trust(2014; 2016)



Both Māori and Europeans introduced mammalian pests that have caused significant declines in native NZ dune animals as well as destroying native and indigenous dune vegetation (Figure 30) (Jaimeson, 2008). Arguably one of the most destructive introduced animals for coastal sand dune flora and fauna is the rabbit, *Oryctolagus cuniculus*. Rabbits browse native shoots and leaves, and their burrows exacerbate dune erosion. Other pests introduced by the Europeans include mice (*Mus musculus*), feral cats (*Felis cattus*), hedgehogs (*Erinaceus europaeus*) rats (*genus Rattus*) and dogs (*Canis lupus familiaris*) (Jaimeson, 2008). Mice are commonly found in coastal sand dunes, preying on lizards, invertebrates, and native vegetation. Analysis of their stomach contents indicates they target spiders, moth larvae, and beetles (Lettink et al. 2008; Miller & Webb 2001; Jones & Toft 2006). All these pest species degrade the ecological value of the New Brighton coastal sand dune system.

Figure 30- Common pests in NZ coastal sand dunes

Note: images sourced from Nga Manu Image (n.d.); Wallace (n.d.), Williams(n.d.).

European Rabbit (Oryctolagus cuniculus) | Feral cats (Felis cattus) | Hedgehog (Erinaceus europaeus)

The relationship between flora and fauna

Previous studies in NZ's coastal sand dunes have indicated that assumptions on the richness of fauna can be deduced from the ecological condition of the sand dune vegetation present (Costall, 2006). Various studies have documented linkages between plant species in the sand dunes and faunal communities. Faunal diversity and abundance are a function of habitat diversity and heterogeneity (Thomsen et al., 2022). Additionally, it has been found that native vegetation support higher biodiversity than exotic vegetation. For example, a study conducted by Costall (2006) showed that the kaitpō spider tends to avoid marram grass when selecting a habitat for web construction. Native species such as sand coprosma (tātaraheke, *Coprosma acerosa*), spinifex and pīngao were preferentially selected for building webs. Sand daphne (autetaranga/ toroheke, *Pimelea villosa*) and pohuehue (wire vine, *Muehlenbeckia complexa*) also provided preferred habitats (Bergin et al., 2014). Additionally, as stated earlier toheroa shellfish rely on indigenous vegetation such as pīngao for habitat (Costall, 2006).

5.1.1 Method developed to assess the ecological value of the New Brighton dune CBGI

The ecological value of coastal sand dunes can be complex to measure and quantify as multiple components contribute to high ecological value, such as species richness and diversity, number of endemic species, rarity, habitat availability, and productivity (Bar, Becker, & Segev, 2015; 2016). For this research, a simplified approach was used, modified from Cohen and Bar (2005) who assessed the uniqueness and importance of different index species for nature conservation. Cohen & Bar ranked plant species with positive values (increasing in value from 1 to 8) if they were perceived as important, such as rare, native, protected, very rare, and/or psammophilic, or negative numbers (decreasing in value from -1 to -4) for species that were non-endemic, opportunistic, and invasive.

Cohen and Bar (2005) then used the following equation to calculate the ecological value of the coastal sand dune:

$$\mathbf{DEV = \Sigma\ (Vi * Ci/C)} \qquad \textbf{[Equation 1]}$$

where DEV= the total ecological value of the dune, Vi= the ecological value of species, Ci= the species landcover, and C= total landcover of all vegetation on the given sand dune type.

For this research, Cohen and Bar's (2005) methodology was simplified and then applied to analysing the vegetation in the three research study areas using the 3D orthomosaiced images (Figure 31). The ranking system was adapting for the New Brighton plant species assessment to include the categories: indigenous vegetation (2), exotic vegetation (1), and bare sand (0). An excel spreadsheet was created with the site number, quadrat number and columns percentage cover of vegetation versus bare sand, introduced versus indigenous species, rongoā and mahinga kai resources. Five key species were also assessed for their percentage cover: spinifex, marram grass, pīngao, South African ice plant and willow (*Salix spp.*). This method assumes-the higher the percentage cover of vegetation and/or percentage of native vegetation, the higher the ecological value. This approach has its limitations, because it does not incorporate wildlife habitats or faunal richness and diversity. Also, and importantly, it is specific to the broad type of dune system vegetation found throughout the New Brighton dune area (i.e., modified, well vegetated dunes) and would need adjustment if applied to other dune types (e.g., transgressive dunes) where patchy cover (patchiness) can be associated with ecological diversity. In the type of dunes found along the New Brighton coast, animal diversity typically co-varies with plant attributes, since vegetation provides food and shelter – that is, the more vegetation the higher the potential for faunal habitat (Costall, 2006). Additionally, native species of high ecological value rely on indigenous vegetation such as spinifex to provide their habitat (Jaimeson, 2008).

Figure 31- Ecological quadrat placement across study site 3

Note: image created using ESRI (2020).

Once the raw cover and species data were collected, the ecological value was determined by applying the following formula to each quadrat,

$$Ev = \Sigma (Vt \times Pt) / (Qn \times 2) \qquad \text{[Equation 2]}$$

where Ev = the ecological value, Pt = the percentage cover of plant type per quadrat, Vt = the vegetation type (ie, indigenous, native, or bare sand), and Qn = the total number of quadrats within the study site, with 2 being the potential maximum ecological value score for each quadrat. The total ecological value was calculated by accounting for the area of the quadrats sampled ($4m^2$), where the area assessed (A) was

$$A (m^2) = Qn \times 4m^2 \qquad \text{[Equation 3].}$$

Once A was calculated, the total ecological value (Tev) of each study site was calculated as

$$TEv = Ev \times A \qquad \text{[Equation 4].}$$

The total ecological value was finally classified according to the following categories where the ecological value (Ev) was measured against what the maximum potential ecological value of each quadrat would be if it had a full cover of native vegetation:

1. 0 < Ev < 0.5 = *poor* ecological value
2. 0.5 < Ev % < 1.5 = *average* ecological value
3. 1.5 < Ev % < 2 = *good* ecological value

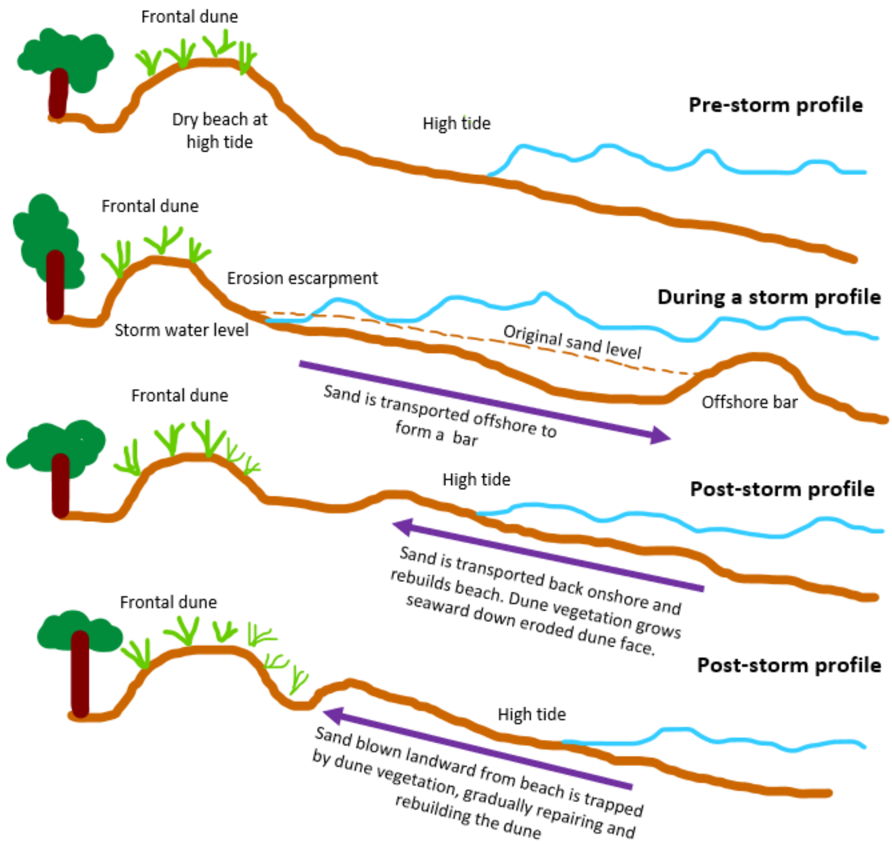
5.2 Coastal protection benefits

As detailed in Chapter 2, coastal sand dunes are a form of CBGI with significant coastal protection benefits. In New Brighton, Tonkin & Taylor (2021) have predicted that by 2050 the CBGI of the coastal sand dune system will still be robust enough to protect the coastal hinterland from coastal inundation in a '100-year' event. However, up to 10 to 20 m width of foreshore could be prone to short-term erosion cycles caused by storms. This erosion could occur between periods of gradual accretion. Additionally, storm surges may be able to infiltrate areas in the dune system where it has been artificially lowered for development or beach access, with such 'weak points' thereby increasing the extent and depth of coastal inundation significantly.

Coastal sand dunes can recover between storm events because of a negative feedback system that helps sandy beach systems remain in dynamic equilibrium during weather related fluctuations such as storms (Masselink, Hughes, & Knight, 2011). During storm cycles, wave height, period, and steepness increase (Gorman, Bryan & Laing, 2003). This causes short-term (within hours) erosion of sediment, producing an erosion scarp. The eroded sand is transported offshore where it forms shallow bars in the surf zone. These bars help dissipate the energy of storm waves preventing further erosion as the waves break further away from the shoreline. Post-storm the waves are smaller in height and less steep, with longer wave periods (Gorman, Bryan & Laing, 2003), conditions whereby the beach can recover as the sediments in the bars are washed back onshore. Sand above the water line can be blown by the wind to reform the dunes that were eroded during the storm as seen in Figure 32. This back beach component of the recovery can take years and depends on the frequency and intensity of storms, the space the sand dune has to migrate inland, the sediment supply, and the density of vegetation on the dunes (Biausque, Senechal, Blossier, & Bryan, 2016; Waikato Regional Council, n.d.).

Figure 32- Ability of coastal sand dunes to recover in between storm events

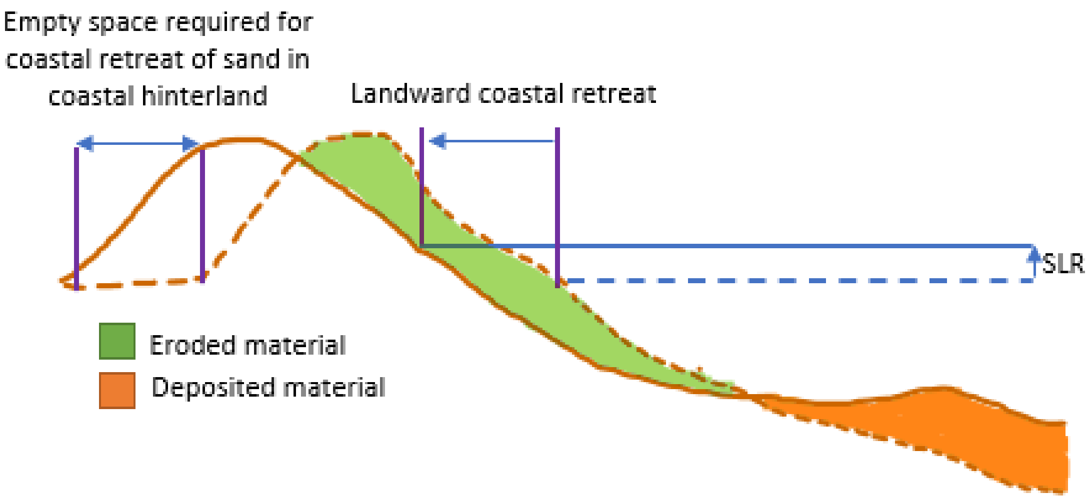
Note: adapted from the Dune Restoration Trust of New Zealand (2011).



The ability of sand dunes to recover and adapt relies, in part, on the amount of space available in the hinterland for the sand dune to migrate to in response to SLR and coastal erosion (Orchard & Schiel, 2021) (Figure 33). Today, urban development has occurred in many coastal places worldwide including in New Brighton in such a shoreline-proximal way as to leave little to no space for dune system migration inland. In this spatially limited context SLR and stronger storms can cause coastal squeeze, exacerbating erosion as the sand dune narrows, with dunes eventually becoming unstable and blowing out, losing their ability to protect a coastal community (Lucrezi, Saayman & van der Merwe, 2014). The ability of the sand dune system to provide coastal protection also relies on the width of the beach in front of the dunes as this is a CBGI, acting to dissipate wave energy and provide accommodation space for the dunes (Cunnif & Swartz, 2015). It is predicted the maximum shoreline transgression (and thus dune toe erosion) distance for the next 50 years along New Brighton Spit is ca. 40 m (Tonkin & Taylor, 2021). If this space is available in the hinterland, sand dunes may adapt to climate change by transgressing and continue to provide adequate coastal protection against inundation and erosion as well as recovering between storm events independently.

Figure 33- How a coastal sand dune system can adapt to SLR by migrating inland, given hinterland space

Note: modified from Zhu, Linham, & Nicholls (2010 p4) based on a 'Bruun Rule' type approach



In addition to hinterland space, sand dunes also need an abundant supply of sediment, to rebuild between storms and migrate inland if necessary (Orchard & Schiel, 2021). Over half (50-75%) of New Brighton Spit's sediments originate from the Waimakariri, Kowhai, Waipara, and Ashley Rivers (Duns, 1995). Longshore southward drift transports the sediment along the beach systems of Pegasus Bay, where it builds berms and is eventually deposited in the dune system. Sand for the spit also comes from smaller rivers, erosion of adjacent coastal areas and, more importantly, is swept onshore from the continental shelf. Sand availability is affected by natural disasters, currents, and weather (Bird, 2008). As most of the sand nourishing the spit is supplied by the Waimakariri River (Figure 34), sand availability increases substantially with large flooding events. Rainfall causes sediments to be washed downstream and out into the ocean where currents carry it south to be deposited on the spit. The availability of dune building sand is reduced during periods with storms-in-series, when the beach and its berm have little time to recover between successive storms, as occurred in the 1970s, 1990s and early 2000s. Lack of sediment supply to a dune long term can result in an erosional dune state whereas plentiful sediment supply can result in an accretional state, with dune stability occurring when the sediment supply is in balance with dune sediment losses to storms, inland transport by wind and other erosional processes.

Figure 34- Current sediment budget estimates for Pegasus Bay

Note: estimates are in m³/ year (adapted from NIWA, 2018, p11)

With climate change, the amount of sediment supplied by the main budget contributors, the large rivers with headwaters in the Southern Alps, may increase. Projections made by NIWA (2018) indicate that the sediment supply to New Brighton Spit could vary between an 11% reduction and a 28% increase, with a mean projection of 9%. While these numbers demonstrate significant uncertainty in the sediment budget, those representing projected increases result from predicted increases in Southern Alp rainfalls, resulting in more sediment transported downstream in the Waimakariri River and out into the coastal system (NIWA, 2018).

Vegetation cover also affects a sand dune's ability to recover between storm events (Jenks, 2018; Mr. D. Todd, Principal coastal and hazard scientist, Jacobs, *pers. comm*. 25/08/21). Sand binding plants such as spinifex stabilise sediment and hence grow or recover between storm events (Bergin, 2011). Higher cover of established sand binding plants (i.e., older than 5 years) increases coastal protection (Bergin, 2011; & Mr. P. Boerchards, CCC Coast Care Park Ranger, *pers. comm*. 16/06/21).

Finally, protection decreases as dune slope increases, since steep dunes are less stable, and increases with dune size (i.e., width x height) since this relates to sand volume (French, 2001; Mr. D. Todd, Principal coastal and hazard scientist, Jacobs, *pers. comm*. 25/08/21). Sand volume is important because it allows 'surplus' sediment to be temporarily washed from the backshore to build storm bars, thereby buffering against hinterland inundation and erosion. Consistency in dune height is particularly important because consistently tall dunes can prevent flooding from storm surges, extreme tides, tsunamis, SLR (Todd, 1995) or some combination of these.

5.2.1 Method developed to assess the coastal protection value of New Brighton dune CBGI

To assess the New Brighton coastal sand dune system's relative ability to provide adequate coastal protection, an array of international literature was reviewed to determine which quantifiable dune characteristics were most applicable. This critical analysis and subsequent selection of different dune components related to the dunes ability to provide coastal protection were supported by interviews with experts on the New Brighton dune environment. Literature that was analysed included assessments of dune values (Barbier et al., 2011, Bridges et al., 2021; Everard et al., 2010; Jones et al., 2011; McLachlan and Brown, 2006; Morris et al., 2021), dune vulnerability index studies (Bertoni et al., 2019; Drius et al., 2019; Garcia-Mora et al., 2001; Penntta et al., 2018) and specialised studies conducted in Ōtautahi and NZ on various components of sand dunes such as vegetation type, beach response characteristics, and required heights of sand dunes to provide tsunami protection (Bergin et al., 2008; Bergin, 2011; Bosserellee et al., 2018; Hart & Knight, 2009; Orchard, 2014, Orchard & Schiel, 2021; NIWA, 2018; Stephens et al., 2015a; Takiwā, 2021; Todd, 1995; Tonkin & Taylor, 2021). Refer to Table 8 in the methodology section of this thesis for experts that were interviewed, expertise ranged from New Brighton coastal park rangers to principal coastal scientists, coastal restoration trust members and coastal vegetation specialists, all with extensive knowledge of the New Brighton dune system.

It was decided from these methods that the ability of the New Brighton coastal sand dune systems coastal protection ability relied on the main following quantifiable parameters: sediment supply which can be determined by dune and MSL excursion plots and long-term changes in dune and beach volume, further coastal protection parameters were type, age, and density of vegetation, the available migration space in the coastal hinterland and the height, width, and slope of the dune system. These key dune characteristics were measured and classified according to a relative ranking system indicating their relative coastal protection benefits across the range of observed values at the three study sites. From personal communication with (Mr. D. Todd, Principal coastal and hazard scientist, Jacobs, *pers. comm.*, 02/11/2022) the separate dune characteristics were then weighted on their relative importance to providing coastal protection and combined to provide an overall proxy coastal protection score. Table 11 summarises the ranking system applied with both the parameters for the scoring system of each study site described in the columns and the weighting of each characteristic supply in the heading of each column. Each individual parameter is described in more detail below.

Table 11- Parameters employed in assessing the relative coastal protection levels provided by the study site dunes

Note: ranks 1 to 3 are relative and indicate increasing coastal protection potential where, 1= poor, 2= average and 3= good. AMSL is above mean sea level. The weighted score is what each characteristic will be multiplied by to reach a total coastal protection value score for study site.

		Rank level		
Weight	**Parameter**	**1**	**2**	**3**
7	Dune width (m)	<72	72-92	93 +
7	Dune crest height (m AMSL)	0 to <4	4 to <8	8 +
6	Seaward dune slope (°)	25 +	1- 12	12 to < 25
5	Berm width (m)	1 - >20	20- >50	50 +
4	Migration space (m)	0 to <20	20 to <40	40 +
3	Volume change of dune (m^3/yr)	Eroding (< -1 m^3/yr)	Stable (±1 m^3/yr)	Accretionary (>1 m^3/yr)
3	Volume change of berm (m^3/yr)	Eroding (< -1 m^3/yr)	Stable (±1 m^3/yr)	Accretionary (>1 m^3/yr)
3	Dune toe excursion trend (1990 to 2020) (m/yr)	Eroding (< -0.1 m/yr)	Stable (±0.1 m/yr)	Accretionary (>0.1 m/yr)
3	MSL contour excursion trend (1990 to 2020) (m/yr)	Eroding (< -0.1 m/yr)	Stable (±0.1 m/yr)	Accretionary (>0.1 m/yr)
2	Foredune vegetation type	Nil	Marram & pīngao	Spinifex
2	Foredune Sand binding plant cover (%)	1 to <50	50% to <80%	80% to 100%
2	Spinifex age (years)	1 to <3	3 to <5	5 +
1	Envelopes of change 1990 to 2020	Eroding	Stable	Accretionary
Total coastal protection score (%)		0-<33	33-<66	66+

Dune and berm width

A wider width of coastal sand dune and berm (i.e., on a sand beach the area between the dune toe and foreshore) provides a greater buffer against coastal hazards (Mr. D. Todd, Principal coastal and hazard scientist, Jacobs, *pers. comm*., 25/08/21). To determine what score to give each study site's cross-shore dune width, the current width of the dune was compared to the future width of the dune needed to withstand storm erosion and erosion due to SLR over 100 years. This was calculated by firstly obtaining the 100-year storm cut average recurrence interval (ARI) from Tonkin & Taylor's (2021) coastal hazard assessment report (p. 47). It was determined to be -29 m. To calculate the 100-year SLR erosion effect the Bruun rule was utilised (Bruun, 1962) whereby,

SLR erosion effect = SLR/ closure slope **[Equation 5]**

The SLR values were obtained from Takiwā SLR maps with SLR projections using a baseline of 1995-2014 with a mid-point (zero) at ~2005 while also accounting for vertical land movement (VLM) (Takiwā, 2021). SLR and VLM values were obtained for 100-year projections of medium confidence for SSP4.5= 0.82 m and SSP8.5= 1.17 m, all with VLM accounted for (Takiwā, 2021). SSP's are shared socioeconomic pathways and are another way of framing potential climate change pathways like RCPS, as discussed in Chapter 1 of this thesis. SSP4.5 and SSP8.5 were chosen for the scoring classification as they indicate a stabilsation pathway and business as usual in relation to carbon emissions and, therefore, are realistic projections (Reimann et al., 2021). The closure slope was obtained from Table 4.2 (p.60) of the Tonkin and Taylor, (2021) report and was determined to be 0.019°.

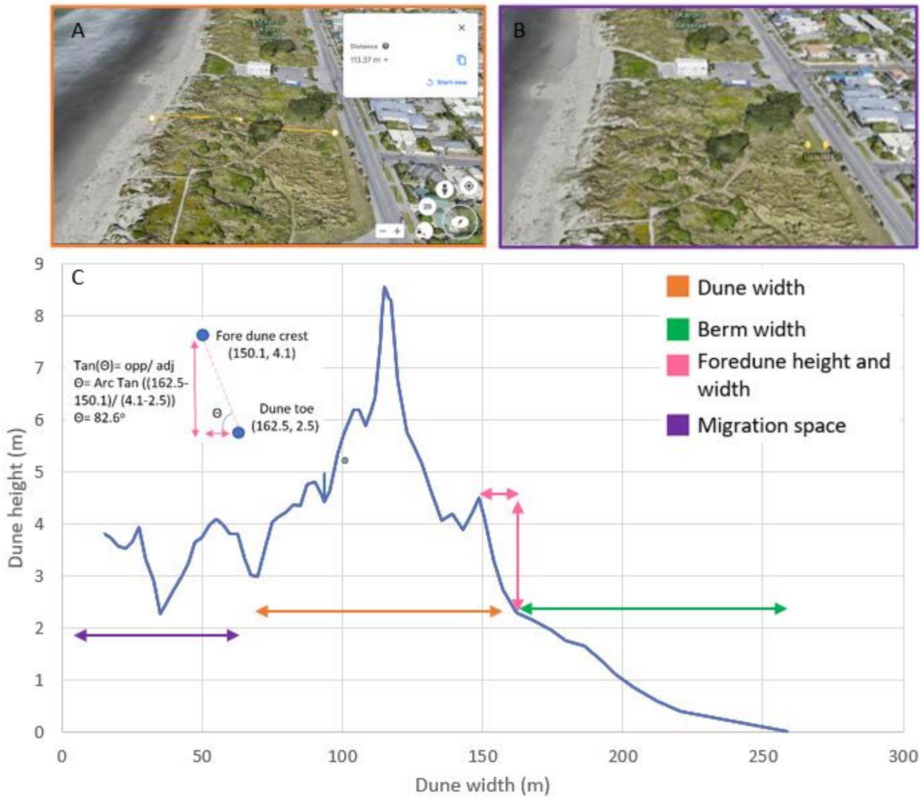
Once these 100 year SLR erosion effect calculations using Equation 5 had been undertaken, giving a result of 64 m and 43 m for the 100 year SSP4.5 and SSP8.5 respectively, the scoring parameters for the coastal protection value of the dune width could be classified as the width being scored 1, if it was under the SSP4.5 + VLM + 100 year ARI storm cut (72 m), a score 2 if it was between this and under SSP8.5 + VLM + 100 year ARI storm cut (72- 92 m), or a score 3 if the dune width was over SSP8.5 + VLM + 100 year ARI storm cut (93 m). These scoring values are outlined in Table 11 and mean that the dune system width is measured in relation to how wide it would need to be to maintain adequate coastal protection over a 100 year timeframe.

The ranking values for the berm width were decided by employing the theory of beach accommodation space in New Brighton. Beach accommodation space is determined by how much berm width is required to accommodate extreme water levels and wave run-up for these types of beaches before these phenomena interact with the dunes or structures behind the beach. Both the local wave climate and slope of the beach factor into beach accommodation calculations (Mr D. Todd, Principal coastal and hazard scientist, Jacobs, *pers. comm*., 25/08/21). Based on Ōtautahi beach slopes, extreme water levels and waves given in Stephens et al. (2015a), berm widths over 50 m (between the MSL and dune toe contours) were determined to be the required to accommodate run-up in large storm events. Table 11 displays the resultant ranking system from employing this logic.

Dune and berm widths were measured in the three study sites using a combination of methods. Firstly, the ruler tool in Google Earth was used to measure width perpendicular to the ocean and directly over the location of the ECan monitoring profiles in the three study sites. Measurements for the dune width started at the foredune, determined by assessing the 3D dune model (indicating where the foredune began as the coastal profile steepened) to the edge of the back dune, (which was determined by where the coastal sand dune vegetation visibly ended). Figure 35 illustrates this approach to measuring the width of the New Brighton coastal sand dune system. The berm width was measured using the beach profile graphs as seen in Figure 35, with supporting data calculated in the beach analysis software programme BMAP. BMAP and scatter plot interpretation could be used to determine the berm width as the seaward edge of the subaerial beach occurred at Y=0m (MSL) and the landward edge of the beach occurred when the dune slope became less steep and transitioned into the berm (Y=2.5m).

Figure 35- Diagram showing the methodology utilised to determine the beach berm and dune width (green and orange), dune height, dune slope, migration space available and foredune extent (pink).

Note: the different coloured arrows and borders of photos measure different things as specified in the key of the beach profile plot (C). This beach profile plot (study site 1) is plotted from ECan (2020) data with the horizontal axis measured from their benchmark seaward and the vertical values measured from Average Mean Sea Level. The pink arrows which indicate the foredune width and height were also used to determine the foredune slope by Pythagoras theorem. Images A and B respectively display the use of the measurement tool with comparisons to the 3D model to determine the dune width and space available in the coastal hinterland for migration of the coastal sand dune system.



Dune system crest height

The height and continuity of the dune crest also impacts coastal protection effectiveness. Todd (1995, cited in Hart & Knight 2009) modelled that the height of a continuous New Brighton sand dune system should exceed 8 m to protect the coastal community of New Brighton and Ōtautahi from tsunami damages. More recent modelling of potential inundation from local source (Canterbury region) tsunamis has indicated that the run up could be 6 m (Bosserelle et al., 2018). Therefore, both the Hart & Knight (2009) research, which investigated tsunami run ups of 2, 4, 6 and 10 m, and the Bosserelle et al. (2018) research, support that the dune height must be at least 8 m

AMSL to protect Ōtautahi from tsunami run up. Therefore, a high score of 3 was given to any study sites which had their lowest point of their crest height above 8m AMSL.

The parameters for an average score of 2 were decided by the height of dune that could provide protection against overtopping events from storm tide and wave run up for a 1 in 100 year event with present day sea levels. This overtopping height value was calculated using the Stephens et al. (2015a) runup calculator. This calculator enabled accurate inputs of New Brighton dune to be entered with the wave height confidence value chosen of "maximum likelihood estimate (median)". The annual exceedance probability (AEP) could then be selected (i.e., 1 in 100 year overtopping event was selected for present day sea levels). The beach gradient input was utilised from Stockdon (2006) and was deemed to be 0.105. The results using the Stephens et al. (2015a) calculations indicated that 3.5 m Lyttleton Vertical Datum 1937 (3.4 m AMSL) is the approximate maximum elevation for overtopping from a storm tide and wave run up for a 1 in 100 year event with present day sea levels. Therefore, it was decided that the New Brighton dune crest must reach >4m to protect against such events, with this research assigning this height a score 2. Anything below this height was given a poor score of 1 as it was deemed this dune height could not provide coastal protection for overtopping events from storm tide and wave run up for a 1 in 100 year event with present day sea levels.

It should be noted that both dune height and continuity are important for coastal protection (Mr. D. Todd, Principal coastal and hazard scientist, Jacobs, *pers. comm*., 25/08/21; Hart and Knight, 2009). However, for simplicity, these measures were combined into a proxy measure, the lowest point of the dune crest in each study area, with the ranking levels listed in Table 11. The lowest point of the dune crest was determined from the DEM .

Dune slope

The slope of the foredune face is affected by beach erosion/accretion processes and the vegetation type on the foredune (Jenks, 2018). If the dune toe erodes, this can steepen the overall slope of the dune face, creating a scarp or near vertical 'cut' in the sand. When an unvegetated dune face is steep or near vertical in angle, it is vulnerable to collapse (Jenks, 2018). Near vertical dune faces indicate erosion scarps while gently sloping seaward faces (e.g., below the angle of repose of sand) indicate the dune may be in a state of accretion or in dynamic equilibrium with the sediment supply (French, 2001). Another key factor affecting seaward dune slopes is the type of vegetation cover (see Figure 27 for details). When assessing the optimal slope of the coastal sand dune for coastal protection both the type of vegetation and beach/dune morphology need to be taken into consideration (Jenks, 2018).

Optimal dune slopes in NZ systems correspond to those supported by the cover of native sand-binding vegetation such as spinifex or pīngao (Jenks, 2018), with steeper slopes indicating erosion or the presence of non-native sand binding species. The slope values used to rank the study site dunes are listed in Table 11. The lowest score (1) was given to slopes with angles higher than 25° as this would indicate an eroding dune face or a dune face associated with non-native sand binding species. A medium score (2) was given to slopes that were 10-12° as these slopes indicated an accreting or stable dune slope while the highest score (3) was given to the optimal angle (12°-25°) of dune supported by native sand binding plants. Seaward foredune slopes were measured using the 3D DEM, with comparisons made against the beach profile plots for each site. The slope was calculated using Pythagoras theorem for the dune face between the dune toe and the seaward-most dune crest above (see Figure 35).

Dune system migration space

The last spatial factor that affects a sand dune system's ability to provide sustainable coastal protection over time with climate change is the space available in the coastal hinterland for migration of the dune system (Orchard & Schiel, 2021). The amount of hinterland space required for the dune system to migrate in response to the 100 year SLR projected ('business as usual'/ RCP8.5 scenario) has been estimated as ca. 40 m in New Brighton (Tonkin and Taylor 2021). This value was employed in setting the migration space categories listed in Table 11 . This value is supported by research conducted by Orchard & Schiel (2021) as this 40 m distance would maintain the current protection value of the dune by allowing the width to be preserved in the face of future SLR. Space available for migration was measured at the study sites using the ruler tool in Google Earth, measuring the distance across each dune site on a line perpendicular to the ocean and running through the ECan beach profile monitoring locations. The measurements were taken from the back of the foredune to the edge of the nearest urban development surface (i.e., a road, house or building infrastructure), as illustrated in Figure 35.

In terms of method limitations, assumptions were made about where the dune toe is and where the beach inland extent ends. This means dune dimensions such as width and slope could vary depending on such measurement assumptions. To minimise human error when making these measurements, the dune width measurements were repeated both using the profile data and the DEM, the latter in Arcmap using the measure tool. In each case all measurements came out very similar (<0.30 m), therefore, there was high confidence that these results are accurate.

Volume change of the dune and berm

The volume change and horizontal distance excursion plots for the dune and berm environments were calculated using long-term beach profile data measured over 30 years by ECan between 1990 and 2020 (ECan, 2020). Note that these profile measurements are taken at 6-monthly intervals by ECan, typically January/February and June/July. These profile measurements were taken from a back dune benchmark location decided by ECan and measured in a seaward direction perpendicular to the ocean.

The volume change of the berm and dune were calculated between each 6 monthly ECan survey by a specialised programme called BMAP[4] (Beach Morphology Analysis Package). The dune volume encompassed the volume of the dune from the 2.5 m contour (dune toe) to the edge of the back dune as determined by BMAP. The berm volume was calculated from Y=2.5 m to the Y= 0 m which is the MSL contour and the limit for a number of profile surveys. These berm and dune volume value changes over 6 monthly intervals from 1990 to 2020 were then plotted to display the change in volume of the dune and berm over time with a linear trendline and R^2 value fitted. The scoring parameters for these volume measurements was developed on the principal that a low score was given to a long-term loss of volume > -1 m^3/yr (1), a medium score to a stable volume of ±1 m^3/yr (2) and a high score when the volume was increasing more than 1 m^3/yr (3). These assigned scores were dependent on the long-term linear trend from 1990 to 2020, as ideally, a dune system would be accreting and have a positive sediment budget. Therefore, when storm events occur there is a surplus of sediment to help them recover from short-term periods of erosion (Orchard & Schiel, 2021). The scores provided in Table 11 for these ranking values have some ‘generosity’: that is the stable range is from ±1 m^3/yr, with more positive values indicating accreting and more negative values indicating erosion. This is because the berm and dune environments are naturally dynamic and therefore a little fluctuation is expected, even when the system is in dynamic equilibrium (Orchard and Schiel, 2021).

Dune toe and MSL excursion distances

MSL excursion and dune toe excursion plots were created using the 6 monthly ECan survey data from 1990 to 2020 (ECan, 2020). Again, BMAP was used to calculate these initial excursion distances with both the dune toe and MSL excursion plots created. The MSL excursion plot helped identify if any trends in the dune system were present on the whole beach system. This is important as dune trends can be rapidly reversed, therefore, having knowledge of what the foreshore trend is doing

[4] BMAP is an integrated set of beach profile analysis routines developed to automate and support mainframe and desktop studies of beach profile change, beach-fill design, and numerical simulation of storm-induced beach erosion.

can give us a clue if this is going to happen in the future (note that nearshore information would also help with this assessment but is unavailable in the ECan data record, which consistently cover MSL only). Linear long-term trendlines with R^2 values were fitted to excursion plots displaying the 6-monthly ECan beach profile data from 1990 to 2020. These plots helped to determine whether the size of the berm and dune toe were accreting, stable, or eroding over time, with the short-term variability (6-monthly) and the overall long-term trend (1990 to 2020) of this relationship taken into account respectively by the linear trendline equation and the R^2 value. Again, there was generosity in these parameters as specified in Table 11 with stable being classified as ±0.1m/yr and eroding being anything less than this and accreting anything more than this.

Doing these excursion measurements alone does not give a full understanding of what is happening to the dune state, that is, changes in volume and shape. However, these measurements when combined with the 5 yearly envelopes of change, and volume analysis of the berm and dune provide an adequate array of data that can be used as a proxy measure to determine if the dune system is accreting, eroding, or stable and thus aid in the long term and short term ability of the dune system to recover after storm events and remain in dynamic equilibrium. This method was discussed with and supported by (Mr. D. Todd, Principal coastal and hazard scientist, Jacobs, *pers. comm*., 25/08/21).

Dune vegetation type

As detailed in the earlier dune vegetation review, the type, age, and density of foredune toe and embryo dune vegetation affects the ability and speed of dune system recovery between storms, with, for example, different vegetation species having different spreading and growth rates and sand trapping capacities (Mr. J., Roberts, CCC Coast Care Park Ranger, *pers. comm*., 29/10/21; Mr. P. Borcherds, CCC Coast Care Park Ranger, *pers. comm*., 16/06/21; Dr T. Konlechner, Senior ecologist at Wildlands Consultants, *pers. comm*. 18/11/21; Mr G. Bennet, Chair of Coastal Restoration Trust, *pers. comm*., 23.6.2021). To take account of this potential vegetative variation in coastal protection effects, the study site foredune toe and embryo dune vegetation were classified according to the dune vegetation ranking categories summarised in Table 11. Vegetation data was measured across the entire dune system as described for the ecological benefits assessment (see earlier sections of this chapter and Appendix B), with ground cover species identified on the foredune toe and embryo dune areas for the purposes of this current coastal protection assessment. To determine how many of the ecological quadrats to include in this foredune toe and embryo dune vegetation analysis, the extent of this part of the dune was determined via the geometry of the beach profile as illustrated in Figure 35. Effectively the foredune toe and embryo dune face's seaward extent begins at the point where the profile slope changes between the flatter berm area and the steeper foredune or embryo dune face. The foredune toe and embryo dune face area reaches its inland limit where the dune geometry changes profile shape between the embryo dune face and upper foredune face, which carries on upwards towards the dune crest.

The vegetation type ranking system was determined by giving higher scores to faster growing sand binding plants such as spinifex that developed embryo dunes of appropriate slope for optimal coastal protection (15^o) (Jenks, 2018). Medium scores were given to plants that were effective sand binders but perhaps could not recover as rapidly between storm events (pīngao) or they were effective sand binders but the dune slope they developed was particularly steep and prone to collapse (Marram grass). Low scores were given to bare sand as although this had coastal protection value and could recover between storm events by geomorphic processes, sand dune vegetation rapidly enhances the speed of dune recovery (Bergin, 2011) (Table 11).

Dune vegetation cover

The denser the sand binding vegetation is on the foredune toe and embryo dune area, the greater the ability of the sand dune to trap sediment and regrow after a storm event (Jenks, 2018 and Mr. J., Roberts, CCC Coast Care Park Ranger, *pers. comm*., 29/10/21 and Mr. P. Borcherds, CCC Coast Care Park Ranger, *pers. comm*., 16/06/21). The density of the vegetation on the foredune of the coastal sand dune system was thus ranked, as determined from the quadrat ecology analysis explained earlier, with the vegetation density classes set for the purposes of coastal protection listed in Table 11.

Dune vegetation age

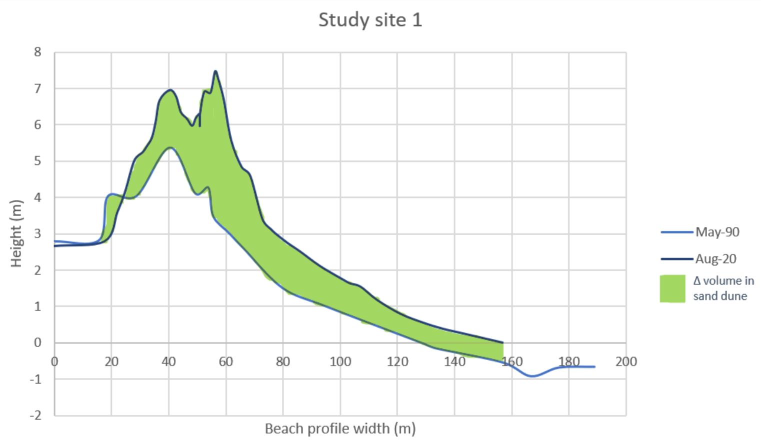
The age of certain vegetation types also affects its ability to aid dune recovery between storms, with older more established plants typically having faster regrowth and recovery since they have greater vegetative reserves, more extensive root and mycorrhizal systems and more seed stock (Bergin, 2011). Spinifex has been determined to be the most effective plant for coastal protection, therefore, vegetation age calculations were determined from this vegetation type. The age at which spinifex plants can withstand (recover from the effects of) storms in an Ōtautahi setting is ca. 5 years (Mr. J., Roberts, CCC Coast Care Park Ranger, *pers. comm*., 29/10/21 and Mr. P. Borcherds, CCC Coast Care Park Ranger, *pers. comm*., 16/06/21). Thus, the spinifex vegetation present in the quadrats was classified according to the categories listed in Table 11. The age of vegetation was determined via interviews with Mr. Pieter Borcherds and Mr. Jason Roberts, the CCC Coast Care Park Rangers who reintroduced the species to our local coast and have been maintaining and managing its vegetation for several decades.

Envelopes of change 1990 to 2020

To support the calculations made by the dune toe and MSL excursion plots, the envelopes of change visual assessment were used as a proxy measure indicating how the dune system had fluctuated in shape overtime giving further indication of the sufficiency of the sediment supply. Again, the long-term beach profile data measured over 30 years by ECan between 1990 and 2020 was used (ECan, 2020). For this assessment, the summertime profiles were sampled at 5 yearly intervals. Areas were classified as eroding, stable, or accreting (Table 11) based on their net 5-year envelopes of change between 1990 and 2020. As illustrated in Figure 36, where the envelope of change between the two beach profiles represented an increase in volume and progradational shift in dune position (i.e., to seaward), this was classed as an accreting area. Alternatively, if the net envelope of change indicated a loss of volume and transgression of the dune position (i.e., to landward), this was classed as erosion, whereas when there was little to no change in dune topography.

Figure 36- Beach profile net envelope of change between 1990 and 2020 for study site 1

Note: this plot indicates changes in topography for study site 1 (data sourced from ECan (2020)). Beach profile width is the distance between the back-dune benchmark (at 0 m) and the seaward limit of the beach profile (towards the plot right side), heights are in elevation relative to Average Mean Sea Level.



Total coastal protection value

To calculate a total coastal protection value for the above coastal protection parameters the score measured for each parameter (scored from 1 to 3) were multiplied by the weight each score had towards contributing to ability of the dune system to provide coastal protection.

The weighting for each parameter was decided as a result of each parameter's influence on the overall coastal protection ability of the dune system. The width, height, and slope of the dune alongside the berm width were deemed most important as these indicated the physical size of the coastal protection barrier between the ocean and coastal hinterland, hence weighted 7, 7, 6 and 5 respectively. The dune width was important as it provides protection against erosion while the height is important to protect the coastal hinterland from overtopping events. The berm width is important for accommodation space and the dune slope is a control for the foredune stability under storm wave attack, so is also clearly important as a coastal protection value (Orchard & Schiel, 2021; Todd, 1995).

The migration space was ranked secondary to this (weight 4), as with climate change the dune width and height, berm width and dune slope cannot be maintained without adequate migration space and a positive or stable sediment budget (Orchard & Schiel, 2021; Tonkin & Taylor, 2021). Therefore, the dune and berm volume (weight 3) followed by the excursion distances from the dune toe and MSL contour (weight 3) were weighted the next most important parameter as these gave indication of the long and short-term berm and dune response to the sediment budget for New Brighton. Having an adequate sediment supply enables the dune system to recover in between storm events and with migration space adjust to climate change induced stressors (NIWA, 2018).

Following this was foredune vegetation type, percentage cover of sand binding species and the age of this vegetation. These parameters heavily influence the existing dune's ability to recover between storm events and the overall sand trapping ability of the dune system (Bergin, 2011), hence given the weighting of 2. However, the vegetation parameters are not as important as the dune size or sediment supply as there would be no area for dune vegetation and no sediment for the dune to trap without a pre-existing dune and a positive sediment budget (Tonkin & Taylor, 2021). The last parameter was envelopes of change, weighted 1. These envelopes of change helped to determine the overall changes in shape of the beach and dune cross shore profile. These are least important as they do not give quantitative measures in dune change like the other parameters, however, they help to pull together the overall picture as to what is happening in the beach and dune environment overtime.

Table 12 lists these weights in column 1. This calculated weighted coastal protection value was then converted to a percentage by dividing this value by the maximum possible total coastal protection score a site could get of 144. These total coastal protection percentage values were then scored so relative comparison could be made between study sites as shown in Table 12. A low coastal protection value was given to the bottom 3rd of possible max score, medium value was the middle 3rd, and a high value is in top 33% of possible scores.

5.3 Carbon sequestration

Carbon dioxide (CO_2) is the second most abundant greenhouse gas in the atmosphere. Atmospheric carbon dioxide has increased from ca. 280 to 420 ppm in the industrial era, largely from the burning of fossil fuels with further contributions from deforestation, habitat degradation and intensive livestock farming practices (Bonito, Ricotta & Varone, 2017). This greenhouse gas is of particular concern due to its long (up to 1000 year) residence time in the atmosphere. To mitigate the effects of climate change caused by excess emissions of greenhouse gasses like carbon dioxide, multiple actions must be taken to reduce emissions and increase uptake into non-atmospheric sinks. Ideally, emissions would be reduced by stopping them at their source, however, this takes time and significant socio-economic changes to society. Thus, ways in which carbon can be sequestered also need to be investigated. One way to increase carbon dioxide uptake is through plant carbon sequestration (Knoke and Weber, 2006). Plants sequester carbon by fixing carbon dioxide through photosynthesis and store carbon as biomass (Beaumont et al., 2014).

Different plant species and plant life stages sequester carbon dioxide at different rates. For example, the sequestration rate depends on the growth rate, structure, coverage, and physiology of the plant species (Gratani et al., 2013). Carbon sequestering in plants is a biological process, limited by stress and disturbances (Freudenberger et al., 2012). Therefore, if carbon sequestering by plants is valued to mitigate climate change impacts, it is important to protect the plants that underpin these ecosystem services.

There is extensive literature focussing on the role terrestrial plants have in carbon sequestering. However, research into the ability of coastal and marine habitats to sequester carbon ('blue' carbon) is a relatively new field (Beaumont et al., 2014). Emerging research suggests that blue carbon could play a significant role in offsetting carbon dioxide emissions with an estimated one-third (GtC yr^{-1}) of anthropogenic carbon dioxide emissions sequestered by the oceans (Nellemann et al., 2009). Additionally, coastal habitats such as salt marsh, mangroves, and sand dunes also sequester carbon rapidly, particularly along accreting coastlines (Alongi, 2012; Bonito et al., 2017; Drius et al., 2019; Yang & Tang et al., 2019).

For example, in NZ, the researchers have calculated that salt marsh can sequester carbon at 100 times the rate of terrestrial forests (NIWA, 2017). Unfortunately, the ability of NZ sand dunes to sequester carbon has been excluded from calculations of current and future carbon stocks as well as Kyoto-compliant carbon gain on conservation land (Mason et al., 2012). Therefore, in this research international case studies are assessed and modified for application to NZ coastal dune ecosystems.

Carbon sequestering potential of NZ coastal sand dunes

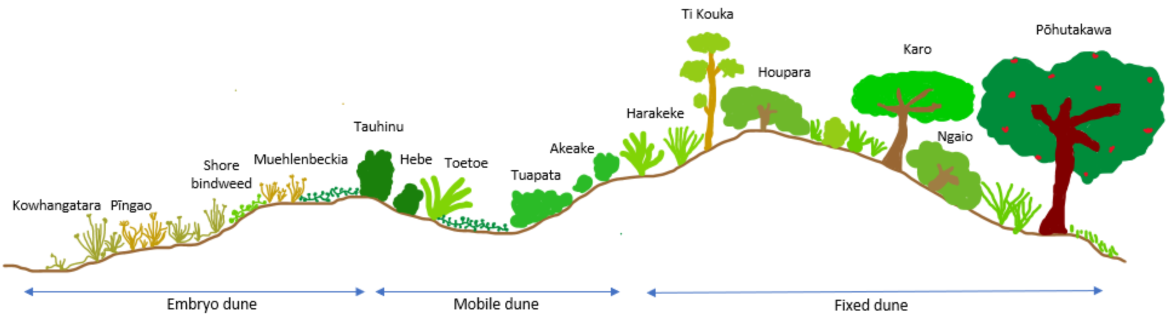
One of the benefits of a healthy NZ dune ecosystem is carbon sequestering. Carbon sequestering by dune plants is particularly important in early successional stages, where growth rates are high and standing biomass and soil carbon are accumulating rapidly (Jones et al., 2008 & Rohani et al., 2014). However, although area-based carbon sequestering can be high, the total contribution to offsetting greenhouse gas emissions is relatively small because coastal dune areas are small. Still, Drius et al. (2015, p.2) argue that "*in the context of widespread coastal habitat loss and land-use change at a fine scale, and within a wider context of habitat management for multiple benefits, their role in regulating greenhouse gas emissions is worth taking into consideration*".

5.3.1 Method developed to assess the carbon sequestration value of New Brighton dune CBGI

Globally, few studies have measured carbon sequestration values of coastal sand dunes, and no studies have been done in NZ. Instead, an international study was used to approximate the absolute carbon sequestration rate of the New Brighton coastal sand dune system: Drius et al. (2016) quantified carbon sequestering rates of different European dune habitats in Italy, dividing the dune into embryo, mobile, fixed, and wooded sections (Figure 37). This approach was transferred to the New Brighton sand dune by measuring the equivalent area of each type of dune habitat and utilising carbon sequestration rates measured for European dune habitats.

Figure 37- Different carbon sequestration habitats of coastal dune environments adapted to a NZ dune system similar to the New Brighton coastal sand dune system

Note: adapted from Drius et al., 2016 & Auckland City Council, 2018



Note, that Drius et al.'s (2016) 'fixed' dune habitats are somewhat different to most coastal dunes in NZ, many of which are typically highly dynamic, with transgressive dunes having been common at least historically (Nordstrom, 2018). However, New Brighton's present dunes may be more like those in Europe than most NZ dunes due to their highly modified nature and the ecological domination of introduced species.

In this study the New Brighton coastal sand dune system was, like in Drius et al. (2016), re-classified into embryo, mobile and fixed sections. The area (length and width) of each section was measured from aerial UAV imagery (see Figure 31 for an image example). This reclassification was possible because each habitat has a visually distinct vegetation type, where the embryo dune had rapidly growing grasses, the mobile dune had slower-growing grasses and shrubs, and the static dune section was dominated by woody species (Prisco et al., 2012).

Drius et al. (2016) measured carbon sequestration rates for each dune section based on analysis of sand/soil cores and vegetation samples. The above-ground biomass carbon sequestration rate and soil carbon sequestration rates and stocks, resulting in carbon sequestration rates per year are listed in Table 12. The carbon sequestration rates calculated for the embryo, mobile and fixed dune vegetation environments are relatively like those reported by Beaumont et al. (2014) and Jones et al. (2008) from dune grasslands in the UK and dry dune grasslands in Wales, respectively, suggesting that carbon uptake rates are relatively similar between countries and dune systems (and therefore can be transferred to modified NZ dune systems such as at New Brighton as a first approximation).

Table 12- Total carbon sequestration rate of soil and sand dune vegetation for embryo, mobile and fixed dune habitats in Italy.

Note: this table displays the total carbon sequestration rate (± standard deviations) of soil and sand dune vegetation measured in meters squared per year (t m-2 yr-1) for embryo, mobile and fixed dune habitats in Italy. Adapted from Drius et al. (2016 p132) 5.72, 5.57, 7.49

Dune Habitat	Carbon sequestration rate of dune vegetation (g m^2 yr^{-1}) (TCO_2)
Embryo	5.72 (± 2.28)
Mobile	5.57 (± 3.10)
Fixed	7.49 (± 2.56)

Equation 6 was used to determine the average rate of carbon sequestered per study site for the New Brighton coastal sand dune system. The rates shown in Table 12 for European habitats were used even though the dune plant species in New Brighton are different from those found in Italy.

$$\text{Average carbon sequestration rate at study site } (\text{g area}^{-1}\ \text{yr}^{-1}) = \frac{[(TCO_2\ \text{embryo} * Ea) + (TCO_2\ \text{mobile} * Ma) + (TCO_2\ \text{fixed} * Fa)]}{3} \quad \textbf{[Equation 6]}$$

The below listed criteria were used to score each sites' carbon sequestration value on a scale of 1 to 3, describing how much carbon a study site could sequester in its current state per year in both the soil and biomass relative to how much carbon a healthy non-anthropogenically constricted or degraded dune system could have sequestered at this site historically. The average width of the healthy non-restricted historic dune system across the three study sites was estimated from the 1856 Blackmaps as 929 m. Note that a wider dune would have a wider set of plant types, with their different canopy heights and plant structures. Thus, the relative carbon sequestration scores determined here are likely to be a best-case scenario comparison or overestimate of the contemporary carbon sequestering capacity relative to the dunes' historic capacity.

1- Measured carbon sequestration value for study site <33% of carbon sequestration value for the unmodified dune area
2- Measured carbon sequestration value for study site is 33% to 66% of carbon sequestration value for the unmodified dune area
3- Measured carbon sequestration value for study site >66% or more compared to the sequestration value for an unmodified dune area

This carbon sequestering method completes the third and final method developed in the first part of this chapter to explore the regulatory benefits of the New Brighton dune system. Below, in the second part of Chapter 5, the results of applying these methods to the case study sites are presented and discussed.

5.4 Regulatory benefits of the New Brighton dune system results and discussion

5.4.1 Ecological value

Appendix B details the three study sites relative ecological analysis data, with these sites' total ecological value scores ranging from 1 = *poor* (sites 1 and 2) to 2 = *average* (site 3) as a function of the percentage cover of indigenous, introduced, and bare sand present in each quadrat. No study sites scored above a 2 (average score), due to high cover of marram grass and low cover of spinifex. Study site 3 had the highest ecological value, due to its higher percentage cover of indigenous vegetation compared to sites 1 and 2. The indigenous vegetation present at study site 3 included spinifex, taupata (*Comprosma repens*), Cabbage tree, harakeke and karo. This type of vegetation can support, for example, the katipō spider (Costall, 2006). Table 13 displays a summary of the ecological value results.

Table 13- Summary of ecological value for study site 1, 2 and 3

Note: the top section of the table displays the average (mean) and the standard deviation (Std Dev) calculated for each percentage cover vegetation type of indigenous, introduced, and bare sand for each study site, as well as the average and the standard deviation for each study sites weighted vegetation type percentage scores and the sum of these scores for each site. The second part of the table displays the formula steps used to determine the total ecological (ECOL) value of study site 1, 2 and 3 and their associated total ecological values scores (Tev). Pt= Percentage cover of plant type, Vt= vegetation type (ie, indigenous, native or bare sand), Qn= Total number of quadrats within the study site, 2= maximum score potential ecological value score for each quadrat, Ev= Ecological value, A= total area of study site, Tev= Total ecological value and score is the ecological value out of 3.

Vegetation cover		Indigenous (%)	Introduced (%)	Bare sand (%)	Indigenous (x2)	Introduced (x1)	Bare sand (x0)	Sum
Mean (Std Dev)	Site 1	11.56 (± 18.23)	68.44 (± 40.49)	20.00 (± 31.46)	0.23 (± 0.36)	0.68 (± 0.40)	0 (± 0)	0.92 (± 0.32)
	Site 2	11.00 (± 19.75)	64 (± 42.27)	20.33 (± 29.18)	0.22 (± 0.39)	0.64 (± 0.42)	0 (± 0)	0.86 (± 0.27)
	Site 3	16.10 (± 31.00)	80.63 (± 35.42)	3.91 (± 13.30)	0.32 (± 0.62)	0.81 (± 0.35)	0 (± 0)	1.13 (± 0.32)
Tev formula steps		Σ(Vt X Pt)	Qn	Qn x 2	**Ev**	A	**Tev**	**Score**
ECOL value results	Site 1	14.65	16	32	**0.46**	64	**29.3**	**1**
	Site 2	12.9	15	30	**0.43**	60	**25.8**	**1**
	Site 3	36.1	32	64	**0.56**	128	**72.2**	**2**

The ecological value of the study sites were also found to increase in proportion to the cross-shore length of the dune transect (i.e., from the foredune to the back dune). Site 3, with its longer cross-shore transect, included 128 m^2 of sampled area compared to 64 m^2 and 60 m^2 for sites 1 and 2 respectively. The larger quadrat ecological values resulting, reflect that larger habitat patches are typically inhabited by more indigenous species at higher population densities than in smaller areas. Assuming a similar shape, larger patches of dune vegetation can also have a lower proportion of their area affected by edge effects. Edge effects occur when the ecology of an area changes near its boundary. This can occur when habitats are fragmented, with habitat edges being more vulnerable to physical and anthropogenic stressors and thus having diminished ecological values (Fahrig, 2017).

Sites 1 and 2 had lower ecological values, partly because they are constrained in their inland extent by roads and houses. These two sites provide a clear example of how human modification can degrade the ecological value of a sand dune system, introducing exotic species and narrowing and degrading the coastal sand dune system for development in the coastal hinterland.

These results indicate that to increase the New Brighton sand dune CBGI ecological values, more space is needed in the coastal hinterland for dune expansion and migration for at least two of the three study sites examined here. This result is in line with the findings of other recent studies of these dunes and their projected response to accelerated SLR, with accelerated coastal erosion causing coastal squeeze highlighted as a future trajectory where migration space is unavailable (Orchard & Schiel, 2021 & Tonkin & Taylor, 2021).

The ecological value of these dunes could also be improved by replacing marram grass with spinifex and pīngao (Costall, 2006). Despite ongoing efforts of replanting the New Brighton dune system, recently, the CCC rangers recount that challenges have arisen with increased frequency of storm events, washing away young plantings of spinifex and pīngao on the coastal foredune (Mr J., Roberts, CCC Coast Care Park Ranger *pers. comm.* 29/10/21). Additional challenges reported include humans trampling the young spinifex plants and inadequate funding for labour, plant purchasing, fencing and fertiliser, access to adequate spinifex or pīngao seedling stock (Mr P., Borcherds, CCC Coast Care Park Ranger *pers. comm.* 12/10/21). The results from this study clearly indicate that, although there is higher spinifex cover on foredunes with plantings, there remains ample opportunity for further native species plantings in the mid dune and higher foredune zones.

The methodological approach employed to obtain the ecological value of the New Brighton coastal sand dune system relied on transect/quadrat analysis. The benefit of using quadrats along a transect is that it is an inexpensive and non-resource intensive approach (Murray, Ambrose & Dethier, 2006). However, there are limitations to this approach. Due to the breadth and time constraints of this project (i.e., multiple assessments in addition to this ecological assessment), only three sites were selected and sampled to represent the variety of dune vegetation cover and dune sizes within the New Brighton coastal sand dune system. Having only three transects to analyse, meant that the data obtained may not be truly representative of the whole population (dune system). To minimise any site selection bias introduced it is recommended that future sampling is done at more sites (Murray et al., 2006).

Another limitation is that within the quadrats, the plant identification and cover were determined from aerial UAV imagery. This makes it more difficult to identify different coastal sand dune vegetation types, additionally, sub-layered vegetation below the primary canopy cannot be seen (Tait, Orchard & Schiel, 2021). These limitations were, however, minimised by ground truthing with data gathered using the Trimble GPS of where different types of identifiable homogeneous vegetation were situated. These co-ordinates of vegetation type could then be used to check the accuracy of vegetation types identified from aerial imagery. This minimised the subjectivity of the user's ability to accurately determine what vegetation type was present in each quadrat from aerial imagery alone (Jensen, 2005).

Further research could also be conducted to undertake a more detailed assessment of floral characteristics (e.g., heights of plants) and associated fauna in the New Brighton coastal sand dune system. In this ecological evaluation assessment, the amount of fauna was assumed based on the relationship between different vegetation types and the existence of different species. However, a more accurate approach would be to count the fauna present either by quadrat analysis or other methods such as observations (Murray, 2006).

Despite these limitations and opportunities for more in-depth ecological analysis, the results seen here for the ecological value still provide us with a clear indication that the ecological value of the New Brighton dune system can be enhanced. As will be detailed later, in the next sections and subsequent results chapters, enhancement of the dune ecology could increase other dune CBGI benefits such as well-being, recreational, coastal protection, carbon sequestration, touristic and educational benefits and the sense of place offered by the dunes. As such, dune system ecology forms a vital or core component of the overall values set that dune CBGI provide, with ecological protection and enhancement being central to ensuring maximal dune benefits are experienced.

5.4.2 Coastal protection value

The results from the coastal protection methodology developed above will now be presented and discussed.

Evaluation of dune and berm geometry

The dune geometry attribute measurements and their associated value scores for the three dune study sites are shown in Table 14 and discussed in more detail below.

Table 14- Dune geometry attributes

Note: results of dune crest height, dune width, foredune seaward slope angle, berm width and dune inland migration space analyses of each study site, with their associated relative scores (see section 5.2.1 for details of the measurement methods). AMSL is above mean sea level and migration direction is inland.

	Site 1	**Site 2**	**Site 3**
Dune width (m)	64.2	58.8	135.1
Dune width score	1	1	3
Dune crest height (m AMSL)	5.23- 8.93	6.35- 7.47	7.82- 8.46
Crest height score	2	2	2
Berm width (m)	70.3	68.5	71.1
Berm width score	3	3	3
Seaward slope (°)	82.6	83.1	78.3
Seaward slope score	2	2	2
Migration space (m)	0	0	8.6
Migration space score	1	1	1

In 1995 a resource consent allowed the New Brighton coastal sand dune system to be lowered to 8 m AMSL (Hart & Knight, 2009). The 1990 beach profile data showed a maximum height of ca. 10 m AMSL, meaning up to 2 m in height would have been removed, potentially decreasing the value of the dune height attribute for coastal protection. Today, the dune heights are ca. 5 to 8 m AMSL within study sites 1-3 (Table 14), although in areas with accessways dune heights are much lower, increasing the risk of inundation from storm surges and tsunamis through these anthropogenically created gaps (Hart & Knight, 2009 & Todd, 1995). Dune heights lower than 8 m AMSL implies that New Brighton is not protected from the potential runup from a 5 m tsunami wave. Thus, we can conclude that in each study site dune height could be increased to improve their coastal protection functioning. Furthermore, 8 m AMSL minimum dune heights could be made more continuous along the shore, for example, by elevating pedestrian accessways, to provide enhanced protection from inundation hazards. The author recognises that this may not be possible in every part of the dune, since some surf lifesaving clubs currently rely on longshore interruptions to the dune crest heights to enable surf lifesaving equipment to be readily moved between storage buildings and the foreshore.

The slope of the coastal foredune and their associated scores are shown in Table 14. Results indicate that the slopes are relatively high (78.3 ^{o} to 83.1^{o}) hence coastal protection scores are low (>1). This steep slope could indicate erosional scarps present on the foredune in all 3 study sites. However, further analysis of the sand dune system (Table 15) indicated that it is predominantly covered by marram grass, hence, promoting this steep foredune slope (Mr. P. Borcherds, CCC Coast Care Park Ranger, *pers. comm*., 16/06/21). To ensure a lower more sustainable foredune seaward slope, existing sand-binding spinifex could be maintained, and further spinifex could be planted, though space in the coastal hinterland would also be required for migration.

The cross-shore extent of the coastal sand dunes and the beach berm were evaluated and scored, as summarised in Table 14. The New Brighton berm widths measured all score highly (3) as their widths were over 50 m which is the minimal accommodation space for the New Brighton dune system. This indicated that at all three study sites their berm widths were wide enough to accommodate extreme water levels and wave run-up from large storms at current sea levels, before these phenomena interact with the dunes or structures behind the beach. This is good; however, these scores may lower with SLR and therefore it is important that the dune width is monitored and potentially maintained through processes such as allowing the dune system to migrate inland with SLR.

The New Brighton coastal sand dune system cross-shore extent has been reduced to make space for hinterland residential development. As evidenced in the 1856 Black Maps, this dune system was historically between 360 to 929 m in its cross-shore extent on the New Brighton Spit, but it now ranges from 58 m to 146 m. Accordingly, the cross-shore extent scores for study sites 1 and 2 were comparatively low (<1), while study site 3 had a high score of a 3. The reduction in cross-shore extent implies that the current dune system has only a fraction of the potential coastal protection resource compared to pre-urbanisation. However, hinterland urbanisation is well established now such that it would be very costly to move all dwellings, families, and community facilities in order to recreate the historic extend of the sand dune CBGI (Orchard, 2020). The historic extent of the sand dune when looking forward to what dune width could be required to withstand 100 year ARI storm erosion and potential SLR, would have been sufficient. However, due to this discussed degradation and significant narrowing of the dune system 2 of the 3 study sites are now deemed too narrow to withstand a projected SSP4.5 SLR and storm cut erosion. It is important to note that these projections were made using SSP scenarios, which include some future uncertainty regarding how much SLR will occur and over what time period. Therefore, although this is based on the best current SLR projection, the levels of SLR experienced at different timescales in the future may differ such that the rate and extent of any future dune migration might also differ.

The scores associated with the space behind the coastal sand dunes (hinterland) are shown in Table 14. The results highlight that there is virtually no space for future inland dune migration and, therefore, the migration capacity scores are low (1). This is problematic because it is predicted that with 1 m of SLR, a third of the New Brighton coastal sand dune system could be eliminated (Orchard, 2020). Although these dune system losses could be minimised by maintaining and adding dune plantings, enhancing the dune height, or adding CBGI hybrid approaches to coastal dune enhancement, to avoid such dune system losses could imply that almost all coastal infrastructure, properties, families and social networks would have to be moved from New Brighton spit to make space for migration of the dune system inland with climate change. This would mean uprooting communities and figuring out a suitable approach in which the property owners were compensated (Barnett et al., 2014). This managed retreat possibility and the range of process options available to carry out any such change require careful analysis and consideration, topics which are noted here but the details of which are beyond the scope of this research.

Dune vegetation attributes evaluation

This section examines summary results for vegetation type, spinifex age, and cross-shore vegetation extent measurements (Table 15) made to evaluate the coastal protection attributes of the study site dune vegetation. The detailed quadrat data from which these summary results have been derived are recorded in Appendix C.

Table 15- Vegetation coastal protection attributes

Note: results of vegetation type, spinifex age, and cross-shore extent of vegetation analyses in quadrats at each of the study sites, with their associated value scores (see section 5.2.1 for details of the calculation methods).

	Site 1	**Site 2**	**Site 3**
Vegetation type total	24.58	28.47	33.56
Vegetation type score	1	1	1
Spinifex age (years)	9- 12	2- 14	15-16
Spinifex age score	3	3	3
Vegetation extent (%)	64.2	58.8	135.1

The average scores for each study site in relation to its quadrat vegetation cover is displayed in Table 15. Scores were generally low (≤1 out of a possible 3) due to the lack of spinifex on the foredune (Appendix B). As discussed earlier this plant is an effective sand binding species and, therefore, a key species in this area for coastal protection purposes (Bergin, 2008). The most common species found in quadrats at all sites was marram, with some quadrats being dominated by bare sand. Marram is less effective than spinifex for coastal protection purposes in terms of its ability to bind dune toe sand and assist with rapid recovery of the dune after erosion episodes, resulting in low vegetation scores. As such, the vegetation scores of the study areas could be improved by planting more native sand binding species, particularly spinifex (Mr. J., Roberts, CCC Coast Care Park Ranger, *pers. comm.* 29/10/21). Replanting the coastal sand dune system with spinifex implies that the sand dune system would recover faster between storms and/or accrete and prograde at a faster rate, creating a more effective and larger barrier between the hinterland urban infrastructure and coastal hazards.

The vegetation in each study site was overall found to be well established (> 5 years), and therefore somewhat able to withstand and recover from storm events. This meant the study sites received high (3) spinifex age scores (Table 15). A limitation of assessing vegetation age is that it relies on the memory of people. To minimise errors associated with vegetation age, interviews were done in situ, with the person who was typically responsible for doing the plantings. The main issue with this approach is that it only assesses the vegetation currently present on the foredune. Furthermore, individual study sites contain vegetation of different ages as a result of plantings at different times, and storms potentially having washed away vegetation with recovery occurring afterwards. Despite these limitations, spinifex age was evaluated and given its well established nature at the study sites (>5 years), it can be inferred that the vegetation scores well in terms of its potential effectiveness for sand binding, post-storm dune repair abilities and coastal protection function.

Dune and berm excursions

The excursion plots display both the overall trend of the berm and dune width from 1990 to 2020 as well as the short-term erosion, stable or accreting patterns over 6 monthly intervals (Appendix C, Figure C1). These short-term variations explained by the R^2 value, could be due to storm events with periods of successive storm events causing erosion and periods of less intense and frequent storms allowing accretion to occur. The linear trend equations indicate the long-term trend of the berm and dune width. For the dune toe and berm width long term trends, the slope of the line ranges from 0.00001 to 0.0001 for study site 3 (Appendix C, Figure C1a & C1d), 0.000004 to -0.022 for study site 2 (Appendix C, Figure C1b & C1e) and 0.000009 to 0.000007 for study site 1 dune toe and MSL excursions respectively (Appendix C, Figure C1c & C1f). This indicates that from 1990 to 2020 the beach is in a stable sediment supply state, hence a score of 2 is given to all three study sites for their long-term berm and dune width excursion distances. The R^2 value for each study site was low (ranging from 0.00000007 to 0.0117). This tells us that there is a very high proportion of variance in the dune toe and berm width overtime, indicating a dynamic dune and beach environment which responds rapidly to changes such as storm events and anthropogenic measures like dune vegetation trampling events. The berm width has more variation than the dune width, as indicated by a lower R^2 value ranging from (0.0007 – 0.000009) compared to (0.0117- 0.00000007) and a visually higher variation in the 6 monthly short term excursions overtime, fluctuating from -30.6 m to 28.4 m compared to -13.5 m and 5.4 m respectively (Appendix C, Figure C1).

Dune and berm volume changes

The dune and berm long term volume trends from 1990 to 2020 can also be classified as stable (Appendix C, Figure C2). This is because for each study site the slope of this linear trend in volume change overtime is near horizontal with the slopes of this trend ranging from -0.0032 to -0.0029 for study site 3 (Appendix C, Figure C2c & C2f), -0.0022 to -0.0022 for study site 2 (Appendix C, Figure C2b & C2e) and 0.0028 to 0.0005 for study site 1 dune and berm volume changes from 1990 to 2020 respectively (Appendix C, Figure C2a & C2d). Therefore, both dune and berm volume coastal protection parameters were given a score of 2. Again, their associated R^2 values were low, ranging from 0.0005 to 0.0123, indicating that over 6 monthly periods the dune and berm volume fluctuated significantly, though not as significantly as dune and berm widths (R^2 ranging from 0.000009 to 0.0117) (Appendix C, Figure C2). This makes sense as berm and dune volume are related to fluctuations in dune and berm width, which have already been established to feature a high degree of short-term variation.

Envelope of change analysis 1990 to 2020

The coastal sand dune system envelopes of change from 1990 to 2020 when examined were found to fluctuate in shape but overall be generally stable dune in volume between 1990 and 2020 (Appendix C, Figure C3), suggesting either an adequate sediment supply, careful management of the vegetation and human traffic, or some combination of these factors at New Brighton beach which have enabled it to stay in a dynamic state of equilibrium. At site 1, the dune *appears* to have changed shape between 1990 and 1995 (see the cross-shore area between 40 to 70 m in Appendix C, Figure C3a) but subsequent 5 yearly surveys from 1995 onwards indicate that this is not the case and this apparent change in dune shape was an artefact of the limited data points gathered in 1990. This artificially represented smooth dune seen in 1990 has since grown into a more natural shape as seen in the 2020 beach profile line in Appendix C, Figure C3a, adding on a new seaward dune crest and an eroding swale in between. Therefore, for site 1 between 1990 and 2020 there is a very slight observed overall increase in the total volume of the dune system, indicating an overall stable to slightly positive trend in dune state (Appendix C, Figure C3a). Study site 2 shows the only clear pattern of net dune accretion, with the height and width of the dune increasing overall (with some fluctuations between) from 1990 to 2020 (Appendix C, Figure C3b), indicating an accretionary dune state here. From discussions with the CCC park rangers this is a result of extensive plantings of spinifex here. The results in Table 15 support this, with spinifex ages being 14 years and 2 years, meaning this dune area has been regularly planted and well maintained (Mr. P. Borcherds, CCC Coast Care Park Ranger, *pers. comm*., 16/06/21). At site 3 (Appendix C, Figure C3c) it appears that the foredune crest has somewhat hollowed out, steepened over time, and migrated inland a few meters. There is also evidence of growth of an embryo dune and accretion of the back-berm area. Together these changes give a mixed picture of dune state, with the overall pattern indicating cyclical dynamics rather than sustained accretion here. Therefore, study site 3 was classified as being stable.

To avoid variability associated with seasonal variation in the topography of the dune, only summer data was analysed. This is because in this period the beach is more prone to accretion as there are then slightly less intense/ frequent storm events and a more persistent easterly prevailing wind, meaning roughly onshore and waves are more typically moving southward. Whereas in winter there are more intense and frequent storm events coming from the south, with prevailing westerly winds more common, and typically more coastal erosion of sand (Dune Restoration Trust of New Zealand, 2011). This means there are generally seasonal fluctuations in the sediment on the beach that would cause annual patterns of accretionary and erosional fluctuations. These annual fluctuations are displayed in the excursion plots for the beach and dune toe analysis (Appendix C, Figure C2). For the envelope of change plots, the annual data graphed was in the same month to minimise the visual variance of these seasonal fluctuations. Unfortunately, the surveys taken by ECan were not undertaken in the same month each year, to minimise the impact this could have on the results the months were selected that were closest to each other, therefore, the smallest impact of seasonal variances in erosions and accretion were encountered.

Caution should be exercised when making connections between the above envelope of change assessment and any implications for the state of the sediment supply to each site, not least because the dune envelope of change results are also significantly influenced by dune management practices. Additionally, inferences regarding sediment supply made from dune state alone lack key information from the other active parts of the beach system such as the foreshore and nearshore, with data on nearshore changes over time being unavailable for the New Brighton coast. These dune state measurements also do not account for cyclical or irregular erosion or sediment deposition over the sandy beaches profile (Foster, Healy & de Lange, 1994). However, the MSL and dune toe excursion and volume change plots for both the berm and dune environments from 1990 to 2020 undertaken in Appendix C, Figure C1 and C2 of this thesis, support these envelope of change findings.

The dune toe and MSL excursion plots alongside the volume and envelope of change analysis of these study sites work well together to paint a picture of what has happened from 1990 to 2020 to the dune and beach state. This is because the excursion plots show the high variability in retreat and accretion over 6 monthly intervals while the linear trend line smooths this seasonal variability to give an indication of the overall accretionary, stable, or eroding trend of the data from 1990 to 2020. However, dune toe and MSL excursion plots alone cannot give us strong enough evidence as proxy measure for the dune state as although the berm or dune width may fluctuate horizontally, the dune shape can also fluctuate with changes in height and slope. Therefore, the volume change plots with a linear trendline and R^2 value, alongside the envelope of change plots provide further evidence of the dunes changing state overtime and paint the full picture of the dunes state. It can be concluded that overall, the trend of the three New Brighton study sites has been stable from 1990- 2020.

Despite these three study sites being currently classified as stable, NIWA (2018) has predicted changes in sediment supply with ongoing climate change, including increased magnitude and more frequent Waimakariri River flood sediment input events. The future sediment budget projections include both positive (increased) and negative (decreased) possible scenarios (NIWA 2018, Tonkin & Taylor 2021). Therefore, it is crucial that information of use to analysing the sediment budget of New Brighton beach continues to be collected via beach profile surveys and other observations, so that changes can be accounted for in dune management practices and future dune state projections.

Overall coastal protection evaluation of the New Brighton dune system

Overall, it can be determined from the methodology created from international literature reviews and interviews with local experts that the relative New Brighton coastal sand dune system provides a considerable degree of coastal protection across multiple attributes (Table 16). The overall coastal protection scores range from average (score 2) to good (score 3) with study site 1 (61%) and study site 2 (62%) scoring an average score while study site 3 scores a good score of 72% with 100% being the optimal coastal protection value, differences in scores are largely due to the dune width, with study site 3 having a higher coastal protection value due to its wider width and higher percentage of native sand binding species and hence a slightly more durable slope of the foredune. There is considerable scope for improvement in these overall coastal protection scores and this generally exists regarding attributes like vegetation type, percentage cover of sand binding species, dune width, and space for migration which scored lowly (1) (Table 16). The medium scores (2) of dune crest height, seaward dune slope, long-term volume changes of the dune and berm, and long term changes in dune toe and MSL horizontal excursion distances may need active management to enhance these values to a good score. This is because climate change is only acting to exacerbate coastal hazards and therefore, eventually could act to degrade the current coastal protection scores. Furthermore, the high scores of berm width and vegetation age should also be maintained to ensure the integrity of the coastal protection value with climate change.

Table 16- Compilation of dune attribute scores used to evaluate the current coastal protection value of the New Brighton dune system

Note: migration direction is inland. For score level details, see Section 5.2.1

Weight	Parameter	Site 1	Site 2	Site 3
7	Dune width (m)	1	1	3
7	Dune crest height (m AMSL)	2	2	2
6	Seaward dune slope (°)	1	1	1
5	Berm width (m)	3	3	3
4	Migration space (m)	1	1	1
3	Volume change of dune ($m^{3/}yr$)	2	2	2
3	Volume change of berm (m^3/ yr)	2	2	2
3	Dune toe excursion trend (1990 to 2020)	2	2	2
3	MSL contour excursion trend (1990 to 2020)	2	2	2
2	Vegetation type	1	1	1
2	Sand binding plant cover (%)	1	1	2
2	Spinifex age (years)	3	3	3
1	Envelopes of change 1990 to 2020	2	3	2
Total weighted coastal protection value		82	83	98
Total coastal protection value (%)		57	58	68
Total coastal protection score		**2**	**2**	**3**

The key problem emerging from these analysis results is that inland migration space (and dune cross-shore extent) is virtually non-existent and addressing this could come at a high socio-economic cost. However, these socio-economic costs are altogether complex because if the alternative approach of people not retreating were to be exercised, these people and houses would suffer high costs from future coastal inundation and erosion, the insurance cost of living in a CCC labelled hazard zone, the increased cost from enhanced multi-hazard exposure as well the cost of the lost dune system values as these would be further degraded by coastal squeeze (Orchard & Schiel, 2021; Todd et al., 2019). All these costs and increased hazard risks could exacerbate stress and increase mental health costs in New Brighton residents (McNabb, 2021). Therefore, when considering managed retreat, it is important to not only consider the socio-economic costs of retreating from the area but also the socio-economic costs of staying in an area that is becoming more and more vulnerable to multi-hazards.

5.4.3 Carbon sequestration value

Table 17 indicates that the New Brighton dune system has sufficient ability to sequester carbon with average rates per study ranging from 12623.9 to 28002.57 $g.yr^{-1}$. The back fixed section of the dune has the highest ability to sequester carbon with the total carbon sequestration rate per meter squared of this area respectively 1.77 and 1.92 $g.yr^{-1}$ more than the embryo or mobile dune habitats (Table 17). Additionally, the larger the ecosystem size, the higher the carbon sequestration rate. This can be seen as the study site 3 area (13360 m^2) is more than that, for example, of study site 2 (5689 m^2), resulting in 16972.73 $g.yr^{-1}$ more carbon being sequestered at the former site in large part due to the greater dune ecosystem area there.

Clearly, it is important that future studies measure carbon sequestration for native NZ dune plants. Despite the lack of data for specific dune species from NZ, it can be concluded that although coastal dunes have an ability to sequester carbon, the relative ability of the New Brighton coastal sand dune system to sequester carbon is low (1). To increase the carbon sequestration of the New Brighton coastal sand dune system it is important to protect or enhance the area of the dunes ecosystem and in particular the fixed back-dune habitat that had the highest carbon sequester rates, for example by planting native shrubs and woody species like harakeke, karo, ti kouka, pohutakawa, taupata, ngaio and tauhuni. The relative score of 1 for each study site further supports the need to allow dune ecosystems to have space. Therefore, not squeezing and degrading their ecosystem, loosing essential benefits of the naturally functioning dune system.

Table 17- Results for the carbon sequestration of study site 1, 2 and 3

Note: the embryo, mobile and fixed dune habitat areas are the measured areas of each of these study sites from aerial imagery. The study sites are 100 m wide. The total carbon sequestration rates for the embryo, mobile and fixed dune habitats are the area multiplied by the total carbon sequestration rate of soil and vegetation for each dune habitat classified by Drius et al. (2016). The total average carbon sequestration rate per year of each study site is the average of these carbon sequestration rates for each habitat added together. The resultant values are measured in grams of carbon sequestered per year (g per study site area yr-1).

Parameters measured	**Site 1**	**Site 2**	**Site 3**
Embryo dune habitat area (m^2)	2560	2190	3790
Mobile dune habitat area (m^2)	3190	2940	4870
Static dune habitat area (m^2)	729	559	4700
Embryo dune carbon sequestration rate per area (g $area^{-1}$ yr^{-1})	16463	12527	21679
Mobile dune carbon sequestration rate per area (g $area^{-1}$ yr^{-1})	17768	16376	27126
Static dune carbon sequestration rate per area (g $area^{-1}$ yr^{-1})	5460	4187	35303
Total carbon sequestration rate of each study site (g per study site area yr^{-1})	12624	11030	28003
Percentage comparison to potential rate of unmodified dune (%)	7	6	14
Score	1	1	1

These results are important because they demonstrate that the New Brighton dune system can sequester carbon and highlight quantitative socio-economic values beyond coastal protection (Sutton-Grier et al., 2014). This type of quantitative evaluation also highlights the importance of incorporating dune ecosystems into national guidelines on carbon emission policies. Finally, as the co-benefit of sand dune system's ability to sequester carbon in NZ has been overlooked, these results demonstrate urgent research gaps related to carbon-based research on native dune vegetation (NIWA, 2017 & Sutton-Grier et al., 2014).

5.5 Summary of regulatory benefits findings

Chapter 5 has described and measured the regulatory benefits of the New Brighton coastal sand dune system. Different methodologies were created based on international case studies and local literature where regulatory values of dune systems had been measured. The results from these assessments of the New Brighton dune system indicated that the ecological value of study sites 1, 2 and 3 were respectively 1, 1, and 2 (low and average scores), while the coastal protection scores for each study site were 2 to 3 (average to good) and finally the carbon sequestration scores for each study site were all a 1 (low score). These scores give an indication that the regulatory values of the New Brighton coastal sand dune system are heavily dependent on not only the extent of the whole ecosystem (width of dune system and overall percentage vegetation cover) but the quality of the ecosystem (higher percentage cover of native vegetation the higher the regulatory value). Subsequently, this chapter has therefore explained the importance of protecting and or enhancing these ecosystems through conservation or the hybrid CBGI measures explained in section 2.5 of this thesis.

6 Nonmaterial values of the New Brighton dune system

This chapter is divided into two parts. The first part explores understandings and potential evaluation methods for a suite of nonmaterial benefits provided by dune system CBGI in NZ, namely the aesthetic, sense of place, recreational, touristic, educational, well-being, and material (monetary) values. In the second part, a subset of the evaluation methods developed are applied to the New Brighton dune system CBGI, and the nonmaterial values of this system are discussed.

6.1 Aesthetic value of dunes

Coastal scenery throughout NZ is a valued resource (Collins & Kearns, 2010). A high scenic value promotes well-being, increases property prices, entices tourists, and typically fosters a healthier ecosystem compared to areas of low scenic value. The iconic scenic value of coastal environments form a key element of NZ's landscape identity (Hart & Langley, 2007). Thus, the significance of scenic value is recognised in the RMA (1991) s5, the *Purpose of the Act*, and in s6, *Matters of National Importance*. While these sections of the RMA (1991) mention the importance of protecting scenic landscapes, they do not provide criteria on how this scenic value could be measured or compared. As such, coastal scenic values are typically assessed subjectively based on numerous elements that vary between places and assessments. Consequently, these aesthetic valuations are not comparable across the coastal environments of NZ. Since the aesthetic value of coastal environments has been recognised as an important national asset, a clear valuing framework should be developed that is applicable to different coastal systems such as dunes. Such a framework would allow for monitoring, protection and/or improvement and could help to identify or halt the degradation and loss of aesthetic values in our dune and other CBGI systems.

Globally, coastal sand dunes are known to provide high scenic values, as they are natural features that can block views of terrestrial development for beach users. They can create a natural-looking 'wall' between urban infrastructure and the natural scenery of beaches and oceans, thus enhancing the therapeutic benefits of coastal environments in fostering a sense of wilderness while promoting cognitive resetting (Bell et al., 2015). Sand dunes themselves are also perceived as being aesthetically pleasing as they are areas rich in biodiversity which often appear natural and untouched (Figure 38). Research indicates that natural features typically promote a higher scenic value than environments that are visibly modified (Collins & Kearns, 2010).

Figure 38- New Brighton coastal sand dune system blocking the view of urbanisation from the beach

Note: source of image is author's sister (Thompson, 2022)

Measuring the scenic value of an environment can be challenging as it is subjective and individual perspectives vary due to the positionality or specific ontologies of the assessor (Collins & Kearns, 2010). However, a study completed by Langley & Hart (2007) aimed to create a methodology in which the scenic value of 36 North Canterbury coastal environments could be quantitively measured. Langley & Hart (2007) based their methodology on a study conducted in the United Kingdom which aimed to evaluate the value of coastal scenery objectively while considering the impact of development and increased tourism on the coastal environment. For assessing the scenic value of north Canterbury beaches this methodology was broken into 5 steps, 3 of which were implemented here in Canterbury.

Step one of their methodologies involved assessing 26 coastal scenery parameters as seen in Table 18. These parameters were identified in a United Kingdom and Turkey study by surveying 4000 coastal users. These parameters included 18 physical or natural features and eight human features that helped to determine the scenic value of a coastal environment. A survey was developed from these results which could then evaluate the magnitude of each parameter in any coastal environment. Step two involved weighting the parameters relative to their perceived contribution towards the scenic value of a coastal environment in the UK or Turkey. To implement these parameters a series of fuzzy logic matrices were created to account for the subjectivity of observers. Step three involved undertaking this assessment at 36 coastal sites in North Canterbury. Following step three, the fuzzy logic assessment matrices were then applied to the raw evaluation survey data to calculate a classification for each site, with a maximum potential range from extremely attractive natural sites with very high landscape value to an unattractive site. Therefore, the output from this approach was a measure of how attractive or unattractive a coastal environment was found to be determined by 26 different coastal scenery parameters (Langley & Hart, 2007).

Table 18- Coastal scenery parameters used to assess the scenic value of coastal environments in Canterbury

Note: source is Langley & Hart (2007 p.19)

Physical Parameters No			RATING 1	2	3	4	5
1	CLIFFS	Height	Absent	> 5m – < 30m	30m - <60m	60m – 90m	> 90m
2	CLIFFS	Slope	Absent	Around 45°	Around 60°	Around 75°	Circa vertical
3	CLIFFS	Special features*	Absent	1	2	3	Many >3
4	BEACH FACE	Type	Absent	Mud	Cobble / Boulder	Pebble / Gravel +/- sand	Sand
5	BEACH FACE	Width	Absent	<5m - >100m	5m - < 25m	25m - < 50m	50m – 100m
6	BEACH FACE	Colour	Absent	Dark	Dark Tan	Light Tan / Bleached	White / Gold
7	ROCKY SHORE	Slope	Absent	< 5°	5° - 10°	10° - 20°	20° - 45°
8	ROCKY SHORE	Extent	Absent	< 5m	5m - < 10m	10m - < 20m	> 20m
9	ROCKY SHORE	Roughness	Absent	Distinctly jagged	Deeply pitted and / or Irregular (uneven)	Shallow pitted	Smooth
10	DUNES		Absent	Remnants	Fore-dune	Secondary Ridge	Several
11	VALLEY		Absent	Dry Valley	Stream (< 1m)	Stream (1 – 4m)	River / Limestone gorge
12	SKYLINE LANDFORM		Not visible	Flat	Undulating	Highly undulating	Mountainous
13	TIDES		Macro (>4m)		Meso (2 - 4m)		Micro (< 2m)
14	COASTAL LANDSCAPE FEATURES **		None	1	2	3	> 3
15	VISTAS		Open on 1 side	Open on 2 sides		Open on 3 sides	Open on 4 sides
16	WATER COLOUR & CLARITY		Muddy brown / Grey	Milky blue / Green Opaque	Green / Grey Blue	Clear blue / Dark blue	Very clear Turquoise
17	NATURAL VEGETATION COVER		Bare (<10% Vegetation)	Scrub / Garigue (Marram, gorse, bramble etc)	Wetlands / Meadows	Coppices, Maquis (+/- Mature trees)	Variety of mature trees / natural cover
18	VEGETATION DEBRIS		Continuous >50cm high	Full strand line	Single accumulation	Few scattered items	None
Human Parameters			1	2	3	4	5
19	NOISE DISTURBANCE		Intolerable	Tolerable		Little	None
20	LITTER		Continuous accumulation	Full strand-line	Single accumulation	Few scattered items	Virtually absent
21	EVIDENCE OF SEWAGE DISCHARGE		Sewage evidence		Some evidence (1 – 3 items)		No evidence of sewage
22	NON-BUILT ENVIRONMENT		None		Hedgerow / Terracing / Monoculture		Field mixed cultivation +/- Trees / Natural
23	BUILT ENVIRONMENT ***		Heavy industry	Heavy tourism and / or Urban	Light Tourism and/or Urban and / or Sensitive Industry	Sensitive Tourism and / or Urban	Historic and / or None
24	VEHICULAR IMPACT		No buffer zone. Car park & traffic visible.	+ Buffer zone. Car park & traffic visible	+ Buffer zone Traffic visible. Car park not visible	No buffer zone Traffic & car park not visible	+ Buffer zone. Traffic & car park not visible
25	SKYLINE		Very unattractive	unattractive	Sensitively designed High / Low	Very sensitively designed	Natural / historic features
26	UTILITIES ****		> 3	3	2	1	None

* Cliff Special Features: Indentation, banding, folding, screes, irregular profile.
** Coastal Landscape Features: Peninsulas, rock ridges, irregular headlands, arches, windows, caves, waterfalls, deltas, lagoons, islands, marshes, stacks, estuaries, reefs, fauna, embayment, tombola, mudflats, attractive offshore breakwaters/groynes.
*** Built environment: Caravans fall under tourism. Grading 2: Large intensive caravan sites; Grading 3: Light but still intensive caravan sites; Grading 4: Sensitively designed caravan sites.
**** Utilities: Power lines, pipelines, unattractive street lamps, fences.

This methodology is clearly a logical and thorough approach to assessing the scenic value of Canterbury coasts, though it relies on the assumption that New Zealanders value the same scenic resources as people in the United Kingdom. Therefore, this technique is very useful in highlighting the general strengths and weakness of a Canterbury coastal environments scenic value, but it lacks cultural contextualisation, therefore, not fitting into the NCP framework for valuing nature. This includes the incorporation of tangata whenua values on scenery, an integral component of determining the value of ecosystems in NZ (Awatere et al. 2011).

The Māori worldview does not specifically measure the scenic value of an area, however, their culture and understanding of the world holds many values that intertwine with the western approach to measuring the scenic value of an environment. These concepts include the ability of

Māori to carry out tikinga (traditions) (Harmsworth & Awatere, 2013). For this to occur the land must be as natural as possible with an abundance of mahinga kai species present. This aligns with the ecosystem needing to be healthy as the degradation of ecosystems directly impacts the well-being of Māori (Durie, 1982). These Māori values were added to the coastal scenic value assessment of New Brighton sand dunes; therefore, the assessment was conducted in a contextually appropriate manner, thus, aligning with the NCP approach to valuing nature.

6.1.1 Method developed to assess the scenic value of New Brighton dune CBGI

For the purpose of this study and with time limitations in mind the parameters input into the approach of determining the aesthetic value of the New Brighton sand dune system were simple and aimed to effectively provide a contextual understanding of the aesthetic value of the New Brighton coastal sand dune system. Table 19 lists the parameters chosen to measure the aesthetic value of the New Brighton coastal sand dune system at the three study sites, as explained in detail below.

Table 19- Parameters used to assess the aesthetic value of the Ōtautahi dune study sites in this research

Aesthetic value subcategory	**Ranking**		
	1	**2**	**3**
Vegetative cover (all species types)	<35%	35 to <70%	70 to 100%
Indigenous vegetation species cover	<20%	20 to <70%	70 to 100%
Built features disturbing coastal environment natural aesthetic (e.g., stormwater outlets, benches, fences, boardwalk)	Multiple features	Minor features	None visible
Residential development visible from standing on beach	Fully visible	Visible 50% of the time	None visible
Litter: number of pieces present at study site	≥5 pieces	<5 pieces	None
Beach width visible at high tide	0m	>0m to 4m	>4m
Total aesthetic value level	**Little to none**	**Some**	**High**

Percentage vegetation cover was measured as vegetation cover enhances the natural aesthetic of a coastal sand dune system (Langley & Hart, 2007). Therefore, the more vegetation cover, the higher the aesthetic value. This idea plus the range of cover values observed through the 3 study sites was used to set the relative cover scale employed here (Table 19). A lower score (1) was attributed to those study sites within the dune system that had minimal vegetation cover (<35%), while a higher score (3) was given if there was >70% vegetation cover. While this scale was deemed appropriate for the highly modified New Brighton dune system today, it would need to be altered for application to more natural dune systems in NZ such as in transgressive dunes, where patchiness can indicate high biodiversity values and, therefore, might score higher aesthetically than dense cover, which can indicate the presence of invasive plants.

The vegetation cover in the New Brighton dune was measured by assessing the virtual quadrats on the aerial imagery gathered from the UAV fieldwork at the three study sites (see Chapter 4 for details of the UAV methods). Calculations were based on the whole cross-sectional width of the dune system from the beginning of the foredune all the way through to the edge of the back dune. Each quadrat was assessed visually to quantify the percentage cover of vegetation, with the average percentage of vegetation cover for all quadrats per site then calculated and scored according to Table 19.

From a Māori perspective, the value of a place is intrinsically tied to the sense of place of an area. This sense of place can be developed through the ability of tikanga Māori traditions to occur, such as mahinga kai practises (Harmsworth & Awatere, 2013). Mahinga kai practises are heavily dependent on the naturalness of the area and thus the abundance of indigenous species present. In the New Brighton coastal sand dune, potential mahinga kai species are pīngao and spinifex, which are used for weaving, and harakeke and the karo tree, which is used for Rongoā Māori traditional healing practises (Matapopore Charitable Trust, 2015). An indigenous plant species scale was thus determined whereby if there were minimal indigenous species present at the study site (>20%), the score attributed was low (1), whereas if there was >70% cover of indigenous plant species present then the score attributed to this study site was high (3), with values between 20 and 70% scoring moderately (2) (Table 16). As for general vegetation cover explained above, visual analysis of the UAV imagery was employed to assess the quadrat scores for each study site, with all quadrats included from foredune to back dune.

The visualisation of built features in a coastal environment such as stormwater outlets, benches, fences, and boardwalks, is typically regarded to degrade the natural aesthetic value of environments in NZ (Collin & Kearns, 2015). The presence of these features in the dune systems and/or on the adjacent visible portions of the beach at the three study sites was assessed in the field on foot, with support from aerial imagery gathered from the UAV. An in situ visual survey was undertaken by the researcher, with all built features visible on the beach or coastal sand dune system recorded. This survey was supported by the visual assessment of the UAV aerial imagery, which gave a more consistent overview of all features present in the study site since it was unaffected by on-the-ground access. A scoring system was applied based on that of Collin and Kearns (2015), as summarised in Table 19.

Research conducted by Collins & Kearns (2010) and Langley & Hart (2007) has indicated that the visibility of urban (including residential) development significantly decreases the natural and wilderness feel of the beach. Consequently, the aesthetic value of the New Brighton coastal sand dune system could be considered diminished where urban development was evident from the beach. The visibility of hinterland urban infrastructure, mainly including residential development, was assessed by standing on the beach and visually assessing any urban development that could be seen. A ranking system was applied whereby lower scores indicated sites where a lot of residential development was visible, and higher scores indicates sites where little to no residential development was visible, with sites in between scoring moderate values (Table 16). Though the scoring system is qualitative, a degree of between-site consistency was achieved since the same researcher rated all sites. And while the scores are somewhat relative to the environments examined, they are comparable to those employed in similar setting, as in Langley & Hart (2007).

Research indicates that the presence of litter on a beach can significantly negatively affect the aesthetic value of the coastal environment (Langley and Hart, 2007; Williams & Micallef, 2009). A scale was developed that reflected this for New Brighton, with lower scores attributed to sites with relatively more litter (Table 16). The quantity of litter was measured in situ by foot surveys in the field on 22nd September 2021, the same day the aerial imagery was gathered. The aerial imagery was also used to support this assessment as it provided a quick and effective means to see the whole study site, including any litter missed in the ground level survey.

Visible beach width can have a significant effect on the aesthetic value of a beach, with a lack of available beach visible and available for non-aquatic recreation activities at high tide being regarded as aesthetically degraded (Collins & Kearns, 2010). Therefore, a higher score was given to beaches with cross-shore width to walk on and visually enjoy at high tide, while beaches that had no high tide beach were attributed a low score (Table 19). This parameter was measured by visiting the beach at high tide and measuring the cross-shore width of beach between the dune toe and water mark as measured by walking a measuring wheel in line with the ECan monitoring transect at each study site.

In order to gain an overall relative idea of the aesthetic value of the New Brighton coastal sand dune system based on these 6 different parameters, their scores were summed and divided by 6, providing each site with a score out of three and a relative descriptor as explained in Table 19.

6.2 Sense of place

A sense of place can be described as the emotive bonds and attachments people develop or experience in particular environments or locations. The environment can range from home to the nation where one is. Sense of place can also refer to the unique character of localities or regions with positive bonds of safety, comfort, and well-being engendered by these places as well as feelings of fear, dysphoria, and placelessness (Foote & Azaryhu, 2009). Coastal environments provide a place where unique recreational, traditional, leisurely, and educational practices can occur. They can be described as therapeutic landscapes. These landscapes' function "*through the combination of the built and physical environment, human perception and social conditions to produce an atmosphere conducive to healing*" (Gesler, 1996, p.66). This notion of a therapeutic landscape ties in well with a sense of place, as a therapeutic landscape is often found to be a 'meaningful location' where a strong sense of belonging is present (Creswell, 2014).

In NZ, a large component of the sense of place originates from coastal landscapes (Collins & Kearns, 2010). With over 14,000 km of coastline, many New Zealanders reside in proximity to the sea, and can be described as '*strongly identifying with the sea'* (Eames, 2018, p.79). Access to coastal environments in NZ is often understood as a '*national birth right'* while the beach is often described as a *'kiwi's dream'* (Phillips, 2007, np). In particular, wide sandy beaches with rural backdrops commonly generate strong feelings of attachment (Collins and Kearns, 2009). Additionally, research on the influence of NZ's coastal environments on culture has identified numerous contemporary and historic bicultural relationships between people and the coast (Coleman & Kearns, 2015). These relationships and connections to the coast have developed NZ's national identity, with a large part of our tourism, art, and literature focus on coastal environments (Matthewman, 2004). These values are inherently linked to the visual amenity, environmental quality, and social inclusiveness of the beach (Peart, 2005). Additionally, many of these connections originate in whakapapa, the ancestral links we have with the land, or by repeated visits to the beach, fishing for leisure, or voyaging in various crafts, subsequently, creating a sense of reverence and place (Collins & Kearns, 2010 & Wheaton et al., 2020).

Māori attachment to ancestral land can be viewed in terms of the minority world concept of sense of place, however, there are particular characteristics of this attachment which require an extension of this minority world view for Māori to gain a tūrangawaewae. These characteristics of a place include "*whakapapa, whanaungatanga and 'uri'- tanga (generational and familial linkages), wairuatanga and atuatanga (the spiritual dimension relating to godlike ancestors and the unlocking of environmental and human potential), and tirangawaewae and kaitiakitanga (inherited rights and obligations associated with belonging to a place that claims those with Māori ancestry by virtue of all* *the above)*" (Smith, 2004, p1). This connection to place is often expressed through the mediums of waiata (songs), whakataukī (proverbs), and whaikōrero (oratory) (Smith, 2004). The relationship Māori have with the environment incorporates the genealogical, cognitive, affective, spiritual, and behavioural ties to the natural environment as a result of the meaning and history within it. The Māori worldview '*contains no dichotomy between humans and the natural world'* (Patterson, 1992, np). Therefore, iwi, hapū, and whānau gain their sense of mana (authority and prestige) through inherent connections with the natural world (Walker, 2004).

This mana is gained from the natural world as Māori see the environment as an interconnected whole, connected by whakapapa. Whakapapa connects people to the environment, each other and other living and non-living entities (Wheaton et al., 2020). The ocean, lakes, rivers, and waterways are regarded as taonga by Māori. This reflects the concept of whakapapa and develops the tūrangawaewae Māori have in these natural environments (Jackson et al., 2017). Coastal areas are particularly special as they are an area for mahinga kai practices, thus tikanga Māori traditions can be undertaken in these areas connecting people to the land and their ancestry, thus promoting wairuatanga (Selby et al., 2010).

Kaitiakitanga is also an important component of tūrangawaewae to Māori. It can be described to "*weave together ancestral, environmental and social threads of identity, purpose, and practice"* (Selby et al., 2010, p. 277). This is because kaitiakitanga in practice recognises that the environment provides many necessary resources for good health, thus there is a responsibility to care for these environments and maintain them for generations to come (Selby et al., 2010). Kaitiakitanga, therefore, ensures coastal spaces remain a taonga tuku iho (treasures handed down by our ancestors) so that whānau can continue to utilise and enjoy these places for generations to come (Raureti, 2018).

6.2.1 Developing a method to assess sense of place for New Brighton dune CBGI

Measuring the sense of place can be difficult as it is a personal construct that changes significantly, not only at a cultural and religious level but at an individual level as a sense of place is developed through individualised place-based well-being encounters (Conradson, 2005). These encounters can be described as "*a relational outcome, as something that emerges through complex transactions between the person and their broader socio-environmental setting"* (Conradson, 2005, p.338). Despite the challenge of developing a framework that could measure the capacity of an environment to elicit the emotional response in someone of belonging, general conclusions can be drawn on the characteristics of a place that aid a positive sense of place to develop.

Research has been conducted on what might cause such strong feelings of sense of place in relation to coastal environments in NZ (Collins & Kearns, 2010). It has been found that when experiencing an environment, although we have five senses, sight overpowers other senses (Collins & Kearns, 2010). Therefore, it is mainly the aesthetic of the beach which can elicit the emotional response of a person to developing a sense of place. However, other attributes that also promote a sense of place are the environmental quality, social inclusiveness, heritage value, and leisure activities available, all of which the coast is rich in (Gurran et al., 2006 as cited in Collins & Kearns, 2010). It is important to note that a sense of place developed may not always be a positive one, as negative experiences can also be associated with certain places. (Collins & Kearns, 2007). Coastal environments such as sandy beaches can be perceived as risky places in NZ. This is from, for example, the risk of drowning, getting sick from polluted water, or getting skin cancer from sun exposure. Thus, developing a sense of place should be seen as a *'relational outcome'* between place and person, further consolidating the notion that a sense of place is highly individualised (Collins & Kearns, 2007; Conradson, 2005, p.338 & Wheaton, 2007).

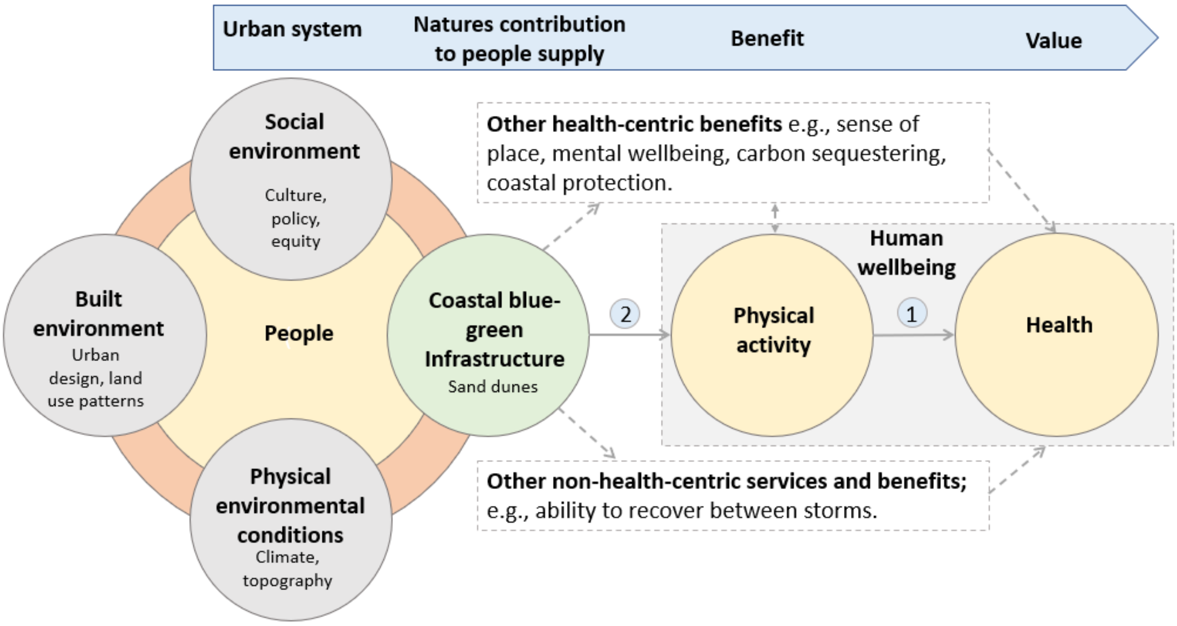
Research conducted by Wheaton et al. (2020) specified that the prevailing indicators of sense of place in the minority world, cannot necessarily include the kinds of sentiments expressed in Te Ao Māori narratives. This is because, from a Māori world viewpoint, coastal environments can provide leisure and adventure, however, more importantly, these places provide areas where whakapapa is strong, wairuatanga is present through historical practices such as mahinga kai, atua are present and kaitiakitanga is being carried out (Collins & Kearn, 2010 & Wheaton et al., 2020). Therefore, it is important to incorporate both a Māori perspective and a western perspective on how a sense of place is developed. When incorporating both perspectives it can be deduced that key factors that influence the capacity of an environment to develop a sense of place include its aesthetic, the recreational and educational activities it can harbour, the ancestral linkages and mahinga kai resources in the area, the spirituality of the environment and the presence and strength of kaitiakitanga.

6.3 Recreational value

Natural infrastructure in urban environments such as the CBGI of sand dunes positively impacts human well-being in many ways such as contributing to more equitable, healthier, and sustainable cities (Figure 39) (James et al., 2015; Hartig et al., 2014). Coastal sand dunes and sandy beach environments can provide areas for recreational and leisure activities. For example, many activities can occur in the dunes and on the beach, such as walking, running, fishing, bird watching, hand gliding, kite flying, resting, surfing, swimming, and community plantings (Pascoe, 2019). Therefore, sand dunes have a high recreational amenity value (Harris et al., 2020).

Figure 39- Conceptual model of the relationships between coastal blue-green infrastructure, recreational activity (quality and quantity) and health, aligned with the nature's contribution to peoples' approach

Note: sourced from Remme et al. (2021 p4).



The ability of dunes to provide recreational benefits has been assessed globally with research conducted across 18 countries by the BlueHealth organisation discovering that people who live within 1 km of major blue spaces such as sandy beaches are often physically healthier and have better mental health than those living further away (White et al., 2021). One reason for this is that these people are wealthier and, therefore, can afford to live near such an asset. However, blue spaces have also been found to promote healthcare to all demographics (Garret et al., 2019). It has been noted in the UK that the health benefits of blue spaces associated with increased recreation and the creation of positive social networks has the greatest effect amongst socioeconomically disadvantaged groups in society if the blue space is readily accessible (White et al., 2021). Thus, blue spaces can aid deprived communities in building well-being and resilience, fostering equitable health benefits across all demographics. This type of well-being has been termed equigenetic well-being (Hoffimann et al., 2017).

If the coast is accessible, people can build greater connections with nature, meaning physical and mental health are benefited via exercise and stronger immune systems (Kuo, 2011). Joanne et al's. (2020) research has found that people residing within 5 km of the coast are more likely than those living >20 km away to meet a country's physical activity guidelines, due to coastal recreational activity. This is significantly important for well-being, as regular physical activity reduces the risk of more than 20 chronic health conditions, ranging from cardiovascular diseases, osteoarthritis, poor bone health, poor mental health, diabetes, and hypertension to numerous types of cancer

(Warburton et al., 2006). Additionally, when walking in a blue space compared to in an urban environment, reported well-being and mood responses are significantly improved (Cristina Vert et al., 2020; Markyvech et al., 2017). Our immune systems are strengthened by access to nature due to its high biodiversity and, thus, increased potential introduction of new and diverse micro-organisms into our microbiome (Flies et al., 2017).

With the recent COVID-19 pandemic a lot of research has arisen which indicates that having green/ blue space within proximity to your home boosted well-being by promoting more physical activity and exposing people to cleaner air (Strain et al., 2020). Conversely, when natural environments were lacking close to home, it was reported people found it harder to stay motivated to participate in physical activity (Hartig et al., 2014). Consequently, research has found that insufficient physical activity is a leading risk factor for premature mortality globally, with inactivity responsible for 6% of global premature mortality and 1.4 billion adults at risk of developing exacerbating diseases due to inactivity (Guthold et al., 2018; Strain et al., 2020). CBGI such as the New Brighton coastal sand dune system provide a natural blue/ green space that promotes physical activity and recreational activity and, therefore, the health of society.

6.3.1 Method developed to assess recreational value of New Brighton dune CBGI

Social values, such as recreational value, are challenging to measure as they are typically measured on a subjective scale. However, a simple way of measuring the recreational value of an area is to count how many recreational activities are being undertaken in this study area and how frequently they are being conducted.

In a New Brighton dune context, this approach could involve observations taken for an hour in the morning and another hour in the evening for 1 day each month of a year, yielding data on the different recreational activities being undertaken at different times of the year and day. If such observations are made on weekends, a greater number of people are likely to have time available to participate in beach recreation. Weekday observations typically yield lower numbers but can record the activities of different population groups, such as retired, unemployed, carers of young children and those with flexible working arrangements. Activities counted in such observations might include: *footpath use (running/ walking), bird watching, community plantings, hang gliding on the drift of dunes, bench use (sitting), participating in appreciating nature (resting/ picnics) and photography*. The number of activities can then be added together with each activity having a score of 0.5 points. This would provide the total score for the recreational value of the sand dune over an observed 2 hour period. At the end of the year, once the 12 recordings over 2 hours are gathered, this score can be divided by 12 to produce an average score for the recreational activities observed. Due to unforeseen researcher health events these methods developed for recreational observations were not employed in this study but rather it forms the basis of a recommended method that could be applied in a future assessment.

6.4 Education value

As well as dunes promoting physical recreational activity, they also provide an area for tourism and education (Jamieson, 2008). In a general sense, education is very important globally as it develops critical thinking and hence develops the ability of a person to use logic when interacting with people or making decisions. Additionally, a basic education aids an individual's ability and capacity to secure employment (Smeyers & Depaepe, 2006). More specifically, educating people on nature can aid the process of kaitiakitanga, whereby these people feel connected to the land and want to protect it for future generations (Woods, 2016). This subsequently embodies sustainability. Thus, education on the CBGI of coastal sand dunes can help bring awareness to the values of the dunes and help to protect them (Everard et al., 2010). Subsequently, the values and benefits of the dunes could be retained, protected, or enhanced which brings benefit to coastal communities and the flora and fauna that reside in the coastal sand dune system (Jamieson, 2008).

6.4.1 Method developed to assess the educational value of New Brighton dune CBGI

Measuring the educational value of the New Brighton dune system is very challenging to undertake, let alone quantify. No prior literature available had this done this in a coastal environment and no techniques for measuring the educational value of an ammenity were transferable to assessing the educational value of the New Brighton dune system. Therefore, analysing the number of known educational projects being undertaken by different people and groups in and in relation to this environment was used as a proxy indicator of the potential educational value of the New Brighton dune system in the present study.

6.5 Tourism value

Globally coastal sand dunes are known to enhance tourism due to the sense of wilderness they elicit while their coastal protection and ecological value harbour many topics that have the potential to be researched from global visitors (Everard, Jones & Watts, 2010). However, not all coastal sand dune systems and sandy beaches have the same touristic value. There are characteristics of a place that influence the environments' ability to promote recreational and leisure activities while enhancing or decreasing its touristic appeal (Van der Meulen et al., 2004). Additionally, the benefits of the coastal sand dune system can be substantial or minimal depending on the location of the dunes in relation to where the benefit is wanted or needed (Everard, Jones & Watts, 2010).

Tourism is important in coastal areas as it generally brings in a significant amount of money. This money can then be used to help protect the coastal area while promoting the importance of natural environments for enjoyment (Everard et al., 2010). For example, in NZ before the COVID-19 pandemic, tourism was the largest export industry delivering $40.9 billion per year to the country. Regional economies were significantly positively impacted with tourism directly employing 8.4% of the workforce (Statistics New Zealand, 2019). A study conducted in 2013 on why people come to NZ for tourism indicated that over 1/3 of tourists came to see the natural beauty and spectacular natural landscapes (Tourism Industry Association New Zealand, 2014).

Unfortunately, NZ does not have specific statistics for the tourism value of coastal environments or coastal sand dunes, but international literature suggests that coastal sand dunes are areas of natural beauty which attract tourists on an annual basis due to the feelings of wilderness they elicit and their high recreational value. For example, the Sefton coast in England receives 4.6 million visits annually, providing £62.7 million in tourism revenues, with 26% of visitors specifically visiting to go to the beach (Stewerd, 2001). In the Netherlands, approximately 1 million people visit the Meijendel Dunes each year, creating substantial revenue for the area (Van der Meulen et al., 2004). Tourists enjoy the wilderness value of the coastal sand dunes as well as activities in surrounding coastal environments such as walking, cycling, and horse riding.

6.5.1 Method developed to assess the touristic value of New Brighton dune CBGI

Measuring the touristic value of a beach can be done by looking at the annual revenue tourists bring into the community or by assessing the hedonic value of the sand dune system (Mendoza-González et al., 2018). The latter is more suitable for the NCP approach to valuing nature as it recognised the numerous values a place can have beyond its economic value. When assessing the touristic value of the New Brighton dune system through a hedonic lens, the assumption made is that the value of tourism in the area is dependent on the characteristics and attributes of the New Brighton sand dune system. This technique is a well-established approach used for estimating ecosystem services of natural infrastructure, with it being used in numerous studies to assess the willingness of tourists to pay for the aesthetics of the landscape and the potential for recreation (Hamilton, 2007; Mendoza-González et al., 2018).

It has been deduced that when tourists travel to a place with the purpose of visiting the beach, they do this because of the *water quality, safety, facilities, absence of litter, wilderness feel, and scenic beauty of the area* (Penn et al., 2016). These parameters, therefore, form the hedonic values assessed to determine the touristic value of the New Brighton sand dune system in this study. Each characteristic was given a score from 1 to 3 for each study site, indicating poor, average, and good value levels, respectively. The latter three characteristics have already been assessed as explained earlier in this research, so their results were simply input into the hedonic value calculations to determine the touristic value of the sand dune system. The water quality, beach safety, and facilities parameters, by contrast, had not been measured earlier, hence the method used to determine these values is explained below.

Firstly, the water quality was evaluated using pre-existing data from ECan, which is available online. This data provides results of the water quality in relation to its suitability for swimming. It is measured each week from March through to November. The results provide either indicated safe swimming or unsafe swimming water quality conditions. The pre-existing data gathered also gives an indication as to what percentage of time the water in each area has been safe or not for swimming over the monitored history, with the scoring scale applied listed in Table 20.

Table 20- Parameters for assessing the water quality, and beach facility values of the Ōtautahi dune coast

Parameter	Score		
	1	2	3
Water quality	Unsafe water quality for swimming ≤50% of the time	Safe water quality for swimming >50 to ≤90% of the time	Safe water quality for swimming >90% of the time
Beach safety	3+ excess hazards	1-3 excess hazards	No excess hazards
Beach facilities	No facilities	Some useable facilities	Adequate useable facilities

The next parameter that was assessed was beach safety. The safety of a beach in this case was interpreted from the literature on how safe it is to swim at New Brighton beach, including information on the beach morphology, wave height, and nearshore current systems including rips. The beach safety was scored on the number of hazards present at the beach over and above what the existing hazards of swimming in flat, shark protected water would be, such as big waves (>1 m), rip currents present, lifeguards needed, and high chance of shark attack. The last parameter to be measured was the number of facilities located at the beach. For example, Surf Lifesaving and swimmer facilities available at New Brighton Beach were evaluated by measuring the type and number of facilities available and their usability, as summarised in Table 20.

Once these six characteristics had been scored, they were added together and divided by six to give a final value out of three. The higher the value the higher the tourism value the New Brighton sand dune system has and the lower the value the lower the tourism value the New Brighton sand dune system has.

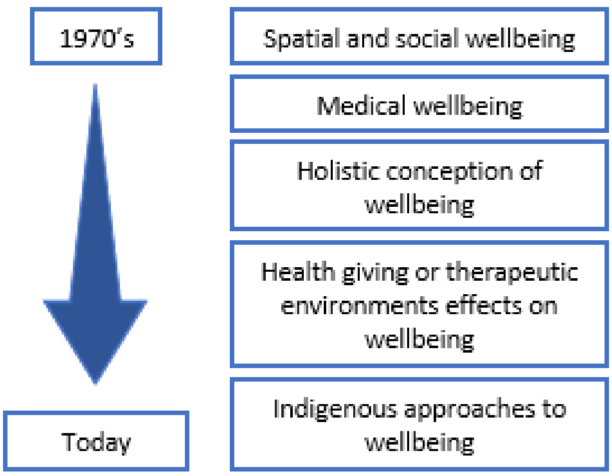
6.6 Well-being value

Well-being is a broad term, with various conceptualisations and definition approaches depending on the contextual setting and research positionality (Carlisle & Hanlon, 2008). Geographers have been researching well-being for several decades, with numerous pieces of work contributing to development of the well-being concepts and terminology commonly used today (Conradson, 2012; Schwanen & Atkinson 2015). A review of the historical development of well-being concepts was conducted to gain the necessary understanding to select a well-being framework appropriate for measuring the benefits of dune system CBGI.

In the 1970s, social scientists researched spatial patterns of social well-being, thereby gaining an understanding of inequality and how to intervene in the processes that generated it. Then from more of a medical perspective, disease ecology successfully established a relationship between environmental conditions and the presence/absence of infectious diseases, including dysentery and cholera (Emch et al., 2017). A third area of well-being work focused on health-giving, salutogenic or therapeutic environments. This promoted the idea that certain environments are supportive and enabling environments of well-being (Bell et al. 2018; Duff 2011; Gesler 1992 & Gesler 2005). For example, there has been research into the benefits of 'green' and 'blue' spaces on health and well-being. Recently, a fourth type of well-being research emerged which critically analysed the conception of well-being. This research looked at all aspects of well-being definitions, with a particular focus on the divergence between western constructs of well-being and the more place-based ecologically attuned understandings of indigenous peoples (Biddle and Swee 2012; Prout 2012). Research into different aspects of well-being over time can be seen in Figure 40.

Figure 40- Timeline showing how well-being concepts have developed over time

Note: adapted from Conradson (2012)



The various definitions and understandings of well-being that emerged during development of this research field (Figure 40) can present challenges when investigating what characteristics of a place, community, or person influence well-being. However, despite the broad range of views, there are multiple shared points of understanding in well-being definitions and research (Carlisle & Hanlon, 2008 & Conradson, 2012). Well-being is commonly understood as a holistic conception of positive human functioning, for instance, extending beyond a physiological or biomedical notion of health to encompass the emotional, social, and in some cases spiritual dimensions of what it means to be human. Well-being is also framed as a positive concept: more than the absence of illness or disease, it describes the presence of positive qualities and experiences (Conradson, 2012 & Wiseman & Brasher, 2008).

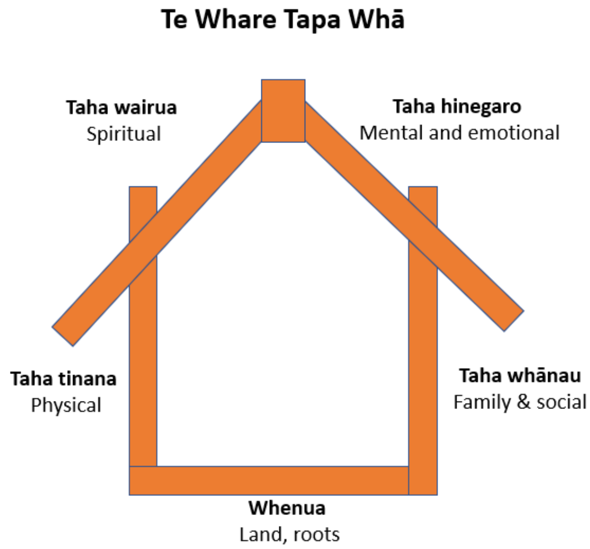
While acknowledging this prior research, to progress towards a context appropriate conceptualisation of well-being, as well as honouring the NCP contextual approach to valuing nature, it is necessary to also examine indigenous well-being frameworks that could be applicable to the New Brighton coastal sand dune system. In NZ, recent scholarship has highlighted that research is needed to better understand the relationship between healthy coastal ecosystems and human well-being (Wheaton et al., 2021). This research gap exists globally, with the impacts blue spaces can have on well-being being an inherently understudied topic (Britton et al., 2020). To address this gap requires an inter and trans-disciplinary approach across science, arts, social sciences, and technological disciplines. This also means including culturally diverse knowledge systems, such as ingenious Māori worldviews, that promote sustainable relationships with coastal ecosystems (Wheaton et al., 2021). Thus, the next section examines Māori conceptual frameworks relating to well-being.

6.6.1 Te Whare Tapa Whā

Te Whare Tapa Whā is an indigenous ‘meeting house’ framework representing the dimensions of well-being to Māori as seen in Figure 41. This well-being model has four ‘meeting house’ walls, all of which must be strong to ensure well-being and good health. The walls represent four key aspects of life – te taha hinengaro (psychological health); te taha wairua (spiritual health); te taha tinana (physical health); and te taha whānau (family health) (Durie, 1982).

Figure 41- Te Whare Tapa Whā, a Māori well-being framework model

Note: adapted from Durie (1982)



The most important and essential wall or requirement for good health is te taha wairua. This includes the acknowledgment of the need to humble oneself to the world and its elements as well as understanding that humans have limited control over the environment. Te taha wairua includes the spiritual connection one has with the environment, with the natural environment holding spiritual significance. Disconnection from the natural world is often associated with, or can contribute to, poor spiritual health. In terms of te taha whānau, from a tikanga Māori perspective family extends beyond your nuclear family to an extended kinship system. Māori gain a sense of identity as part of this extended whānau. This denotes the Māori worldview of communal connection as opposed to individual identity (Durie, 1985). Te Taha Hinengaro is vital to well-being as healthy thinking is integrative and holistic, as well as existing with the feeling of full self-expression and the ability to be yourself. The importance of te taha tinana is rooted in rituals that aim to separate the sacred and the common. To achieve good well-being, all dimensions of the Te Whare Tapa Whā must be in balance. To achieve this balance an understanding and respect for humankind's relationship with the natural world is crucial (Durie, 1982).

Te Whare Tapa Whā is based on the concept of mauri ora. Ora is understood as life, health, and well-being, while mauri is a life force "*immanent in all things, knitting and bonding them together*" (Royal, 2003, p. 47). Therefore, mauri ora, is the well-being of all-of-life, or, of a life-field. This idea is reflected through the understanding that the integrity of the meeting house is based on whenua and the connection people have with the land. It is important to understand that whenua encompasses wai (water) and water has mauri, and thus, all life and well-being partly is dependent on water, including coastal water (Waitangi Tribunal, 2012).

Te Whare Tapa Whā and Wai

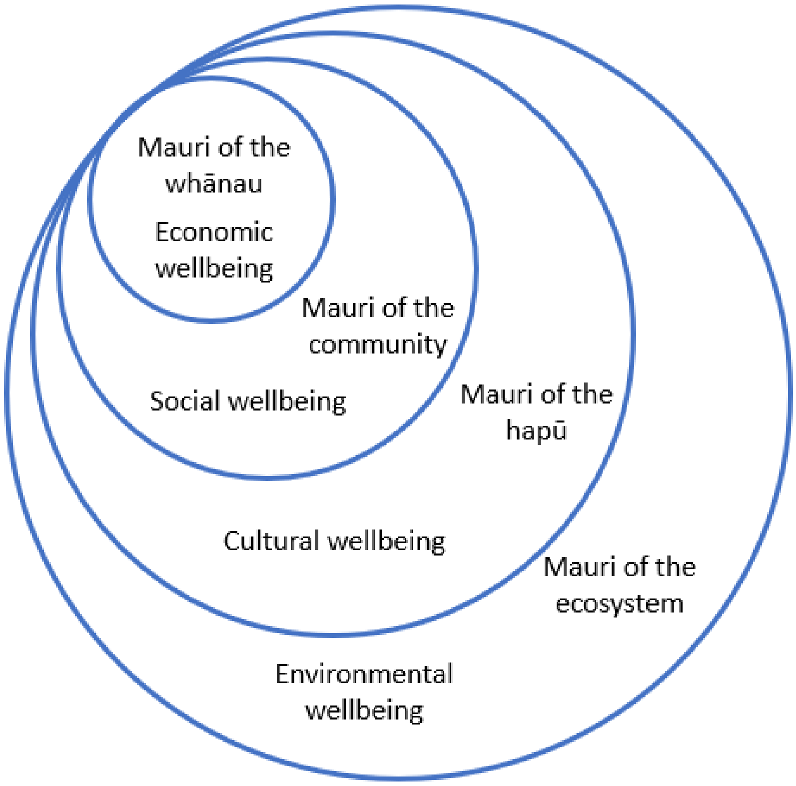
To describe the importance of wai in relation to its ability to give life and sustain well-being, there are six categories for the health of the mauri of water and subsequently its capacity to maintain life. These categories include waiora or healthy water, which is associated with a strong mauri and can be used for healing and giving life. Other types of healthy water include waiunu which is drinking water, waiwhakaika which is ceremonial water used for embedding knowledge, and wairiki which is water that can heal. On the contrary, when the health of the mauri of water has been depleted or is absent, wai can be described as waikino which described polluted waters, or waimate which is stagnant, dead, or death-inducing waters (Ngata, 2018). It is, therefore, very important to Māori well-being that the health of water and hence natural coastal environments are protected, subsequently, the spiritual connection Māori have with the land is not lost and the coastal waters do not become waikino or even waimate due to detrimental anthropogenic activity. Should this occur, it could negatively affect the mana of the hapu to offer hospitality and mātauranga relating to mahinga kai (Harmsworth, 2013). Thus degradation of, or disconnection from the environment can adversely impact human well-being (Dick, 2013; Harmsworth, 2013; Harrison et al., 2020). More specifically, Dick (2013) indicates that ecological degradation can cause "*severance between people and food species, the reduced connection between people in their community, erosion of ways that kinship is maintained, the severed transmission of mātauranga Māori and impaired health and tribal development*" (Dick et al, 2013 p.117).

Te Whare Tapa Whā - beyond the living world

This philosophy of well-being is a holistic one that promotes all aspects of well-being and "*exceeds human-centric frameworks of Euro-Western well-being*" as the non-living world is just as important as the living world for maintaining well-being (Yates, 2019 p.6). This can be seen in Figure 42, where it is clear the health of the environment encompasses all other aspects of well-being. This conceptualisation of well-being promotes kaitiakitanga as the health of the environment is directly related to the health of the individuals and communities which interact with this place. According to a Te Ao Māori perspective, the environment is valued not just in financial terms but more deeply in relation to whānau and spiritual connection (Yates, 2019), tied to the concept of whakapapa, whereby we are connected to the natural world both spiritually and traditionally.

Figure 42- Diagram situating the importance of the health of the environment for all aspects of human well-being

Note: adapted from Morgan (2003, p5).



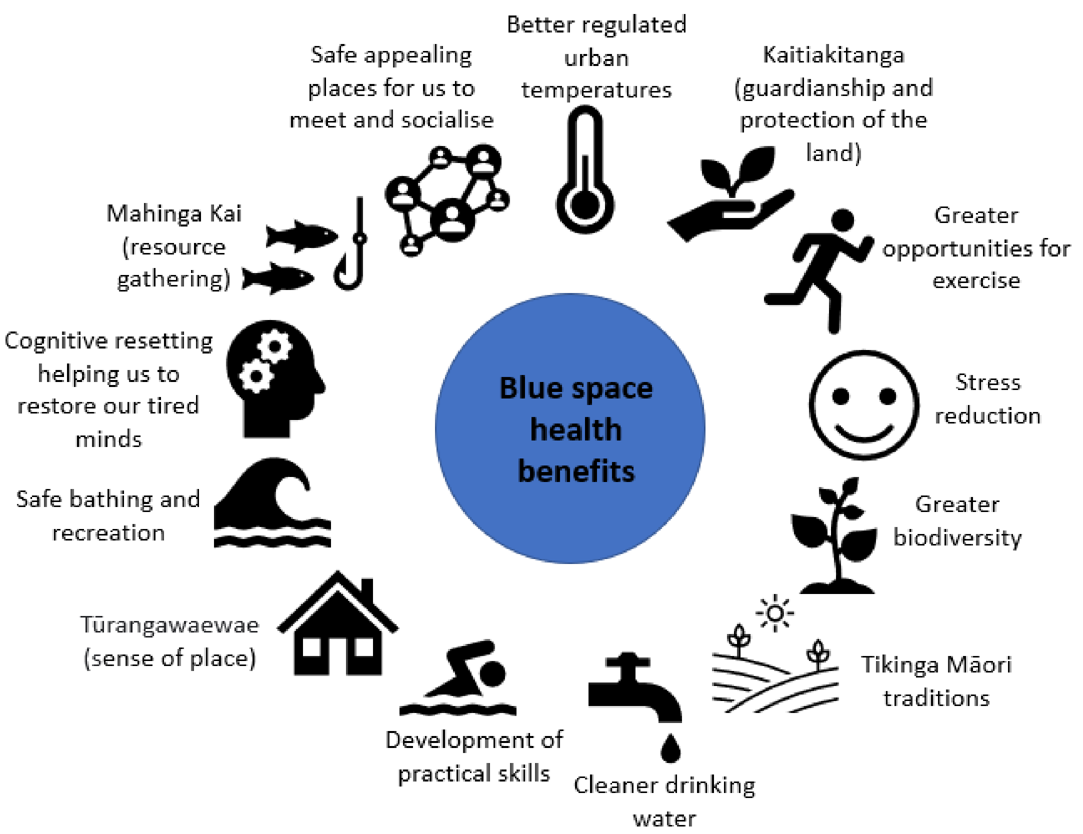
The well-being model of Te Whare Tapa Whā is an appropriate model to implement in this research in seeking to assess the New Brighton coastal sand dune system well-being value. This is because it honours diverse influences on well-being and originates from an indigenous worldview (Wheaton et al., 2021). This Māori framework supports the idea that well-being is not produced from our health systems, but rather is a product of where and how we live. Therefore, the development and maintenance of our coastal environments and infrastructure should be central in the decision-making processes regarding the well-being of coastal communities (White et al., 2021). Subsequently, coastal communities should investigate the possibility of implementing *'upstream'* well-being aids, such as implementing, maintaining, or restoring CBGI in coastal environments (Maller et al., 2006, p45). In this way the various benefits of healthy ecosystems can be utilised, and the well-being of coastal residents or visitors enhanced or maintained. The well-being framework of Te Whare Tapa Whā also aligns with the NCP approach to valuing nature as it ensures that culture is a component of all well-being benefits promoted by CBGI, rather than being confined to one sub-category.

Blue spaces and their ability to promote well-being

Over time, a large body of research has been generated on the ability of green spaces to promote well-being at an individual and community level (Houlden et al., 2018; Mitchell et al., 2015; Olsen et al., 2019; Twohig-Bennett & Jones, 2018). However, the concrete well-being benefits of *blue* spaces have only recently begun to be explored and quantified (Barton et al., 2016; Hartig et al., 2014 & Wheaton et al., 2020), with significant research gaps remaining (Barton et al., 2016; Hartig et al., 2014 & Wheaton et al., 2020). Studies completed in Europe by the recently constructed organisation of 'Bluehealth', which focuses on the well-being benefits of blue spaces, indicate that blue coastal spaces such as sandy beaches have multiple well-being benefits. Sand dune CBGI falls into the blue space category since it is associated with sandy beaches, but it also comprises a 'green space' since dunes are an area of rich plant and other biodiversity and ecological value. Research that looks at both the well-being benefits of blue and green spaces will be explored here to determine how sand dune CBGI could benefit human well-being under a Te Whare Tapa Whā Māori well-being framework. Figure 42 shows some of the health benefits of blue spaces explored in the next section of this thesis.

Figure 43- Well-being benefits of blue spaces

Note: adapted from Hall et al.(2020 p1)



The potential impacts CBGI can have on the four fundamental components of the Te Whare Tapa Whā framework (physical, spiritual, family, and phycological well-being) are explored here. All four aspects interrelate and are required together to create well-being such that their assessment cannot be conducted individually (Durie, 1982). Alongside this, assessing, for example, mental health benefits in isolation from the physical health benefits of CBGI is difficult as improved physical health is inherently linked to enhanced mental health (Remme et al., 2021). Therefore, this research assesses the benefits together, rather than scoring benefits individually and missing the positive effects on well-being of their interrelationships and balance.

Overall, recent literature has made it clear that blue spaces have a direct benefit on well-being in that they aid mental health and psychosocial well-being. A literature review conducted by Britton et al. (2020) reported that most scholarship on the relationship between blue spaces and well-being identifies a link between positive well-being indicators and blue spaces. They also found evidence that blue spaces promote enhanced social connectedness within communities and social groups. The review article indicates that globally if the investment is made in maintaining the efficacy of blue spaces, human well-being will be enhanced.

The BlueHealth organisation has discovered that blue spaces are linked to enhanced happiness and well-being via three key pathways. The first beneficial pathway is the regulatory health benefits of natural spaces. For example, for sand dunes these include coastal protection, reducing air pollution, wind protection, carbon sequestering, water filtration, and regulating urban temperatures (Barbier et al., 2011; Cunniff & Schwartz, 2015; Morris et al., 2018; Orchard, 2014; Zhu et al., 2010). Secondly, people who reside near water tend to be more active due to the appeal of recreating in nature. Thirdly, blue spaces have an edge over green spaces as water has a natural psychological restorative effect (White et al., 2020). This means water can contribute to restoring overloaded and tired brains to a state where people feel refreshed and can deal with the adversity of everyday life.

It has been found that spending time in blue spaces consistently produces higher levels of benefit compared to time in green spaces in regards to inducing positive emotions and reducing stress and negative emotions. White (2020 in Hunt, 2019, p.n.a.) stated that "*By spending time in these environments, you're getting what we call 'health by stealth' – enjoying the outdoors, interacting with the physical environment – and that also has some different health benefits*."

The BlueHealth organisation found that people who reside in neighbourhoods with good accessibility to green/ blue spaces reported higher positive well-being. This was because feeling psychologically connected to, recreating in (see earlier section on Recreation value), or even living near the natural world is associated with better mental health (Grellier et al., 2017). The Ministry for the Environment and Statistics NZ (2021 p. 9) stated that "*A healthy whenua is fundamental to our health and physical, mental, spiritual, and social well-being. It provides resources to feed, shelter, and heal our whānau, opportunities to learn, and connects us to Papatūānuku*". BlueHealth research, along with other emerging global scholarship, has found that a feeling of connection to nature was directly related to positive well-being and negatively associated with mental distress, with regular recreation visits to blue spaces associated with a significantly lower likelihood of a person using medication for depression (Garrett et al., 2021; White et al., 2021). Consequently, this association between the benefits to well-being of blue-green spaces is degraded if people do not have access to, or do not visit, green/ blue space. An 18 country assessment found a minimum of two hours a week in blue space was needed to feel the benefits of blue space (White et al., 2021). It is important to note that the benefits were only felt if the person was to intentionally visit the blue coastal space, with well-being benefits not felt when people were unintentional or unwilling visitors to an area (White et al., 2021).

If people lack easy access to blue spaces, research indicates they will seek these spaces to make them feel better. People in Europe have been found to willingly travel 10 times further to access coastal blue space compared to terrestrial blue space such as a lake, and 20 times further thanto access a river (Lewis et al., 2020). While the physiography of European countries may play a role in this, it also speaks volumes in terms of the capacity of coastal environments to aid people's well-being compared to other areas. This statistic is supported by a multitude of research that promotes coastal environments as an optimal natural health promoting environment. For example, an extensive study that was conducted in 2013 on happiness in natural environments found that coastal margins were found to be by far the happiest locations, especially when compared to continuous urban environments (MacKerron & Mourato, 2013). Living by the coast has been associated with better general and mental health, with both visiting the coast and having sea views intrinsically linked to enhanced well-being (Hunt, 2019).

Benefits to the mental well-being of blue and green spaces have also been assessed in various settings, with a prominent UK study revealing that neighbourhoods with more birdlife and vegetation result in less stressed, depressed, and anxious people (Cox et al., 2017). A 10% increase in the amount of green space in an area is associated with decreased stress and anxiety related symptoms comparable to a five-year decrease in age (de Vries et al., 2003). Additionally, choosing to visit nature can have significant positive impacts on a person's well-being if they suffer from an underlying mental health disorder. It has been found that people with anxiety are more likely to visit blue spaces, and that people who suffer from depression and/ or anxiety report feeling happier with lower anxiety levels during these visits (Tester-Jones et al., 2017).

Another impact of CBGI on mental well-being could relate to its coastal hazard protection value. Since CBGI like sand dunes can reduce the risks to communities of being exposed to coastal hazards they can reduce solastagia, the anxiety caused by the fear of the impacts of climate change (Albrecht et al., 2007). This fear is very real and has been reported as heightened in low-lying coastal areas, including amongst New Brighton residents (McNabb, 2021).

Green and blue spaces also promote social interaction within communities. Social ties are created, and when the community is faced with adversity such as natural disasters, these social ties can enhance resilience and well-being (Aldrich, 2012; Miller, 2020).

COVID-19 has had, and is having, severe impacts on people's well-being. This is due to the loss of loved ones, lockdowns, restrictions, and the pandemic's socio-economic consequences. Numerous studies undertaken globally indicate that COVID-19 has caused increasing depression, anxiety feelings of loneliness, and other nonspecific symptoms of deteriorating mental health. Lockdowns are generally linked to decreased physical activity, which significantly impact both physical and mental health (Vert, 2020). Blue spaces provided a coping mechanism to help people deal with lockdowns (Kleinschroth & Kowarik, 2020). All the benefits mentioned above, such as their ability to promote recreational activity and boost mood, have helped and are helping people deal with the stress associated with the COVID-19 pandemic.

6.6.2 Developing a method to assess the well-being value of New Brighton dune CBGI

Although BlueHealth's research is very progressive in investigating the impacts blue spaces can have on well-being, the influence of blue spaces on people is only assessed through a minority world (Western, Global North) well-being point of view. There is a significant lack of research which honours the spiritual and traditional connection we have with the land and how blue spaces influence linkages between people's well-being and the environment.

In NZ there is very limited research on the impacts of blue spaces on well-being from a Māori worldview. However, research conducted by Coleman & Kearns (2015) and Völker & Kistemann (2012) found that living near water helps to develop a sense of belonging, shared place-making, social experiences, and identity. Moreover, immersive coastal recreational activities such as surfing, fishing, swimming, or beach walking can offer unique psychological and cognitive benefits. This is of particular interest to Māori well-being, as tangata whenua gain their well-being, sense of belonging, and identity from their connection with the natural environment (Smith, 2004). Thus, having healthy blue spaces nearby to interact with benefits well-being. Durie (1998, p. 70) reports that given the natural environment is integral to tangata whenua identity and sense of well-being, tribal elders regard '*lack of access to tribal lands or territories'* as an important indicator of poor health.

Urban Māori are particularly at risk of losing a connection to their ancestral land, as well as associated mātauranga, tikanga, and all the dimensions of Te Whare Tapa Whā (Walker et al., 2019). This is because the connection between Māori and whenua can significantly affect all aspects of well-being. Consequently, if a nature-based environment is degraded, such as the ecosystem of the New Brighton sand dune system, taha wairua, taha hinengaro, taha tinana, and taha whānau are reduced. Degradation of the environment means that the ability to participate in tikanga and mātauranga that has been passed down through generations is either diminished or lost. Consequently, not having the ability to manaaki (show hospitality) and share kai (food) with whānau and manuhiri (guests) negatively impacts mana of the people and the whenua (Ministry for the Environment & Stats NZ, 2021). This significantly negatively impacts well-being and is a clear indication of how strong the connection is between the health of the environment and well-being from an indigenous viewpoint.

In Ōtautahi, sand dunes and coastal environments provide a place where tikanga Māori traditions can be undertaken, connecting Māori to the land and to their traditional practices. For example, gathering pīngao for weaving is a traditional practice which is associated with the New Brighton dune system (Matapopere Charitable Trust, 2015; Mr G. Bennet, Waimakariri DC and Coastal Restoration Trust, *pers. comm.*, 23/08/21). This tradition connects Māori with the land and their ancestors, promoting spiritual health which is the most important well-being dimension in the Te Whare Tapa Whā framework, alongside promoting all other dimensions of well-being in mātauranga Māori.

Measuring the well-being value of the New Brighton sand dune system accurately is challenging as there are multiple components to well-being. However, if it is assessed through the Te Whare Tapa Whā model the four key types of well-being that need to be measured are: te taha hinengaro; te taha wairua; te taha tinana; and te taha whānau (Durie, 1982). These four dimensions are all based on the health of the coastal sand dune system; therefore, the health of the New Brighton coastal sand dune will be the basis used to determine its well-being value. Carass, (2021) indicated that the most important well-being to the people of New Brighton was environmental well-being. This reflects the inherent link human well-being has with the environment, and how important it is to protect and restore New Brighton's dune system. In this way the intrinsic link to people's mental, physical, family, and spiritual health can be maintained or enhanced. It is very clear that degraded environments and water bodies will have significant negative impacts on human physical health as well as on aspects of health that are fundamental in the Te Whare Tapa Whā framework (Durie, 1985).

It is recommended that the well-being value of the New Brighton coastal sand dune system could be measured via:

1. percentage of native or indigenous species present,
2. number of rongoā or mahinga kai species present,
3. number of tikanga Māori activities taking place,
4. number of recreational activities taking place, and
5. number of community groups actively present here.

List parameters 1, 2, and 5 have already been measured in this research, with their methodologies and results explained earlier. A methodology for assessing parameter 4 was also explained earlier, though this has not been implemented in the current project due to researcher health-imposed time constraints. It is suggested here that the remaining two parameters, the number of community groups and tikanga Māori traditions, could be assessed through reading literature and interviews with experts on the New Brighton coastal sand dune system, as well as using the earlier review of the educational value of the dune system, which summarises community education and engagement aspects of the dune environment.

6.7 Material (monetary) value

The last aspect of the NCP approach to valuing nature is the material value of the sand dune system. In reality, this value is much broader than what can be assessed in the scope of this research. For example, material values that are not assessed due to time restraints include the value of the sand that the dunes are made from, the mahinga kai resources, and the cost of fish and shellfish that benefit from the presence of the coastal sand dune system alongside the risk reduction value the dunes provide. Measuring the monetary value of these dune system components is beyond the scope of this initial (much broader than monetary values) investigation. Instead, the below section reviews approaches that could be suitable to measuring the monetary value of the New Brighton coastal sand dune system as a whole.

Very limited scholarship is available on the monetary value of coastal sand dunes. Nevertheless, it can be assumed that coastal sand dunes ought to have a high monetary value as they have multiple benefits that extend beyond the sole purpose of coastal protection. Van der Biest et al. (2017) claim to have published the first piece of research to take the descriptive ecosystem services of coastal sand dune systems and try to quantitatively monetise these to a singular value. Their research focused on coastal sand dunes in Belgium, with a particular focus on the difference between the monetary benefits of stable and dynamic coastal sand dune systems. Stable dunes were dunes fixed by hard engineered infrastructure, while mobile dunes were dunes that had constant sand movement. It was deduced that these dynamic dunes provided five main ecosystem services: water provision, coastal safety maintenance, water quality regulation, climate regulation and recreation, with each value having a measurable monetary value. Their results provide evidence that a dynamic dune system when compared to a stationary one can provide 50% more economic benefits. The main benefits come from coastal protection and recreational opportunities. These results importantly support other research indicating that governments and communities can benefit from the services of coastal sand dune systems if they accept their mobile nature. To do this we must ensure enough coastal hinterland space for dunes to manifest their dynamic nature (Van der Biest et al., 2017).

6.7.1 Developing a method to assess the monetary value of New Brighton dune CBGI

Van der Biest et al. (2017) argue that quantifying the monetary benefits of CBGI is difficult because in most locations, insufficient understanding exists concerning the contextual public preferences for risk reduction and identifying communities at risk. Even where adequate data and sufficient resources are available to calculate the monetary value of CBGI, the task is still challenging since methodologies must vary depending on the social priorities and vulnerabilities of communities at risk (Olander et al., 2018).

The *Natural or Nature Based Solutions International Guidelines* presents a review of multiple ways for valuing CBGI (Bridges et al., 2021). This guide also identifies the limitations of each approach and argues that further research is needed to produce a robust methodology to measure monetary values accurately for different locations. In this study, calculating an accurate monetary value for the New Brighton coastal sand dune system was not possible. Time and resource constraints combined with the initial nature of this exploration of a broad suite of CBGI benefits, meant that other dune benefits needed to be prioritised. However, the review of methods currently available completed in the present research indicates that the risk reduction and avoided damages approach would be a beneficial approach to apply to the New Brighton dune CBGI in future research.

The monetary value of CBGI could be evaluated from the perspective of how much risk reduction the CBGI can provide and the avoided monetary damages to the dune co-benefits. The risk reduction monetary value can be calculated through the approach of expected damages. Expected damages is currently the most popular approach to calculating the monetary risk reduction value of blue-green infrastructure globally. There are four main steps to the expected damages approach. As stated in the *International guidelines for Natural and Nature-based features (NNBF)* by Bridges et al. (2021, p.227) these are:

- “*Step 1: Estimate coastal and fluvial hydrodynamics.*
- *Step 2: Estimate effects of NNBF on hydrodynamics.*
- *Step 3: Estimate flooding and erosion with and without NNBF*
- *Step 4: Assess expected damages with and without NNBF*.”

Step 4 involves calculations of potential damages, (a) with the CBGI present and (b) without it, for a single storm, annual storms, and the net present value of risk reduction. All these calculations need to be evaluated to create a full picture of what the monetary value of the risk reduction benefits are (Bridges et al., 2021).

These steps provide a brief overview of an approach that could be used to calculate the monetary risk reduction benefits of CBGI (for additional details, see Bridges et al., 2021). Calculating the flooding extent as part of this approach is a complex task, especially for CBGI where there is limited experience modelling flooding protection capabilities, such as for dunes. CBGI flood protection calculations have produced highly variable estimates in the past (Cameron & Englin, 1997). Such complex modelling and calculations are beyond the scope of the present research but attempting such estimates is highly recommended for a future, more narrowly focussed, research project.

As with the expected damage costs, numerous approaches exist for calculating the monetary value of CBGI co-benefits, each with associated strengths and weaknesses. The *International Guidelines on NNBF* (Bridges et al., 2021) explain this would be a very complex undertaking. From the limited information they do provide, it appears that the most appropriate approach to calculating the monetary value of the co-benefits of the New Brighton coastal sand dune system would be an ‘avoided damages’ approach.

The avoided damages approach measures the potential costs due to lost benefits provided by ecosystems. For example, one could seek to measure climate change effects on individual and social well-being if coastal sand dunes no longer existed (Reddy et al., 2016). The costs measured could be market values or social costs (Fisher, Bateman, & Turner 2011; Morris et al., 2021). This approach could be useful for calculating the monetary benefits of the New Brighton coastal sand dune system since the monetary value of both social and physical parameters are accounted for.

The other factor to consider when calculating the monetary value of CBGI is the costs of existing and newly proposed infrastructure, including those of land required, permitting, design, creation, protection, restoration, monitoring and maintenance (Morris et al., 2021). Of these components, land may be by far the costliest component of implementing new CBGI or allowing existing CBGI to adjust with SLR, especially in urban areas where significant development may need to be moved to provide space for CBGI. However, climate change related hazards and other coastal hazards could reduce land values, and, therefore, perceived CBGI costs over time. After land, other key CBGI costs are design, permitting, creation, protection, and restoration. However, there are significant advantages to these costs when comparing CBGI to traditional/ hard engineering based coastal protection. These are that well-designed CBGI has considerable self-maintenance capacity, potentially reducing maintenance costs and infrastructure upgrades (Temmerman & Kirwan, 2015).

The New Brighton sand dune system protects not only the adjacent communities but also a significant proportion of low-lying eastern parts of Ōtautahi from potential tsunami flooding (Orchard, 2021). The dunes provide social benefits to both the local and urban community and to visiting tourists. Thus, the risk reduction and avoided damages are significant, and it is predicted that the economic value of the New Brighton coastal sand dune CBGI system is high.

6.8 Nonmaterial values results and discussion

This second part of Chapter 6 presents the results and discussion of the nonmaterial values that were assessed in the present study along with general discussion of the nonmaterial values of the New Brighton dune system CBGI as a whole.

6.8.1 Aesthetic value

A summary of the aesthetic value results for each sub-category analysed is provided in Table 21, while Appendix D contains the raw measurement data, statistics, and value calculation results from which this summary was derived.

Table 21- Overall aesthetic value of the New Brighton coastal sand dune system

Note: average scores per site are rounded to 1 significant figure

	Site 1		**Site 2**		**Site 3**	
	Measured value	Score	Measured value	Score	Measured value	Score
% cover of vegetation	80	3	77.67	3	96.09	3
% cover of indigenous species	11.56	1	11.00	1	16.09	1
Built features	1	2	0	3	0	3
Urban infrastructure/ development (incl. residential)	0	3	0	3	0	3
Litter presence	2	2	2	2	0	3
Beach width at high tide	17	3	18	3	16	3
Average score (1.s.f)		2		2		2

The results for the percentage vegetation cover and indigenous vegetation cover were similar between study sites. All three sites received the highest score (3) for percentage vegetation cover and the lowest score (1) for percentage indigenous vegetation cover. This indicates that on one level there is sufficient vegetation cover on the New Brighton coastal sand dune system to provide a broadly natural, pleasing aesthetic to general beach users. However, this vegetation is of little value in terms of indigenous *natural character* (c.f. RMA 1991) and tikanga Māori value. The introduced nature means the dune vegetation provides little support for tikanga Māori traditions, and very little mahinga kai resources. The replacement of indigenous with introduced vegetation can be considered degradation in these contexts, thereby diminishing the well-being support the dune system can provide. In terms of determining aesthetic value, vegetation parameters analysed through a contextually appropriate lens indicate that the New Brighton coastal sand dune system scores only moderately overall, with significant scope for improvement via planting more indigenous mahinga kai species such as pīngao, harakeke, karo, and kawakawa vegetation (Matapopore Charitable Trust, 2015).

Table 21 includes the summary results for the number of built features and any residential development visible from the viewpoint of a beach user in situ, with the raw results in Appendix D. There was only one built feature visible in the study sites, this being the Surf Life Saving Club in study site 1. Figure 44 illustrates in situ views from a beach user perspective in the three study sites. These images provide supporting evidence that the only built feature or residential development visible from the beach is in study site one. The presence of this built feature decreases the aesthetic value of the site as it does not appear to be completely natural, thus its apparent beauty and wilderness value are diminished (Collins & Kearns, 2010). Aside from this one built feature in study site 1 the New Brighton coastal sand dune system does an effective job of blocking views of urban infrastructure and other built features including residential development.

Figure 44- Images taken of each study site from the beach which give an indication of built features and residential development present

Note: the source of these images is author's sister (Thompson, 2022)

To maintain this effective blocking of urban infrastructure and residential development it is important that the coastal sand dune system maintains its height, as well as no more coastal buildings being built on the seaward side of the dune system. To enhance the aesthetic value of the New Brighton coastal sand dune system in regard to built features, the existing built features on the beach would need to be removed. However, the benefits of some built features for the safety of beach users in this urban beach context may outweigh the importance of naturalness aspects of aesthetic value. The surf club and fenced beach accessways at sites 1 and 2 fit this safety criteria whereas above-ground concrete outlet pipes elsewhere along this coast might not fit these criteria. Therefore, for an urban beach the New Brighton coastal sand dune system as represented by the study sites examined is as good as it gets in terms of built environment aesthetics.

The quantity of litter was measured in situ on 22nd September 2021. The results for the amount of litter are displayed in Table 21 and in Appendix D. These results indicate that, in terms of observable litter, New Brighton beach is a clean beach with minimal litter present. The limitations of these results are that they were gathered on one ‘snapshot’ day, with the litter reality potentially significantly varying between days and seasons depending on human activity and environmental conditions such as wind. In future studies it is recommended that this variable is measured on multiple days across different parts of the week and in different seasons, with averages and variabilities in results calculated to gain a more complete picture of litter levels on New Brighton beach.

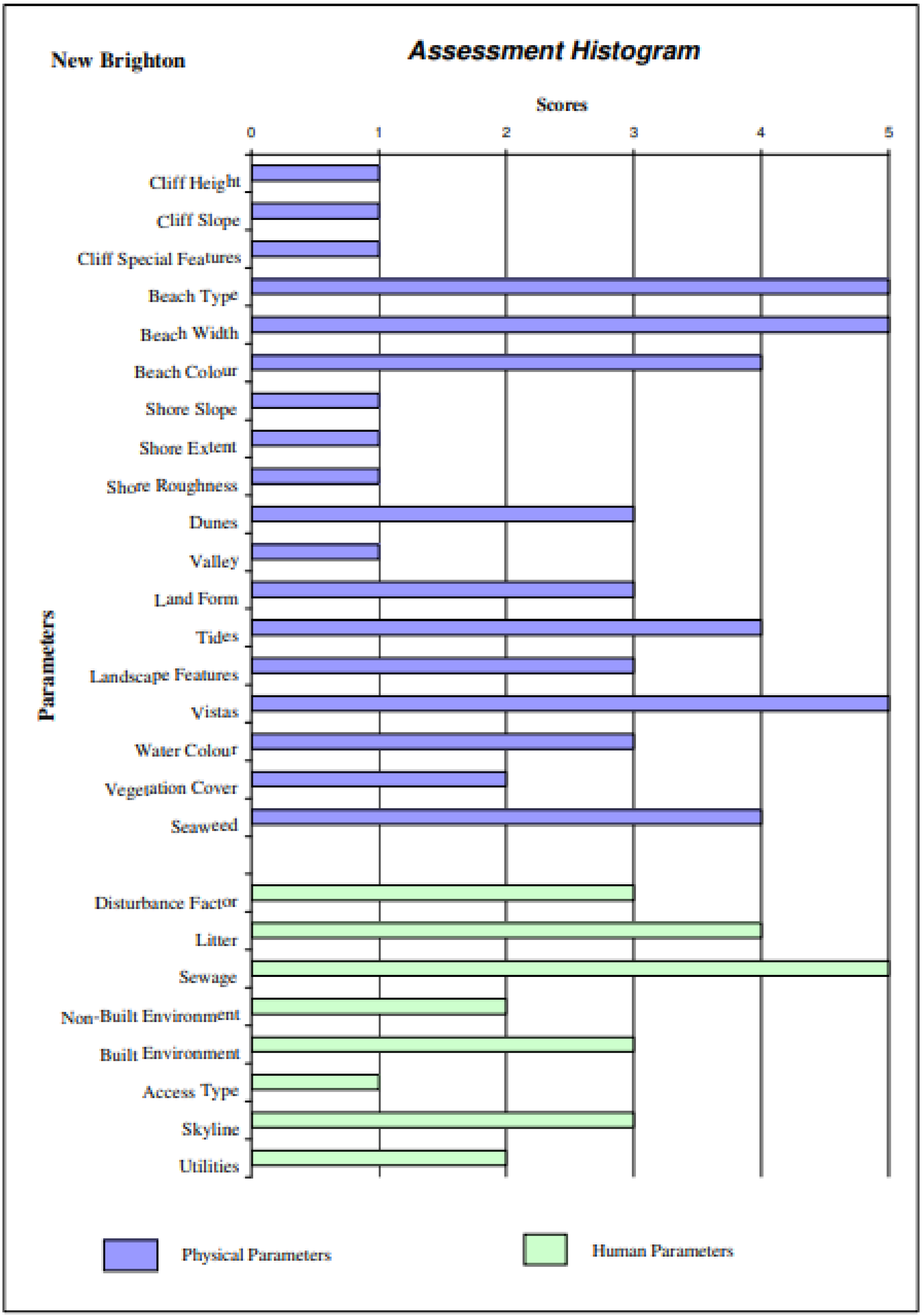
The beach width at high tide at each study site was measured in situ with results summarised in Table 21, and in Appendix D. Beach widths on gently sloping sand beaches can vary significantly depending on the barometric pressure on the day and the tidal cycle, both of which affect daily water levels (Masselink, Hughes & Knight, 2014) as well as in response to medium-term storm erosion and recovery cycles (i.e., weeks to months). In future research, a more complex picture of beach width could be gained from taking the high-tide beach width measurements on several days across spring/ neap and perigean/ apogean cycles and in different seasons throughout a year to form a picture of average high tide beach widths and variability in this parameter. The beach width results gathered in this study indicate that New Brighton berm is of sufficient width at high tide to form a valuable aesthetic resource. This resource could be degraded with erosion induced by changes in the balance between sea levels, sediment supply and wave conditions as a result of climate change, meaning it is an important parameter to monitor (French, 2001; Garcia-Mora et al., 2001; Tonkin & Taylor, 2021).

Overall, the general aesthetic value of the New Brighton coastal sand dune system, evaluated via the three case study sites, was found to be medium (2.5 out of a potential score of 3) (Table 21). This is because the dunes have a high percentage of vegetation cover, a lack of on-the-beach built features and visible hinterland urban infrastructure and development present from the perspective of users standing on the beach, low amounts of observable litter, and enough beach width for recreation at high tide. However, when cultural and ecological context are taken into account, there is significant room to improve the aesthetic value by planting more indigenous plant species including sand binders and mahinga kai species. This would have multiple benefits, by simultaneously enhancing the ecological, coastal protection, tourism/ education, sense of place, and well-being values of the dune system. Thus, the Māori value of the New Brighton coastal sand dune system would be enhanced alongside the aesthetic value for beach users distinguishing between native and introduced plant species. The CCC park rangers are actively working towards this shift in vegetation quality so that, with time, the New Brighton coastal sand dune system will have improved aesthetic value.

The aesthetic value results gathered for the purpose of this study differ from the scenic value results of Langley and Hart (2007) (Figure 45), and not just because of the difference in measurement approach as explained earlier in this chapter, with the present study being better contextualised in that it considers Te Ao Māori. Langley and Hart's (2007) results indicated that around 15 years ago the New Brighton beach had a low scenic value because of degradation from infrastructure. They recommended to increase the scenic value the dune system would need to be restored to a more natural state and the infrastructure surrounding the beach would need to be upgraded. Much work has occurred between times to remove the ugliest infrastructure from the active beach system, to enhance the dune vegetation cover and to hide or enhance remaining infrastructure using seaward plantings, such as around the central New Brighton pier area (Dr Deirdre Hart, University of Canterbury Professor of Coastal Science, *pers. comm.* 1/11/22).

Figure 45- Previous research (2007) aesthetic assessment results for New Brighton Beach

Note: this approach is based on that developed by Professor A.T. Williams, as adapted for a NZ context by Langley & Hart (2007, p. 44).



The results from this study indicate that ongoing aesthetic enhancement potential remains in that the dune system could be restored to a more natural state by planting more indigenous species. A limitation of the current research is that due to the breadth of parameters needing examination in this first study of its kind, aesthetics were measured at only the three case study sites. These may not represent the aesthetic value of the whole New Brighton coastal sand dune system, such that in future research it is recommended more study sites could be investigated.

Another limitation with the approach used in this research is that it relied on one researcher's field observations and has not been cross-checked (Mu, 2013). This could mean some aesthetic qualities of the beach went unnoticed. An additional consideration is that aesthetic values vary between individuals, with the subjective parameters employed in this study having been derived in part from studies of population-level perceptions. This means that individual differences in peoples preferences in regards to beach aesthetics are not taken into account. For example, when determining how vegetation contributes to the New Brighton dune system aesthetic value, the scoring system is ultimately subjective, with individuals having different thresholds for low, medium, or high value aesthetics. An effort to counter this problem was made in quantitatively measuring percentage cover and indigenous cover types, which arguably translate into tikanga Māori and natural character assessments. But ultimately the results provide a general overview and not a set of scores that are necessarily meaningful at the individual level for each visitor to the dune system. However, these limitations are deemed accepted for the current CBGI scope of the present research.

Drawing comparisons between the results from this study and the Langley & Hart (2007) study it can be seen that their approach contains many more measured parameters (Figure 45) and, in that respect, produces more detailed results on scenic values, which was the sole focus of their study. However, their study did not consider Māori perspectives on the quality of the dune system. When critically analysing both approaches, for further research focussing on aesthetic or scenic values alone, a hybrid methodology merging the two approaches could be beneficial. This could include the level of detail and parameters measured by Langley & Hart (2007) alongside the culturally contextualised parameters of this study. However, for the purposes of CBGI co-benefits analyses, which are necessarily far broader than aesthetic or scenic assessments alone, something closer to the approach presented in this research is recommended, since many other non-aesthetic parameters also need to be assessed and balanced alongside aesthetics.

Finally, it would have been valuable to this research if a greater level of Māori consultation could have been achieved in terms of obtaining primary data on the Te Ao Māori view of beach aesthetics. Although a Māori ethics process was completed, no appropriate individuals could be found in working with Te Waka Pākākano | Office of Māori, Pacific & Equity. Thus, secondary peer-reviewed literature was relied upon to give consideration to Te Ao Māori. The results, therefore, comprise an initial attempt at formulating a contextuality appropriate approach to measuring the aesthetic value of the New Brighton coastal sand dune system in Ōtautahi. Research alongside and including indigenous scholars and community members is recommend as a next step in future research, as well as weighting these aesthetic characteristics of the New Brighton dune system when combining them to create an overall value (e.g. as done in section 5.2.1 for the coastal protection value). This could ensure that tikanga Māori views are weighted in favour, thus, the scores are more representative of indigenous worldviews.

6.8.2 Sense of place

Living near water promotes a shared sense of belonging, therefore, the New Brighton community is predisposed to developing a strong sense of place due to their shared proximity to the sea (Collins & Kearn, 2010; Völker & Kistemann, 2012). As explained earlier, aesthetics have a strong influence on the sense of place. Therefore, development that degrades coastal aesthetics can hinder or alter the capacity of someone to feel a sense of place at the beach (Collins & Kearns, 2010 & Peart, 2005). The aesthetic of a coastal environment is viewed as degraded if it is interrupted by human development such as urban houses or infrastructure in NZ. At a physical level, impacts of coastal development on sandy beaches include coastal erosion, fragmentation of native vegetation, and habitat destruction. While at a social level, impacts may include a loss of treasured landscape values, affordable housing, and consequently a sense of place (Collins & Kearn, 2010). Research has indicated that relatively untouched natural landscapes have a higher aesthetic value, thus, can promote a more positive sense of place (Collins & Kearns, 2010). However, it is important to understand that most coastal areas that appear to be 'natural' have been highly modified in the past. Interestingly, research indicates that if these natural looking modifications to the coastal environment were in the past (such as planting marram grass on the dunes) and these changes are relatively stable now, they can appear natural to many coastal users. Therefore, this implies that modified natural environments such as the New Brighton sand dune system can promote the same level of development of a sense of place in some people as a more natural dune system (Peart, 2004).

The suburb of New Brighton is a highly developed area; therefore, the visual amenity of the beach could be perceived as being negatively impacted, and consequently, the sense of place could be degraded. However, the coastal sand dunes block views of this development almost all the way along New Brighton Spit, providing a high '*wilderness value'* (Mr. J. Roberts, CCC Coast Care Park Ranger, *pers. comm.* 29/10/21). These dunes have been anthropogenically planted and modified in the past, however, they still provide high visual amenity and contribute to the feeling of wilderness of New Brighton beach. Therefore, the dunes help to foster a strong sense of place at New Brighton as they are perceived as natural and block the development that would disturb the feeling of wilderness one feels when undertaking leisure activities at the beach.

Immersive coastal leisure activities like swimming and surfing have been seen to offer unique cognitive and physiological benefits such as aiding the development of a sense of place someone may feel (Collins & Kearn, 2010). As discussed elsewhere in this chapter, New Brighton is home to numerous leisure activities such as community dune plantings, surfing, walking, running, rowing, kayaking fishing, and photography as well as many educational programs. These recreational activities help to foster a sense of place as they connect people to the area and each other (Remme et al., 2021).

Community dune plantings are a significant component of developing a sense of place at New Brighton as these activities connect neighbourhoods, build community connections, and subsequently enhance the social capital of the New Brighton community. Thus, when the community is faced with adversity, they can bond together and provide each other with resources and support (Wilson, 2012). This enhances whanaungatanga. Community dune restoration also enacts kaitiakitanga as the coastal dune system is being protected for generations to come.

New Brighton is of great cultural significance to tangata whenua (Drayton, 1992). New Brighton's Māori place name is currently Kaiaua, which means to eat yellow-eyed mullet or herring. However, it has had a multitude of names in its history of Te Karoro Inutai (coast dwellers), Te Karoro Karoro (seagulls), Te Kōrero Karoro (the seagull's voices - chattering seagulls), which is the sandspit at Brighton and Te Kai o te Karoro (the food of the seagull), an area in the southern part of the sandspit (Te Maire Tau et al., 1990). Māori place names as discussed in Chapter 4 of this thesis embody the relationship Māori have with a place (Nā, Maahanui Kurataiao Ltd, 2017) with these placenames indicating that mahinga kai has always been an important aspect of the New Brighton area (McMurtrie & Kennedy, 2012).

Ōrua Paeroa was a Māori village in North New Brighton located near the Travis Wetland. Ōrua Paeroa was known as the place where powerful eastly winds blew in from te moana (the ocean). Supporting the Māori place names of New Brighton, Ōrua Paeroa was used for mahinga kai and abounded with eels and birdlife as recalled in Ngāi Tahu traditions identifying that shark could be caught here at certain times of the year (Taylor et al., 1952).

Today, New Brighton is also home to mahinga kai such as toheroa, and pingaō which are used for weaving as well as rongoā such as harakeke and karo (Mr Greg Bennet, Waimakariri District Council and Chairperson of the Coastal Restoration Trust, *pers. comm.* 23/08/21; Matapopere Charitable Trust, 2015). The gathering of mahinga kai provides a spiritual connection to the land (Wheaton et al., 2020). As explained above, coastal waters are taonga and, therefore, are treasured places that inherently build a sense of place both spiritually and physically. Thus, the cultural components, activities and history that occur and has occurred in the New Brighton dune system also help develop a strong Tūrangawaewae.

Consequently, as found by previous research, many residents and visitors have developed a strong sense of place in New Brighton (Carass et al., 2020). It can be seen that the dunes are a significant contributing factor to this sense of place with Jason Roberts (CCC Park Ranger, *pers. comm.* 29/10/21) expressing the situation effectively in reference to the benefits of dunes: "*we take them for granted and we wouldn't understand all the benefits they provide until they were removed.*" This quote sums up the amenity dunes have in providing a sense of place to New Brighton residents and visitors. They provide a beautiful aesthetic, are home to recreational activities, and have deep spiritual and mahinga kai values. These components all contribute to the sense of place developed by residents and visitors of New Brighton spit alike. However, it is important to understand that a sense of place cannot be imposed or created by these measures, since the term sense of place has humanistic origins, it is complex and difficult to measure accurately, with individuals having different experiences of the world due to their ontologies and positionality (Gurran et al., 2006 as cited in Collins & Kearns, 2010). Despite this, it can be deduced in broad terms from supporting literature that the sense of place found in New Brighton has partly developed from and is strongly connected to the coastal dune system. Thus, the coastal dunes are an irreplaceable resource as they are an integral component of the mental well-being of the New Brighton community.

6.8.3 Touristic value

It had been deduced from prior literature that when tourists travel to a place to visit the beach, they do this because of the water quality, safety, facilities, absence of litter, wilderness feel, and scenic beauty of the area (Penn et al., 2016). The water quality results gathered from NIWA indicated that New Brighton was a safe beach to swim at 98% of the time over the past 5 years. Therefore, each study site gets a score of 3 for the water quality evaluation.

In general, the literature assessed implied that New Brighton beach was also a safe beach for swimming if the swell height was under 1m. However, due to the exposed nature of the beach conditions can change quickly. Additionally, on either side of New Brighton pier, there is a rip current, thus swimmers are warned to avoid swimming too close to the pier. Lifeguards patrol the beach during the summer months to ensure the safety of swimmers during the busier time of the year (Safeswim NZ, 2022). Safeswim NZ (2022) rates this beach overall as safe for swimmers due to the availability of these patrols, therefore each study site was scored a 2 out of 3 for beach safety.

In terms of facilities, New Brighton beach has parking, toilets, changing rooms with showers, hot pools, a pier, a public library, cafes, food carts, and surf lifesaving facilities. Therefore, there are adequate facilities, such that all three study sites were scored 3 in relation to the facilities available.

The aesthetic value measurements reported earlier in this chapter (Table 20) also provide an important component in assessing the touristic quality of the beach. As indicated earlier, the study site scores were medium.

When combining all the hedonic values of the New Brighton coastal dune system (Table 22), these values indicate that the tourism value of the New Brighton coastal dune system would be high. This is because the study sites have very good water quality, adequate and well-maintained facilities for visitors, and relatively good levels of swimmer safety and aesthetic appeal. Since swim safety and aesthetic value of the beach scored lower than the other two hedonic values, these could be areas to examine if aiming to achieve a very high overall level of touristic appeal. However, swim safety is affected by some relatively difficult to alter features of the built environment (the pier) interacting with the high-energy incident wave climate. For some beach users these constraints may be an appealing feature of these sites. For example, if you enjoy surfing, the bigger waves and rip currents that produce only a moderately-high swim safety characteristic for New Brighton may be a draw card, along with the lack of water crowding. The existing parameters which score highly can be maintained by prioritising terrestrial water treatment and marine pollution prevention, thereby maintaining high water quality, by keeping the beach clean from litter, maintaining the facilities, preventing new residential development in the dunes, and by preventing degradation of dune system including its geomorphic and ecological attributes.

Table 22- Combined scores of relevant parameters which give an indication of the touristic value of the New Brighton coastal sand dune system.

Note: average scores per site are rounded to 1 significant figure

Parameter measured	**Site 1**		**Site 2**		**Site 3**	
	Measured value	Score	Measured value	Score	Measured value	Score
Water quality	98	3	98	3	98	3
Safety	-	2	-	2	-	2
Facilities	-	3	-	3	-	3
Aesthetics	6.31	2.33	18.11	2.50	21.36	2.67
Per site overall average (1.s.f)		3		3		3

Limitations of this approach to measuring the touristic value of the New Brighton coastal sand dune system are that the measurements are made based on hedonic parameters. There are many other parameters that can influence tourism that are difficult to measure. An ideal approach would be to have measures of the monetary value of tourism in New Brighton combined with hedonic analysis, but this data does not currently exist. Undertaking the detailed investigation required to get a more complete picture of all kinds of touristic values for the study site is beyond the scope of this research, since the current project is seeking to gain an overview of many other values in addition to touristic ones. A detailed hedonic and non-hedonic examination of the touristic value of New Brighton beach is recommended should the local community decide to prioritise valuing and enhancing coastal tourism in the area.

6.8.4 Educational value

Numerous projects are being undertaken on the New Brighton dune system by primary through to secondary school children and university students, while the CCC and ECan also run educational workshops on these areas for both the community and school children (CCC, 2022). There are also community groups such as Coast Care which work to restore the dune system as well as educate others on the importance of the New Brighton coastal sand dune system. In addition, ongoing research is being conducted by organisations such as NIWA, Jacobs and Tonkin and Taylor, to assess the coastal protection value of the dune system and dune vulnerabilities to climate change effects. Therefore, it can be concluded that the New Brighton coastal sand dune system has a high educational value, with all three study sites given a score of 3 for this parameter.

6.8.5 Well-being value

Due to limitations in the health of the researcher the well-being components of the dune system could not be brought together here. It is recommended that this exercise could be undertaken in future research, using the extensive review of well-being values provided above. However, based on the review conducted in this study plus the earlier vegetation assessment results, which cover several key well-being related parameters, an initial comment on the well-being value of the dunes is possible. From a general perspective, it is known that the New Brighton coastal sand dune system has been severely narrowed by hinterland confinement and urban development. Also, despite the recent spinifex and pīngao planting efforts documented in Chapter 5, the dune system as a whole remains significantly degraded relative to the indigenous ecology that existed in the area at the time of the Black Maps in 1856. Thus, according to Te Whare Tapa Whā and Te Ao Māori frameworks, the well-being value it provides has also been significantly degraded, with much potential for improvement existing in terms of dune system restoration. This could be done by planting more indigenous plant species; by preventing further degradation from human activity such as walking over vegetation, building infrastructure on the dunes and/or the invasion of introduced species; and by allowing the dune system to widen across the coastal hinterland. The first two of these steps may be simpler to achieve along most of the New Brighton coast, while allowing the dunes to widen may be more achievable in areas backed by pine forest relative to those where the dunes border urban infrastructure and residences.

6.9 Summary of nonmaterial benefits and findings

Chapter 6 has explored, through methodological review and selected analyses, the nonmaterial benefits of the New Brighton coastal sand dune CBGI system. These include the aesthetic, sense of place, recreational, educational and tourism values, well-being value and lastly its material or monetary value. Such values are highly complex to measure due to their subjectivity. In terms of the scope of the present initial and wide ranging CBGI assessment, the aesthetic, recreational, touristic and education values of the New Brighton dune CBGI system were robustly quantified. In future, the sense of place and well-being values of dune system, somewhat explored in theory in this research, could be measured via in situ surveys, with more research and experimentation needed to determine the details of optimal monetary value assessment approaches.

7 Discussion and Conclusions

This chapter discusses the methodological development and results of the New Brighton dune system benefit assessment and what this means for the management of the New Brighton dune system moving forwards as well as where this research sits in the existing literature. A summary of the research findings is provided, followed by comments on the research context in terms of its applicability and limitations and, finally, future research and coastal management recommendations arising from this study are outlined.

7.1 Developing a methodology for valuing New Brighton dune CBGI

In successfully achieving the research aims, this study has developed the first wide ranging, NCP-based methodology applicable to assessing multiple CBGI values provided by the New Brighton coastal sand dune system of Ōtautahi. Perhaps in an ideal scenario, the multiple values provided to communities by CBGI like the New Brighton dunes would not need to be measured but rather they would be inherently appreciated. However, as with many other CBGI resources worldwide, the significant historic degradation of this dune system that has accompanied settlement and urban development demonstrates that evaluation frameworks are needed to ensure policy and decision makers recognise the importance of protecting nature, ensuring that 'it counts' in policy (Bresnihan, 2017).

Evaluation frameworks can consider a broad and complex range of nature values, combining them into a universally understood measure. A multitude of approaches to valuing nature exist, with many traditional approaches producing what amounts to an economic assessment. The disadvantage of a largely economic lens to valuing nature is that it can divert efforts away from nature protection motivations, where these were prime, and such traditional approaches also tend to exclude key socio-cultural and intrinsic nature values (Kadykalo et al., 2019; Montenegro, 2017).

Using an NCP approach to valuing nature, by contrast, enables a pluralistic assessment of the benefits of nature through contextual worldviews. Thus, NCP valuations can be diverse and integrative, while also being measurable and understandable by a variety of people and decision makers. Employing a diverse set of holistic values means the outputs from measuring the biophysical, sociocultural, economic, and health benefits of nature, can result in sustainable policy integration with shared responsibilities (Pascual et al., 2017).

The methodological development of an NCP approach to valuing the New Brighton dune CBGI was challenging due to the broad set of benefits provided by this system and the dearth of prior research into value aspects of the dune resource. Each benefit required development of a unique measurement methodology, identifying parameters and indicators that were both locally relevant and globally meaningful, with their assessment being reliable and repeatable. The benefits of the New Brighton dune system were grouped using the NCP categories of regulatory, material, and non-material, with the subcategories of ecological, coastal protection, and aesthetic values being measured in relative terms (i.e., specific to the New Brighton context) while the carbon sequestration value was estimated in absolute (transferrable) terms. The differentiation between relative and absolute measures is noteworthy since parameters with relative values need to be adjusted for the specific CBGI context where they are applied, while parameters with absolute measures are more readily transferable, with more minor adjustment, to environments elsewhere in NZ and globally. The flexibility of the NCP approach enabled both relative and absolute measures to be developed and applied, highlighting the utility of this lens for a diversity of CBGI types and locations. However not all New Brighton coastal sand dune system values could be measured accurately using either absolute or relative methods in the present study, with further methodological development recommended, proceeding on from this first, wide ranging baseline methods development and assessment exercise.

In this study the measurements taken to evaluate each NCP benefit were applied to three study sites on the New Brighton dune system, spanning 50 m either side in a longshore direction of an ECan beach profiling transect. It is noted that this exploratory and methods-development focussed thesis has employed only three representative study sites, comprising only a small proportion of the total New Brighton dune system. With multiple methods now critiqued, and suggested methods developed and piloted, a logical next research step would be to expand their application, measuring values and testing method reliability across a larger expanse of this dune system. This could be achieved using more study sites with a greater diversity of dune characteristics, or by testing remote-sensing-supported large scale value measurements across the entire dune system. For the latter, the methodology could be evolved to include false colour imagery vegetation classification, replacing or with classification support from the true colour UAV imagery quadrat analysis approach. False colour imagery methods were employed successfully by Case, Buckley, & Fake (2019) on the nearby Kaitorete Spit dune system, enabling the large-scale identification and differentiation of vegetation types and their percentage covers.

It is important to understand that, although the raw results produced during application of the NCP approach in this research are largely objective, the scoring systems used to classify the raw data are somewhat subjective and locally contextualised. Determining each set of scores was achieved via discussion with multiple experts and/ or referenced to measurements in published literature.

Nevertheless, depending in part on researcher positionality, this component of the methodology is flexible and arguably subjective as people tend to value nature subjectively based on their own wants, needs, and beliefs ((Drucker, Fleming & Chan, 2016; Morris, 2021). A degree of subjectivity in the scores applied is unavoidable as individuals have different values depending on their culture or ontologies (Creswell, 2014). However, this subjectivity also means that the assessment methodology is able to capture the current local state of an area's CBGI, with a view to which areas of CBGI exhibit the highest current value and which areas could benefit the most from enhancement. In effect, there is little point comparing the touristic value of New Brighton's coast to that of the northern Great Barrier Reef in absolute terms, but rather there is much to be gained in assessing the relative touristic values of different areas of Ōtautahi's coast in order to identify priority areas for conservation and enhancement of access and facilities from the perspective of district and regional coastal managers, planners, and policy makers.

This research has revealed that an NCP approach to measuring New Brighton dune CBGI benefits is appropriate and enables development of an evaluation framework that produces readily understandable results. The large variety of benefits identified could now be employed by local and central government to help shape decisions around coastal adaptation to existing and exacerbated climate change coastal hazards, thereby promoting more sustainable management of CBGI in systems like the New Brighton dunes. This research could also be used to better understand the value of dune systems throughout NZ, in line with growing international recognition of the diverse value range inherent to nature-based coastal environments and resources (Bridges et al., 2021).

The NCP approach developed here attempted to place importance on, and incorporate, Māori values for each benefit measured. This enabled indigenous viewpoints to be integrated into the ecological, coastal protection, carbon sequestration, sense of place, aesthetic, recreational and well-being values measured from the New Brighton dune system. Therefore, the NCP approach to valuing the dune system was contextually appropriate while also highlighting the importance of incorporating indigenous viewpoints into the coastal adaptation space (Kench et al., 2018; Urlich, White, & Rennie, 2022). The NCP framework for valuing nature promotes a significant variety of values to be measured so that the final synthesis values are diverse rather than narrow and only economic factor focused such as in other evaluation methodologies, including some ecosystem services approaches (Kadykalo et al., 2019). In conclusion, this research supports the recommendation of using NCP approaches when valuing CBGI environments due to its capacity to include many values as well as a focus on the incorporation of indigenous viewpoints throughout the value assessment.

Highlighting the importance of this research

This research has contributed towards filling several significant knowledge gaps. New terminology for CBGI was created in Chapter 2 out of a review of existing terms, and evidence provided that natural and nature-based infrastructure can exist and be very beneficial in coastal environments for hazard mitigation while bringing multiple additional benefits to human communities and coastal ecosystems. Development of the CBGI terminology is important since previous literature (Ghofrani et al., 2017; Jansen et al., 2014; Nesshover et al., 2017; Ruangpen et al., 2020; Zuninga et al., 2020) focussed on nature-based solutions providing benefit in terrestrial environments, with a poor level of recognition afforded to coastal ecosystems, including saltmarsh, dune environments, mangroves, and wetland areas, and to the CBGI benefits these features can provide to society. More recent literature from NZ and elsewhere is beginning to highlight the significant nature-based solutions that exist in coastal environments, and their richness in terms of human benefits (Sutton-Grier et al., 2015; Bridges et al., 2021; Morris et al., 2021; Van Coppenolle & Temmerman, 2020). However, the relative lack of research and awareness amongst practitioners regarding nature-based solutions in coastal environments remains a problem in NZ (Alestra et al., in press) compared, for example, to the long-standing appreciation of the values associated with terrestrial blue-green infrastructure and/or the coastal protection utility of hazard zoning or hard engineering in urban settings.

The CBGI definition developed here could help ensure that in coastal environments nature-based solutions receive the recognition they need moving forwards in a global context where traditional hard-engineered approaches to coastal protection are significantly damaging ecosystems while also being viewed as a preferred approach to coastal protection by many consultants and community members alike (Cunnif & Swartz, 2015; Bridges et al., 2021). Recognition of nature-based solutions in coastal environments is important since these offer more sustainable approaches to coastal protection that can enhance (as opposed to damaging) coastal ecosystems, while also providing multiple additional benefits to people and planet. This research adds support to the emerging body of work seeking to recognise nature-based solutions in coastal spaces.

As discussed earlier, the NCP approach to valuing nature is suitable for valuing CBGI because it provides a variety of pluralistic context-specific measured values as an outcome (Hill et al., 2021; Kadykalo et al., 2019). The research conducted here is also unique as the NCP approach to valuing nature is only just being introduced into NZ literature (Ausseil et al., 2022). The Parliamentary Commissioner for the Environment identified a significant gap in NZ knowledge on how changes in the environment relate to people's well-being in 2019. This gap still exists despite the legal obligation to report on the state of the Environment since 2015, and the focus of the current government on 'well-being' budgetary decisions that include natural capital (New Zealand Treasury, 2019; Parliamentary Commissioner for the Environment, 2019). The research undertaken in this thesis contributes to filling this well-being and environment relationship knowledge gap while also influencing the field of nature conservation research with the more recent NCP approach to valuing nature which emphasises the incorporation of indigenous viewpoints into the values assessed (Hill et al., 2021). It is important to pluralistically value our coastal ecosystems, as globally they help regulate the climate, clean our water, recycle nutrients, purify our air, maintain our soil, and provide us with food (Fisher et al., 2017). Without indigenous viewpoints, the values of these ecosystems are not relevant at a local scale and informed decision making cannot be used to effectively protect them via policy changes if certain groups of people are marginalised (Ausseil et al., 2022; Kench et al., 2018; Urlich et al., 2022).

The act of valuing nature can be an important research contribution in itself. For example, in areas where the values of nature have been assessed through a NCP framework, such as for seagrass in Pacific Island countries, it has been found that having more cultural awareness of the benefits of seagrass can strengthen policies to protect these ecosystems (McKenzie et al., 2021). While in areas where values have not been measured, such as with the New Brighton dune system CBGI prior to this research, degradation of these ecosystems has occurred as connections between the quality of human life and the quality of dune environments were not apparent to many. Therefore, no policy was developed to protect the multiple values associated with the dunes.

Ironically, the more degraded a dune environment is, the fewer benefits it can provide and, therefore, the less likely people may be to recognise the connection to human quality of life and thus, to protect or enhance the dunes. A significant research gap exists in terms of NZ dune environment conservation concerning these systems CBGI values. This research focussing on CBGI values of the New Brighton dune system using a NCP framework represents a first attempt at clearly highlighting why coastal ecosystems need to be recognised, monitored for changes, protected, and enhanced in the context of climate change adaptation option assessment and planning. It is clear from this research that coastal ecosystems need to be conserved due to their extensive benefits to people and environment. This new systematically gathered knowledge regarding dune benefits could be employed to underpin changes in policy and to stimulate community action to conserve dune and other coastal BGI environments given there is clear evidence as to why these environments benefit people and need protection. This research adds to the very few studies completed globally that recognise the CBGI values of dune and other coastal systems (Bridges et al., 2021; Morris, 2018; Everard et al., 2010).

This thesis also provides a detailed critical assessment for other researchers of how dune system values can be measured through a NCP lens. As well as this methodological contribution, the results provide example CBGI benefit data specific to NZ sand dunes. The knowledge gained from this research, namely the CBGI definition, the CBGI adaptation options for dunes, the methodological approach of valuing CBGI through a NCP lens, and the results obtained describing the levels of each value for the New Brighton dune system, could help inform and reform future coastal planning, adaptation, and management policy in NZ.

An example of the type of policy where this knowledge could be applied is in the NZCPS. Currently, this statutory document indicates that it is important to have "*preservation of the natural character of the coastal environment, including protection from inappropriate subdivision, use and development*" (NZCPS, 2010, policy 13). The problem with this objective is, like in the previous iteration of the NZCPS, there is no firm hierarchy in relation to this and other objectives, such that potential for misinterpretation as to what to prioritise in coastal management exists (Rennie, 2009). Additionally, the term natural character is ambiguous (Froude, Rennie & Bornman et al., 2010). A clear definition of CBGI could be incorporated into the policy statement, with that alone potentially raising awareness of the different types of CBGI here in NZ. Each local council plan that sits under the NZCPS could thus promote local and national scale knowledge on CBGI.

Another example of a statutory document that could incorporate the concept of CBGI is the recently released National Adaptation Plan 2022. This plan discusses "*Government-led strategies, policies and proposals that will help New Zealanders adapt to the changing climate and its effects – so we can reduce the potential harm of climate change, as well as seize the opportunities that arise*" (Ministry for the Environment, 2022, p10). Despite this promising objective, this plan does not include CBGI as an adaptation option and, although it discusses managed retreat and its associated implications, it does not discuss processes such as coastal squeeze which have significant detrimental effects on CBGI resources. The present research provided defines the terminology and an assessment approach that could be employed to provide coastal ecosystems a stronger and clearer position in such policy documents.

7.2 Synthesis of the New Brighton sand dune CBGI NCP results

Application of the NCP methodology developed in this research yielded various benefits scores summarised in Table 23 for the New Brighton coastal sand dune system.

Table 23- Summary scores for New Brighton coastal sand dune system values measured in this research

Note: value scores in this table range from 1 = poor (red), to 2 = average (orange), and 3 = good (green). Note that, although these value scores were the subject of extensive methodological review, measuring the well-being, monetary, recreational, and sense of place values of the New Brighton coastal sand dune system were deemed beyond the scope of this initial broad investigation, so these are omitted from this final synthesis table.

	Site 1	Site 2	Site 3
Ecological	1	1	2
Coastal protection	2	2	3
Carbon sequestration	1	1	1
Aesthetic	2	2	2
Touristic	3	3	3
Educational	3	3	3

Overall, the individual results for each of the measured dune values are helpful for clearly highlighting where the dune system currently has higher values and where there is room for improvement via coastal conservation and management measures. The colours of Table 23 indicate, at a glance, the spatial (per site) and value patterns that exist. Through the approach of the NCP lens, the justification for the low (red), medium (orange) and high (green) value scores were developed and explained throughout Chapters 5 and 6. Table 23 provides a very simple and easy-to-process overview of a more detailed and complex underpinning assessment of values. This allows the general public and decision-makers to gain a high-level understanding of the range of values offered by the New Brighton dune system CBGI, as well as a quick overview of where the values are low or high, this helps to determine where dune conservation efforts can be focused.

The individual value scores were not created to be combined into a single final score for the value of the New Brighton dune system CBGI since different communities and individuals value some benefits more than others. The detailed analysis underpinning this table provides the level of information for coastal managers and planners wanting to design CBGI recognising policy, or conservation and management practices and programmes. It should be noted that different components of the dune system were measured on relative scales and that some parameters were included in multiple individual value assessments since they contributed to more than one NCP value (e.g., some vegetation parameters fed into the ecological, coastal protection and indigenous value assessments respectively). Combining all scores into one would mean some parameters influenced the final result more times than others, making the final score questionable. Instead of producing a single score, the next section of this chapter discusses how these multiple value scores can be viewed together as a useful system.

Overall, there is a lower proportion of green compared to orange and red (7 green versus 11 orange and red) value scores in Table 23. The study site dunes scored consistently highly in the touristic and educational value categories, with study site 3 scoring highly in the coastal protection value category. Medium scores were given to the aesthetic values across all sites, for the coastal protection values of study sites 1 and 2 and the ecological value for study site 3. Low scores were given for the present-day carbon sequestration rates of all study sites (compared to these sites historic potential), and for the ecological value of study sites 1 and 2. Clearly a range of scores exists across the different values provided by the New Brighton dune system. The scores for some values are significantly interrelated, since variables such as percentage vegetation cover comprised a component of ecological, coastal protection, carbon sequestration, and aesthetic evaluations. Therefore, it is important to investigate when looking at these simplified scores the underlying reasons why these values scored the way they did, as improvement to certain components of the dune system (such as percentage vegetation cover) could provide swift improvements in several value scores.

It is important to note when analysing this results synthesis table that the recreational, sense of place, well-being and monetary values of the New Brighton dune system were explored but not scored in this research. These additional values, as discussed in Chapter 6, would contribute significantly to the overall NCP picture of the New Brighton dune system. These unmeasured values are also interrelated with the measured values in Table 23. While some of these values could be measured through future NCP work on CBGI (e.g., well-being and touristic values), quantifying others such as sense of place would be problematic due to its humanistic origins (Gurran et al., 2006 as cited in Collins & Kearns, 2010).

The large array of benefits provided by the dune system CBGI, such as coastal protection, ecological, aesthetic, touristic, recreational, educational, monetary, well-being and sense of place values, extend well beyond the values that a hard-engineered approach to coastal protection could provide in New Brighton. It is, therefore, important to note that this scoring system is relative to CBGI and, if this methodology were to be used for a hard engineering approach to coastal protection, the results produced would more than likely reflect poor to non-existent values in most categories.

7.3 Looking to the future: how to maintain, enhance or repair New Brighton dune CBGI

There are many options in the coastal adaptation space to ensure that the values measured through the NCP approach for the New Brighton coastal sand dune system are enhanced, repaired or maintained. The general range of options available for sand beaches and dune systems anywhere were outlined in Section 2.5. Given the assessment information gathered from the case study sites, those most appropriate to New Brighton are now discussed below.

Firstly, discussions with experts reveals that open coast environments such as New Brighton "*do not have as many options for coastal adaptation as people may think*,.. due to *the length of the coastline meaning that discreet management options (walls etc) would not be suitable over long time frames. Similarly, these options will likely degrade the values of the beach and dune*" (Mr. T. Simons-Smith, Principal Advisor Coastal ,CCC, *pers. comm*., 12/09/22). These discussions further emphasise the importance of protecting the New Brighton coastal sand dune system through CBGI adaptation approaches as it appears to be the only viable option for coastal protection in New Brighton that includes maintenance of the dune system values. The Table 23 results further indicate the desirability of enhancing the ecological, coastal protection, aesthetic and carbon sequestration values while maintaining educational and recreational values.

To maintain the overall value of the New Brighton coastal sand dune system "*space will be required for migration of the dune system with climate change if the aim is to enable the dune system to migrate landward and continue to function as a coastal defence* (Mr. T. Simons-Smith, Principal Advisor Coastal, CCC, *pers. comm*., 12/09/22). Allowing space for migration of the dune system inland could ensure the dune system can remain, providing coastal protection during storm-cut erosion events while the system is also subject to SLR, and erosion enhanced by climate change. Further benefits of enabling migration space include enabling the dune system to have more vegetation biomass and ecological habitat, higher carbon sequestration capacity and a more natural 'green' aesthetic (Orchard & Schiel, 2021). Allowing the dune system to have space to widen and migrate could also promote high ecological and aesthetic values as well as greater recreation space and well-being values. This is because there will be more space for native sand binding vegetation plantings which are rongoā and mahinga kai to Māori, as well as enhancing the area of habitats for native species and increasing the aesthetic and touristic value of New Brighton as it takes on a more natural aesthetic. Alongside enabling migration inland, further CBGI adaptation options of plantings of native sand binding species with additional fencing to support people management and sediment deposition on the foredune will ensure the values of this dune system remain intact with climate change (Mr J., Roberts, CCC Coast Care Park Ranger, *pers. comm*., 29/10/21 and Mr P., Borcherds, CCC Coast Care Park Ranger, *pers. comm.*, 12/10/21).

By contrast, adaptation options that could damage the natural functioning of the dunes such as engineered hard cores are not recommended as these would prevent migration of the dune system inland with climate change induced shoreline transgression (Nordstrom, 2018). This method would also reduce the ecological value of the dune system, with the engineered core of the dune ending up functioning like a sea wall (Nordstrom, 2018). Another, more traditionally popular but less sustainable option would be to implement built coastal protection infrastructure with the hope of protecting the dune system and its associated values. Long term, as discussed in Section 2.5, and supported by previous research findings (e.g., in Bridges et al., 2021; Cunnif & Swartz, 2015; French, 2001; Sutton-Grier et al., 2015), sea walls are very expensive to maintain and act to degrade the CBGI of sand beaches and dunes, leading to a loss in amenity value.

Overall, it can be deduced from this research that all values of the dune system are inherently tied to one another and work together to create a significantly valuable coastal protection resource, which is irreplaceable. The dune system is already fragile due to the heavy anthropogenic stressors of urban development and prior dune vegetation degradation in New Brighton. As discussed, implementing a hard-engineered structure would likely severely degrade this CBGI, causing all values to be lost. Therefore, it is important that these values are recognised through methodologies such as that developed in this research, and necessary actions to protect the dune CBGI are taken at central and local government and community levels.

Recognition of coastal sand dune values are promoted by assessments like that conducted here. The resultant enhanced recognition of CBGI values could be the turning point towards a paradigm shift in thinking in NZ towards a more sustainable approach to coastal adaptation. In response to the question of why valuing CBGI was important, the principal coastal hazard expert from the Christchurch City Council stated “*When it comes to community engagement, it’s important that we work to educate people about the full range of options on offer. People tend to know more about options that they have seen in practice and in NZ these tend to be ‘hard’ options*”. This summarises why this research is so important and further research in this field is needed.

7.4 Summary, recommendations, and conclusions

This research has developed a methodology via which the various values of the New Brighton coastal sand dune system could be measured in Ōtautahi. The research aim was achieved by firstly discussing the history of terms related to BGI, including how traditionally there has been an inland or terrestrial environment focus in research on nature-based solutions to hazard management. Hence, this research created the term CBGI to emphasise that nature-based solutions can be situated in coastal environments, working effectively there to reduce hazards and provide a multitude of benefits to local and extended communities alike. This thesis now comprises one of a small group of recent studies supporting the use of BGI in coastal environments, studies which can hopefully catalyse a paradigm shift in understanding of the utility of nature-based solutions in coastal spaces for adaption to climate change.

This research then went on to investigate different types of coastal protection with a focus on CBGI adaptation options related to coastal sand dunes, such as dune planting, beach renourishment, sand dune fencing, dune thatching and resistant sand dune cores. It provided a summary of these types of CBGI with the strengths and weaknesses of each approach explained through a case study. This section also highlighted and discussed why CBGI could be a better adaption solution to coastal hazards compared to hard engineering coastal protection infrastructures such as sea walls and groynes in sand beach environments. The literature review provided would be of use in Ōtautahi and in cities with similar coastal environments as it provides options for how to maintain the values of dune systems in the face of the increasing acute and chronic stressors of climate change. The CCC could use this information to determine how best to maintain the integrity of the New Brighton dune system while also gaining an understanding of the limitations of traditional engineered approaches to coastal protection and how the implementation of these could potentially degrade the value of the dune system while also being expensive and unsustainable in such an environment.

Once CBGI had been defined and compatible approaches to coastal protection explained, this research then determined how the different values of the New Brighton coastal sand dune system could be measured. It was decided that the NCP approach to valuing nature was most appropriate as indigenous viewpoints were an inherent component of each value measured under this framework. They were not compartmentalised like other traditional valuation approaches to valuing nature, such as in the ecosystem services approach. Therefore, a NCP framework was selected to investigate the coastal protection, ecological, tourism, educational, recreational, aesthetic, well-being, sense of place and monetary values of the New Brighton coastal sand dune system.

An extensive review of local, national, and international literature, alongside interviews with experts, aided the development of the NCP methodology applied to each value category, with application involving further local literature reviews, interviews with experts and field area analysis for 3 sites chosen to represent the New Brighton dune system. These study sites were located over existing ECan beach transects, with 30 years of pre-existing profile data available, while a UAV was used in situ to create 3D orthomosaiced images of the study sites.

A simple scoring system was then devised so that each NCP value could be scored out of 3, based on the diversity of raw data types and with 3 being the highest score and 1 being the lowest score across all values. The values were deduced from the analysis of beach profiles and the 3D orthomosaiced images of the study sites created from in-situ UAV analysis. Within the scope of this thesis, the ecological, coastal protection, carbon sequestration, aesthetic and educational values were successfully measured based on the data gathered and the NCP valuation framework, with detailed critique and recommendations provided for how future research might assess key remaining CBGI values where data gathering was beyond the present research scope. Overall, the NCP approach proved helpful in providing a contextual approach to determining these values, with additional recommendations for research with tangata whenua to extend the analysis beyond the positionality and cultural frame of the present researcher.

The results from this NCP assessment of values were measured both relatively and absolutely. The relative scores indicated that the ecological value of the New Brighton coastal sand dune system was low to moderate, the coastal protection and aesthetic values were better, (scoring 2s and 3) but still with much room for improvement in their parameter details, the carbon sequestration ability was low (1), and the educational and touristic value of the study sites were high (3) (Table 23). The ecological value of the New Brighton coastal sand dune system was generally low due to a significant proportion of the dune system being degraded for urban development, including narrowing of the dune system and native vegetation losses alongside historic plantings of marram grass, which is now the predominant vegetation type on the foredune. To enhance the ecological value of this dune system, space is required to allow dune migration landward over time. Also enhancing the vegetation area and native plantings by the community and the Coast Care group could be conducted to enhance the habitat for endangered native species and provide mahinga kai resources for Māori. It is important to note that these plantings would be best planted following methods described in Boxes 5 and 6 (see Chapter 5), and that fencing is recommended to protect these young plants from human trampling.

The coastal protection value could be enhanced in much the same way; however, the native sand binding plants provide a different service of acting to reduce storm-cut erosion and trap wind-blown sand to grow the sand dune system. Space would be needed in the coastal hinterland for the dune system to maintain its coastal protection value as coasts are naturally dynamic and, therefore, as SLR occurs the dune system will need space to migrate landward, maintaining or enhancing the dune system's cross-shore width. Width is a fundamental component of a dune's ability to provide coastal protection.

Other values that were measured include the carbon sequestration value, this could be enhanced again by allowing the width of the dune system to widen while also increasing the overall biomass of the ecosystem through more plantings and or conservation practices such as fencing, weeding, and pest management. Plantings should focus on species that exist in the fixed dune habitat which subsequently have the ability to sequester and store carbon such as karo, taupata, harakeke and tī kōuka. Maintenance and enhancement of the aesthetic value of the dune system includes action such as maintaining a healthy ecosystem with native flora present alongside ensuring that built developments do not occur in sight of beach users. This means the dune height must also be maintained.

The educational and touristic value of the dune system relies heavily on external factors to the dune system, however, ensuring that the importance of the dune system is promoted and recognised will ensure that further research is conducted in this area while ensuring the aesthetic and hedonic values of the dune system are maintained. The overall requirements to maintain the values of the New Brighton coastal sand dune system would need to be discussed with the community as managed retreat would need to occur with time and the socioeconomic gains and losses involved with making this approach could be very high.

Overall, this research is valuable as it provides baseline knowledge on the values that dune CBGI does and could provide in Ōtautahi. This is not only important but necessary if this natural infrastructure is to be maintained or enhanced or recognised, by both government organisations (decision makers) and communities, as an important coastal protection infrastructure. Additionally, it begins research here in NZ on how to measure CBGI values. Although additional research and refinement is needed, this thesis contributes towards the growing appreciation for a wider view of coastal system values and a shift towards pluralistically valuing more natural and sustainable approaches to coastal protection.

Further research and CBGI management recommendations

Further research building on this study could examine how to accurately measure the social values of NCP. As explained, some cannot yet be quantified accurately (e.g., sense of place) but the well-being value could certainly be measured. Over time the well-being research field has increasingly moved away from definitions that depend on personal health parameters alone, to focus more on holistic indigenous well-being frameworks that incorporate the health of whenua as a fundamental component of human well-being. In an Aotearoa NZ context, measuring such socio-cultural values would require robust consultation with local iwi.

To minimise the subjectivity of valuing CBGI and to ensure that all the benefits of CBGI are recognised and accounted for appropriately, it is recommended that future research is undertaken by a team of multidisciplinary and, ideally multi-cultural, researchers. Having a diverse research team could minimise the effects of individual researchers' positionalities, while ensuring values were considered through a multifaceted lens.

Additionally, future research could focus on how to weight these values of CBGI assessment methodology, meaning they can be combined more accurately to paint a simpler picture of the complete value of the dune system. This could be done by determining which values or components within values are more important than others. For example, this was completed in section 5.2.1 of this thesis, and it is recommended that this would be included in all values assessed.

Research could also be undertaken by adapting the NCP methodology to measure the values of other types of CBGI such as salt marshes and wetlands. The methodology would have to be significantly adapted to suit specific CBGI and the area where it was located. For example, the methodology would need to be adapted to suit the type of CBGI, the severity and frequency of the hazards it was exposed to, the number of assets at risk, the climate, the values of the community, and the specific values of that type of CBGI. This would be valuable research to undertake in Ōtautahi, as similar to the CBGI of coastal sand dunes, ways in which other types of CBGI could be enhanced or maintained could be detected by implementing this methodology to determine the various values of these CBGI. Using the NCP approach to valuing other types of CBGI would also promote recognition of these CBGI values in times when coastal adaptation is a topic with many discussions about its future occurring.

From the research conducted in this thesis, further recommended management for the CBGI of the New Brighton coastal sand dune system includes some managed retreat to allow the dune system to migrate inland with SLR. This, alongside the CBGI adaptation options of further plantings of native sand binding species on the foredune, plantings of native woody species in the back dune and fencing to protect these, and management of pedestrian access heights, would promote the physical protection of this dune system and its values. Very importantly it is recommended that further monitoring of the dunes' values is conducted and repeated to ensure that both the public and stakeholders are aware of what is happening to the value of the dune system CBGI over time. Awareness of the significant value of CBGI could promote protection and restoration efforts by all.

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Appendix A- Māori ethics application

<table>
<tr><td>Date: 05/06/2021</td><td>College: Te Rāngai Pūtaiao | College of Science
Department/School: Te Kura Aronukurangi | School of Earth and Environment</td></tr>
<tr><td colspan="2">Principal Investigator: Katie Jane Thompson. School of Earth and Environment. Kth77@uclive.ac.nz

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Derek Todd (co supervisor). Senior Coastal Scientist, Jacobs Engineering (external to the University of Canterbury). Derek.todd@jacobs.com
Cultural Advisors, if any:

Please note if you have sought advice from NTRC, or other mana whenua representatives:</td></tr>
<tr><td colspan="2">Project Title: Assessment of existing Blue-Green coastal infrastructure (BGCI) in Ōtautahi from Te Riu-o-Te-Aika-Kawa to Te Onepoto.</td></tr>
<tr><td colspan="2">Concise description in lay terms of the proposed project, including brief methodology (up to 1 page):

Research aim: This research aims to investigate the amount and value of BGCI that already exists in Ōtautahi coastal environments from Te Riu-o-Te-Aika-Kawa to Te Onepoto and thus, the viability of implementing more BGCI to aid climate change adaptation. To achieve this overarching purpose the research has been broken down into three main objectives as follows.

Research objectives

Define BGCI
Provide a clear definition of BGCI that describes its purposes of coastal hazard mitigation plus co-benefits.
Identify the different types of BGCI used globally and summarise the strengths and weaknesses of each approach.
BGCI Values
Identify values of different BGCI used globally.
Determine what the ‘value’ of each BGCI type is, focussing on its ability to protect coastal settlements from hazards (with a primary focus on coastal inundation and coastal erosion), and to offer co-benefits such as ecological, cultural, social, and economic. From this ascertain the ‘coastal hazard mitigation value’ (primarily coastal erosion and inundation) of the different types of BGCI in Ōtautahi.</td></tr>
</table>

- Create a methodology which can be used to measure and rank the 'value' of different types of BGCI

Case study of BGCI in Ōtautahi

- Undertake a GIS-based exercise to create a database of where BGCI currently exists in Ōtautahi (from Te Riu-o-Te-Aika-Kawa to Te Onepoto including the Avon-Heathcote Ihutai Estuary). Ground truth this using a handheld GPS (extent), GNSS (elevation) and UAV for aerial imagery.
- Based on the methodology developed in Objective 2, attribute a 'value' to the BGCI currently in place in Ōtautahi. Quantify the level of protection that different BGCI is providing (e.g. stopping overtopping up to X% AEP event)
- Discussion and conclusion on the existing BGCI including ways to improve or enhance its efficacy/ potential for the implementation of new innovative BGCI that has yet to be introduced to Aotearoa.

Methodology:

Objective 1

A high-level literature review will be conducted on international and local scholarship with the purpose of gaining an understanding of a definition of BGCI that advocates the purpose of coastal protection and strengths and weaknesses of different types BGCI. This literature will be sourced from the Te Whare Wānanga o Waitaha | University of Canterbury library website, google scholar and Scopus. It will be peer reviewed literature to ensure reliability. Mana whenua perspectives may be gathered from the Matapopore Urban Design Plan 2015, Ngāi Tahu Climate Change Strategy 2018, Mahaanui Iwi Management Plan 2013 as well as literature such as 'The values and history of Ōtākaro and north and east frames' and the 'Grand narrative for Christchurch' written by Associate Professor Te Maire Tau.

Objective 2

This summary of different types of BGCI and their strengths and weaknesses will then be used to ascertain the coastal protection value of different types of BGCI present in Ōtautahi from Te Riu-o-Te-Aika-Kawa to Te Onepoto. This will be conducted by the further reviewing of literature. Global case studies where different types of BGCI have been implemented will be critically analysed. This may include peer reviewed literature as well as grey literature such as governmental documents in countries where there is existing policy on BGCI.

To gain an understanding of local values that BGCI could bring to Ōtautahi, interviews with specialists will be conducted. Interviews with specialists will provide qualitative primary data which can be gathered by open/ closed questions in structured or non-structured interviews (Creswell, 2014 & Hay, 2016). For the purpose of this research both structured and non-structured interviews will be conducted. Finally, to answer this objective, further literature will be reviewed to create a methodology where these different values of different types of BGCI can be assessed and ranked.

Objective 3

To achieve this objective, secondary data analysis will first be conducted on local literature such as previous reports on wetland, saltmarsh, sea grass, sand dune vegetation and the Canterbury Black Maps. This will provide an understanding of reports already done and where there is existing data that can be utilised as a baseline and updated. A desktop analysis using the secondary data of aerial imagery, false colour imagery and LIDAR data will then be undertaken to determine the extent, location and type of BGCI in Ōtautahi from Te Riu-o-Te-Aika-Kawa to Te Onepoto. This data will be sourced from Land Information New Zealand (LINZ), Canterbury images and Retrolens New Zealand.

This digital data will be ground-truthed using a handheld GPS (extent), GNSS (elevation) and UAV for aerial imagery in three chosen case study areas. All this data combined will then be assessed and used to create colour coded polygons in ArcGIS to highlight what type and where the BGCI is located.

Based on the methodology developed in Objective 2, a 'value' will then be attributed to the BGCI currently in place in Ōtautahi. This will be done in the field by visually assessing the BGCI. Three specific case study areas will be completed in detail. A discussion and conclusion will then be undertaken on the existing BGCI including ways to improve or enhance its efficacy and potential for the implementation of new innovative BGCI that have yet to be introduced to Aotearoa. This will be undertaken via interviews with experts and a literature review that assesses the different options of BGCI and the environments they are suitable in.

Does the proposed research involve any of the following? Please underline.

- <u>Significant Māori content</u>
- Access to Māori sites
- Sampling of native flora/fauna
- Culturally sensitive material/knowledge
- <u>Māori involvement as participants or subjects</u>
- <u>Research where Māori data is sought and analysed</u>
- <u>Research that will impact on Māori</u>

If you have underlined any of the above, please explain in more detail:

Significant Māori content

This research will refer to Māori knowledge. It will investigate mātauranga on coastal protection, well-being, and the environment. There will be specific reference to whenua, mana whenua, whakapapa and tikanga. The research will undertake this through a literature review and interviews with specialists with the results being used to recognise and promote the views of of mana whenua in terms of coastal adaption strategies to climate change in Ōtautahi and the value they find in natural coastal protection structures such as sand dunes, salt marsh, wetlands etc. It is envisioned that this content could be used, if mana whenua so desire, for local authorities as an indication of what types of coastal protection community members would like and value. This in turn could be used by local authorities to strengthen resilience to increasing chronic and acute stressors climate change is causing such as coastal erosion and sea level rise. These communities will be given recognition for their contribution by being referenced appropriately throughout the research. Additionally, consultation with the interviews will be conducted to understand how they would like the information disseminated back to their communities so this can be undertaken appropriately.

Māori involvement as participants or subjects

This research will interview Māori participants. First and foremost, we will seek to engage with mana whenua through Te Waka Pākākano to determine appropriate interviewees. I have been working in collaboration with Dr Abby Susko who has organised Liz Brown to speak with Te Maire who will then decide who is suitable to interview from mana whenua. The timeline on this is yet to be determined. Second, we will seek to interview experts in their field and these people will be identified after talking to mana whenua. Participants will be interviewed at a location of convenience to them. Standard good practise with interviewing will be followed whereby consent is fully understood with the participant knowledgeable that they can stop the interview process at any stage. The participant will also be fully notified on the next steps for the research and what will happen with the information I gather from the interview. I will discuss with them the most appropriate way to disseminate the information back to their community. They will have full permission to go through the transcript and make any changes they desire. The interviews will incorporate mihi and whakawhanaungatanga. I will check my understanding of any Māori terms used by the participants with them during the interview to ensure I do not misrepresent them. I will also ensure I have funding for appropriate koha to gift to participants. If mana whenua do not wish to be involved, Māori perspective will be determined from peer reviewed literature.

Research where Māori data is sought and analysed

Māori data will be utilised for this research to gain an understanding of the cultural value natural coastal protection structures have in Ōtautahi. This data will be used respectfully as it will be gained from peer reviewed literature or official plans and interviews with mana whenua. These will be referenced appropriately throughout the research. Results from this research will be emailed to participants of the interviews, fed back appropriately to communities as well as being published online in Te Whare Wānanga o Waitaha | University of Canterbury research repository.

Research that will impact on Māori

Mana whenua may have interest in the proposed research results as they could potentially lead to the implementation of certain adaptation approaches in their communities. This has the potential to impact the relationship they have with the coast and the health of the environment that is surrounding them; thus it is vital mana whenua are consulted. I understand that mana whenua relationships and responsibilities to the coast have been impacted by the processes of colonisation in the past. I acknowledge this and will endeavour to ensure that such practices are not repeated in this research.

Appendix B- Ecological value data and calculations for the New Brighton Dune Study Areas

Table B1- Raw ecological values data for study site 1

Note: the column headings in the top section of the table can be described as; Quadrat number being the quadrat number sampled. Indigenous, introduced, and bare sand % cover is the percentage cover of this type of sand dune vegetation for each quadrat analysed. Different types of vegetation (spinifex, marram, pīngao, ice plant, lupin and mahinga kai species are then individually assessed with the percentage covers per quadrat recorded.

Quadrat number	Quadrat co-ordinates				% cover of vegetation (%)	% cover of bare sand (%)	% cover of woody species (%)	% cover of sand binding plants (%)	% cover of indigenous vegetation (%)	% cover of introduced vegetation cover (%)	Spinifex (%)	Marram (%)	Pīngao (%)	Ice plant (%)	Lupin (%)	Mahinga kai % cover (%)
	Bottom left X	Bottom left X	Top right X	Top right Y												
0	1577709.482	5185131.962	1577711.914	5185134.357	35	65	0	35	35	0	35	0	0	0	0	35
1	1577705.488	5185130.938	1577707.92	5185133.333	50	50	0	50	50	0	50	0	0	0	0	50
17	1577701.44	5185129.9	1577703.872	5185132.295	20	80	0	20	10	10	5	0	5	10	0	10
18	1577697.462	5185128.88	1577699.894	5185131.274	100	0	0	100	0	100	0	0	0	100	0	0
19	1577693.438	5185127.848	1577695.87	5185130.243	100	0	0	100	0	100	0	50	0	0	50	0
20	1577689.436	5185126.822	1577691.868	5185129.217	100	0	0	100	0	100	0	100	0	0	0	0
21	1577685.372	5185125.78	1577687.805	5185128.174	25	75	0	25	0	25	0	15	0	0	10	0
22	1577681.395	5185124.76	1577683.828	5185127.155	100	0	0	100	0	100	0	90	0	0	10	0
23	1577677.294	5185123.702	1577679.727	5185126.096	100	0	40	60	40	60	0	60	0	0	0	40
24	1577673.285	5185122.68	1577675.717	5185125.075	100	0	40	60	40	60	0	60	0	0	0	40
25	1577669.153	5185121.621	1577671.585	5185124.015	100	0	0	100	0	100	0	100	0	0	0	0
26	1577665.066	5185120.573	1577667.498	5185122.967	100	0	0	100	0	100	0	90	0	10	0	0
27	1577661.04	5185119.541	1577663.473	5185121.935	100	0	0	100	0	100	0	100	0	0	0	0
28	1577657.006	5185118.482	1577659.438	5185120.877	100	0	0	100	0	100	0	100	0	0	0	0
29	1577652.838	5185117.457	1577655.271	5185119.851	100	0	0	100	0	100	0	100	0	0	0	0
30	1577648.81	5185116.405	1577651.243	5185118.799	50	50	10	40	10	40	0	40	0	0	0	10

Table B2 – Raw ecological values data for study site 2

Note: the column headings in the top section of the table can be described as; Quadrat number being the quadrat number sampled. Indigenous, introduced, and bare sand % cover is the percentage cover of this type of sand dune vegetation for each quadrat analysed. Different types of vegetation (spinifex, marram, pīngao, ice plant, lupin and mahinga kai species are then individually assessed with the percentage covers per quadrat recorded.

Quadrat number	Quadrat co-ordinates				% cover of vegetation (%)	% cover of bare sand (%)	% cover of woody species (%)	% cover of sand binding plants (%)	% cover of indigenous vegetation (%)	% cover of introduced vegetation cover (%)	Spinifex (%)	Marram (%)	Pīngao (%)	Ice plant (%)	Lupin (%)	Mahinga kai % cover (%)
	X_1	X_2	Y_1	Y_2												0
2	1577762.785	5184909.711	1577765.556	5184912.465	5	95	0	5	5	0	5	0	0	0	0	5
3	1577759.176	5184907.702	1577761.947	5184910.456	30	70	0	30	30	0	30	0	0	0	0	30
4	1577755.658	5184905.565	1577758.429	5184908.318	65	35	15	50	5	60	5	0	0	0	60	5
5	1577752.175	5184903.45	1577754.946	5184906.203	90	10	0	90	0	90	0	70	0	20	0	0
6	1577748.697	5184901.336	1577751.468	5184904.09	100	0	0	100	0	100	0	100	0	0	0	0
7	1577745.211	5184899.219	1577747.981	5184901.972	85	25	0	85	0	85	0	85	0	0	0	0
8	1577741.706	5184897.09	1577744.476	5184899.843	95	5	0	95	0	95	0	95	0	0	0	0
9	1577738.088	5184894.892	1577740.859	5184897.645	100	0	0	100	0	100	0	100	0	0	0	0
10	1577734.555	5184892.746	1577737.325	5184895.499	100	0	0	100	0	100	0	90	0	10	0	0
11	1577730.98	5184890.574	1577733.751	5184893.327	100	0	0	100	0	100	0	80	0	20	0	0
12	1577727.464	5184888.438	1577730.235	5184891.192	60	40	0	60	0	60	0	35	0	25	0	0
13	1577723.79	5184886.206	1577726.561	5184888.96	85	25	0	85	15	70	0	0	15	70	0	15
14	1577720.198	5184884.024	1577722.968	5184886.777	100	0	0	100	0	100	0	80	0	20	0	0
15	1577716.63	5184881.857	1577719.401	5184884.61	100	0	60	40	60	0	0	40	0	0	0	60
16	1577712.99	5184879.646	1577715.761	5184882.399	50	0	50	0	50	0	0	0	0	0	0	50

Table B3 – Raw ecological values data for study site 3

Note: the column headings in the top section of the table can be described as; Quadrat number being the quadrat number sampled. Indigenous, introduced, and bare sand % cover is the percentage cover of this type of sand dune vegetation for each quadrat analysed. Different types of vegetation (spinifex, marram, pīngao, ice plant, lupin and mahinga kai species are then individually assessed with the percentage covers per quadrat recorded.

Quadrat number	Quadrat co-ordinates				% cover of vegetation (%)	% cover of bare sand (%)	% cover of woody species (%)	% cover of sand binding plants (%)	% cover of indigenous vegetation (%)	% cover of introduced vegetation cover (%)	Spinifex (%)	Marram (%)	Pīngao (%)	Ice plant (%)	Lupin (%)	Mahinga kai % cover (%)
	X_1	X_2	Y_1	Y_2												
31	1578686.86	5181581.56	1578689.394	5181584.068	30	70	0	30	30	0	30	0	0	0	0	30
32	1578682.9	5181580.33	1578685.438	5181582.838	70	30	0	70	70	0	70	0	0	0	0	70
33	1578679.06	5181579.14	1578681.6	5181581.645	95	5	0	95	15	80	5	0	0	0	95	5
34	1578675.07	5181577.92	1578677.605	5181580.428	95	5	0	95	0	95	0	10	0	90	0	0
35	1578671.07	5181576.68	1578673.61	5181579.184	100	0	0	100	0	100	0	30	0	0	70	0
36	1578667.03	5181575.4	1578669.57	5181577.904	100	0	0	100	0	100	0	100	0	0	0	0
37	1578663.01	5181574.15	1578665.544	5181576.652	100	0	0	100	0	100	0	100	0	0	0	0
38	1578659.1	5181572.93	1578661.638	5181575.438	100	0	0	100	0	100	0	100	0	0	0	0
39	1578655.15	5181571.71	1578657.689	5181574.21	100	0	0	100	0	100	0	100	0	0	0	0
40	1578651.23	5181570.49	1578653.768	5181572.991	100	0	85	25	85	25	85	25	0	0	0	0
41	1578646.9	5181569.14	1578649.44	5181571.645	100	0	100	0	100	0	0	0	0	0	0	100
42	1578642.92	5181567.9	1578645.461	5181570.407	100	0	0	100	0	100	0	0	0	0	0	0
43	1578638.74	5181566.6	1578641.277	5181569.107	95	5	0	95	0	95	0	95	0	0	0	0
44	1578634.71	5181565.35	1578637.243	5181567.852	100	0	0	100	0	100	0	0	0	0	100	0
45	1578630.72	5181564.11	1578633.255	5181566.612	100	0	90	10	0	100	0	10	0	0	0	0
46	1578626.76	5181562.88	1578629.295	5181565.381	100	0	0	100	0	100	0	100	0	0	0	0
47	1578622.87	5181561.67	1578625.408	5181564.172	100	0	40	60	40	60	0	60	0	0	0	40
48	1578618.95	5181560.45	1578621.486	5181562.953	100	0	0	100	0	100	0	100	0	0	0	0
49	1578615.09	5181559.18	1578617.623	5181561.683	100	0	15	85	15	85	0	85	0	0	0	15
50	1578611.09	5181558.01	1578613.629	5181560.51	100	0	70	30	70	30	0	30	0	0	0	70
51	1578607.26	5181556.81	1578609.799	5181559.319	90	10	90	10	90	10	0	10	0	0	0	90
52	1578603.08	5181555.52	1578605.622	5181558.02	100	0	0	100	0	100	0	100	0	0	0	0
53	1578598.87	5181554.2	1578601.405	5181556.709	100	0	0	100	0	100	0	100	0	0	0	0
54	1578594.67	5181552.9	1578597.204	5181555.403	100	0	0	100	0	100	0	0	0	0	100	0
55	1578590.37	5181551.56	1578592.904	5181554.066	100	0	55	45	0	100	0	0	0	0	0	0
56	1578586.21	5181550.27	1578588.744	5181552.772	100	0	0	100	0	100	0	100	0	0	0	0
57	1578581.9	5181548.93	1578584.433	5181551.432	100	0	0	100	0	100	0	100	0	0	0	0
58	1578577.7	5181547.62	1578580.24	5181550.128	100	0	0	100	0	100	0	100	0	0	0	0
59	1578573.69	5181546.37	1578576.223	5181548.879	100	0	0	100	0	100	0	100	0	0	0	0
60	1578569.37	5181545.03	1578571.905	5181547.536	100	0	0	100	0	100	0	100	0	0	0	0
61	1578565.17	5181543.73	1578567.703	5181546.23	100	0	0	100	0	100	0	100	0	0	0	0
62	1578560.77	5181542.36	1578563.31	5181544.864	100	0	0	100	0	100	0	100	0	0	0	0

Table B4 - Calculations and ecological value results for study site 1

Note: the column headings in the top section of the table can be described as- Quadrat, the quadrat number sampled. Indigenous, introduced, and bare sand % cover is the percentage cover of this type of sand dune vegetation for each quadrat analysed. Indigenous (x2)/100 introduced (x1)/100, and bare sand (x0)/100 is the percentage cover of indigenous vegetation per quadrat divided by 100 and then multiplied by the appropriate score explained in section 5.1 of this thesis. The study site average (μ) and the standard deviation (σ) are then given for each measurement. At the bottom of the table, the equation parameters for calculating the total ecological value (Tev) for each study site are displayed. Pt= Percentage cover of plant type, Vt= vegetation type (ie, indigenous, native, or bare sand), Qn= Total number of quadrats within the study site, 2= maximum potential ecological value score for each quadrat, Ev= Ecological value, A= total area of study site, Tev= Total ecological value and the score is the ecological value out 3.

Quadrat number	Indigenous (% cover)	Introduced (% cover)	Bare sand (% cover)	Indigenous (x2)/100	Introduced (x1)/100	Bare sand (x0)/100	Sum
0	35	0	65	0.7	0	0	0.7
1	50	0	50	1	0	0	1
17	10	10	80	0.2	0.1	0	0.3
18	0	100	0	0	1	0	1
19	0	100	0	0	1	0	1
20	0	100	0	0	1	0	1
21	0	25	75	0	0.25	0	0.25
22	0	100	0	0	1	0	1
23	40	60	0	0.8	0.6	0	1.4
24	40	60	0	0.8	0.6	0	1.4
25	0	100	0	0	1	0	1
26	0	100	0	0	1	0	1
27	0	100	0	0	1	0	1
28	0	100	0	0	1	0	1
29	0	100	0	0	1	0	1
30	10	40	50	0.2	0.4	0	0.6
Site 1 μ (σ)	11.56 (± 18.23)	68.44 (± 40.49)	20.00 (± 31.46)	0.23 (± 0.36)	0.68 (± 0.40)	0 (± 0)	0.92 (± 0.32)
Σ (Vt X Pt)	**Qn**	**Qn x 2**	**Ev**	**A**	**Tev**	**Score**	
14.65	**16**	**32**	**0.46**	**64**	**29.3**	**1**	

Table B5 - Calculations and ecological value results for study site 2
Note: the column headings in the top section of the table can be described as- Quadrat, the quadrat number sampled. Indigenous, introduced, and bare sand % cover is the percentage cover of this type of sand dune vegetation for each quadrat analysed. Indigenous (x2)/100 introduced (x1)/100, and bare sand (x0)/100 is the percentage cover of indigenous vegetation per quadrat divided by 100 and then multiplied by the appropriate score explained in section 5.1 of this thesis. The study site average (μ) and the standard deviation (σ) are then given for each measurement. At the bottom of the table, the equation parameters for calculating the total ecological value (Tev) for each study site are displayed. Pt= Percentage cover of plant type, Vt= vegetation type (ie, indigenous, native, or bare sand), Qn= Total number of quadrats within the study site, 2= maximum potential ecological value score for each quadrat, Ev= Ecological value, A= total area of study site, Tev= Total ecological value and the score is the ecological value out 3.

Quadrat number	Indigenous (% cover)	Introduced (% cover)	Bare sand (% cover)	Indigenous (x2)/100	Introduced (x1) /100	Bare sand (x0) /100	Sum
2	5	0	95	0.1	0	0	0.1
3	30	0	70	0.6	0	0	0.6
4	5	60	35	0.1	0.6	0	0.7
5	0	90	10	0	0.9	0	0.9
6	0	100	0	0	1	0	1
7	0	85	25	0	0.85	0	0.85
8	0	95	5	0	0.95	0	0.95
9	0	100	0	0	1	0	1
10	0	100	0	0	1	0	1
11	0	100	0	0	1	0	1
12	0	60	40	0	0.6	0	0.6
13	15	70	25	0.3	0.7	0	1
14	0	100	0	0	1	0	1
15	60	0	0	1.2	0	0	1.2
16	50	0	0	1	0	0	1
Site 2 μ (σ)	11.00 (± 19.75)	64 (± 42.27)	20.33 (± 29.18)	0.22 (± 0.39)	0.64 (± 0.42)	0 (± 0)	0.86 (± 0.27)
Σ (Vt X Pt)	**Qn**	**Qn x 2**	**Ev**	**A**	**Tev**	**Score**	
12.9	**15**	**30**	**0.43**	**60**	**25.8**	**1**	

Table B6 - Calculations and ecological value results for study site 3

Note: the column headings in the top section of the table can be described as- Quadrat, the quadrat number sampled. Indigenous, introduced, and bare sand % cover is the percentage cover of this type of sand dune vegetation for each quadrat analysed. Indigenous (x2)/100 introduced (x1)/100, and bare sand (x0)/100 is the percentage cover of indigenous vegetation per quadrat divided by 100 and then multiplied by the appropriate score explained in section 5.1 of this thesis. The study site average (μ) and the standard deviation (σ) are then given for each measurement. At the bottom of the table, the equation parameters for calculating the total ecological value (Tev) for each study site are displayed. Pt= Percentage cover of plant type, Vt= vegetation type (ie, indigenous, native, or bare sand), Qn= Total number of quadrats within the study site, 2= maximum potential ecological value score for each quadrat, Ev= Ecological value, A= total area of study site, Tev= Total ecological value, and the score is the ecological value out 3.

Quadrat number	Indigenous (% cover)	Introduced (% cover)	Bare sand (% cover)	Indigenous (x2)/100	Introduced (x1)/100	Bare sand (x0)/100	Sum
31	30	0	70	0.6	0	0	0.6
32	70	0	30	1.4	0	0	1.4
33	15	80	5	0.3	0.8	0	1.1
34	0	95	5	0	0.95	0	0.95
35	0	100	0	0	1	0	1
36	0	100	0	0	1	0	1
37	0	100	0	0	1	0	1
38	0	100	0	0	1	0	1
39	0	100	0	0	1	0	1
40	85	25	0	1.7	0.25	0	1.95
41	100	0	0	2	0	0	2
42	0	100	0	0	1	0	1
43	0	95	5	0	0.95	0	0.95
44	0	100	0	0	1	0	1
45	0	100	0	0	1	0	1
46	0	100	0	0	1	0	1
47	40	60	0	0.8	0.6	0	1.4
48	0	100	0	0	1	0	1
49	15	85	0	0.3	0.85	0	1.15
50	70	30	0	1.4	0.3	0	1.7
51	90	10	10	1.8	0.1	0	1.9
52	0	100	0	0	1	0	1
53	0	100	0	0	1	0	1
54	0	100	0	0	1	0	1
55	0	100	0	0	1	0	1
56	0	100	0	0	1	0	1
57	0	100	0	0	1	0	1
58	0	100	0	0	1	0	1
59	0	100	0	0	1	0	1
60	0	100	0	0	1	0	1
61	0	100	0	0	1	0	1
62	0	100	0	0	1	0	1
Site 3 μ (σ)	16.10 (± 31.00)	80.63 (± 35.42)	3.91 (± 13.30)	0.32 (± 0.62)	0.81 (± 0.35)	0 (± 0)	1.13 (± 0.32)
Σ (Vt X Pt)	**Qn**	**Qn x 2**	**Ev**	**A**	**Tev**	**Score**	
36.1	**32**	**64**	**0.56**	**128**	**72.2**	**2**	

Appendix C- Coastal protection value data

Table C1 – Coastal protection parameter data and calculation results for study site 1
Note: quadrat number is the identification number of the quadrat sampled. i, ii and iii are the percentage cover of the listed vegetation cover types multiplied by their associated value scores of: i=3, ii=2 and i=1. Cover sum is the sum of results from i, ii and iii per quadrat, with 600 being the maximum potential score for each quadrat. The total is the Sum converted to a percentage score (i.e., out of 100) that can be evaluated and given an overall score for the type of vegetation present on New Brighton coastal sand dunes in relation to their ability to provide coastal protection. This was scored out of 3 with 1=poor, 2=average and 3=good. Site averages (μ) and standard deviations (σ) are displayed at the bottom of the table. These averages and standard deviations are given for each vegetation cover type and the scores thereafter.

Quadrat number	i. Spinifex % cover x score	ii. Marram/ pīngao/ iceplant & lupin % cover x score	iii. Bare sand % cover x score	Sum of i,ii,iii (out of 600)	Sum (%)	Score
0	105	0	65	170	28.33	1
1	150	0	50	200	33.33	1
17	15	30	80	125	20.83	1
18	0	200	0	200	33.33	1
19	0	100	0	100	16.67	1
20	0	100	0	100	16.67	1
21	0	30	75	105	17.50	1
22	0	180	0	180	30.00	1
Site 1 μ (σ)	**33.75 (± 59.33)**	**80.00 (± 78.38)**	**33.75 (± 37.11)**	**147.50 (±44.56)**	**24.58 (±7.42)**	**1 (± 0)**

Table C2 – Coastal protection parameter data and calculation results for study site 2
Note: quadrat number is the identification number of the quadrat sampled. i, ii and iii are the percentage cover of the listed vegetation cover types multiplied by their associated value scores of: i=3, ii=2 and i=1. Cover sum is the sum of results from i, ii and iii per quadrat, with 600 being the maximum potential score for each quadrat. The total is the Sum converted to a percentage score (i.e., out of 100) that can be evaluated and given an overall score for the type of vegetation present on New Brighton coastal sand dunes in relation to their ability to provide coastal protection. This was scored out of 3 with 1=poor, 2=average and 3=good. Site averages (μ) and standard deviations (σ) are displayed at the bottom of the table. These averages and standard deviations are given for each vegetation cover type and the scores thereafter.

Quadrat number	i. Spinifex % cover x score	ii. Marram/ pīngao/ iceplant & lupin % cover x score	iii. Bare sand % cover x score	Sum of i,ii,iii (out of 600)	Sum (%)	Score
2	15	0	95	110	18.33333	1
3	90	0	70	160	26.66667	1
4	15	120	35	170	28.33333	1
5	0	180	10	190	31.66667	1
6	0	200	0	200	33.33333	1
7	0	170	25	195	32.5	1
Site 2 μ (σ)	**20 (± 35.07)**	**111.67 (± 90.42)**	**39.17 (± 36.53)**	**170.833 (± 33.53)**	**28.47 (± 5.59)**	**1 (± 0)**

Table C3 – Coastal protection parameter data and calculation results for study site 3

Note: quadrat number is the identification number of the quadrat sampled. i, ii and iii are the percentage cover of the listed vegetation cover types multiplied by their associated value scores of: i=3, ii=2 and i=1. Cover sum is the sum of results from i, ii and iii per quadrat, with 600 being the maximum potential score for each quadrat. The total is the Sum converted to a percentage score (i.e., out of 100) that can be evaluated and given an overall score for the type of vegetation present on New Brighton coastal sand dunes in relation to their ability to provide coastal protection. This was scored out of 3 with 1=poor, 2=average and 3=good. Site averages (μ) and standard deviations (σ) are displayed at the bottom of the table. These averages and standard deviations are given for each vegetation cover type and the scores thereafter.

Quadrat number	i. Spinifex % cover x score	ii. Marram/ pīngao/ iceplant & lupin % cover x score	iii. Bare sand % cover x score	Sum of i,ii,iii (out of 600)	Sum (%)	Score
31	90	0	70	160	26.7	1
32	210	0	30	240	40.0	2
33	15	190	0	205	34.2	1
34	0	200	5	205	34.2	1
35	0	200	0	200	33.3	1
36	0	200	0	200	33.3	1
37	0	200	0	200	33.3	1
38	0	200	0	200	33.3	1
39	0	200	0	200	33.3	1
40	255	50	0	305	50.8	2
41	0	0	100	100	16.7	1
Site 3 μ (σ)	**51.82 (± 93.76)**	**130.91 (± 94.92)**	**18.64 (± 34.65)**	**201.36 (± 49.25)**	**33.56 (± 8.21)**	**1 (± 0.40)**

Figure C1- Dune toe excursion plots (left) for study sites 1 (c), 2 (b) and 3 (a) and MSL excursion plots (right) for study site 1 (f), 2 (e) and 3 (d) (raw data from ECan, (2020))

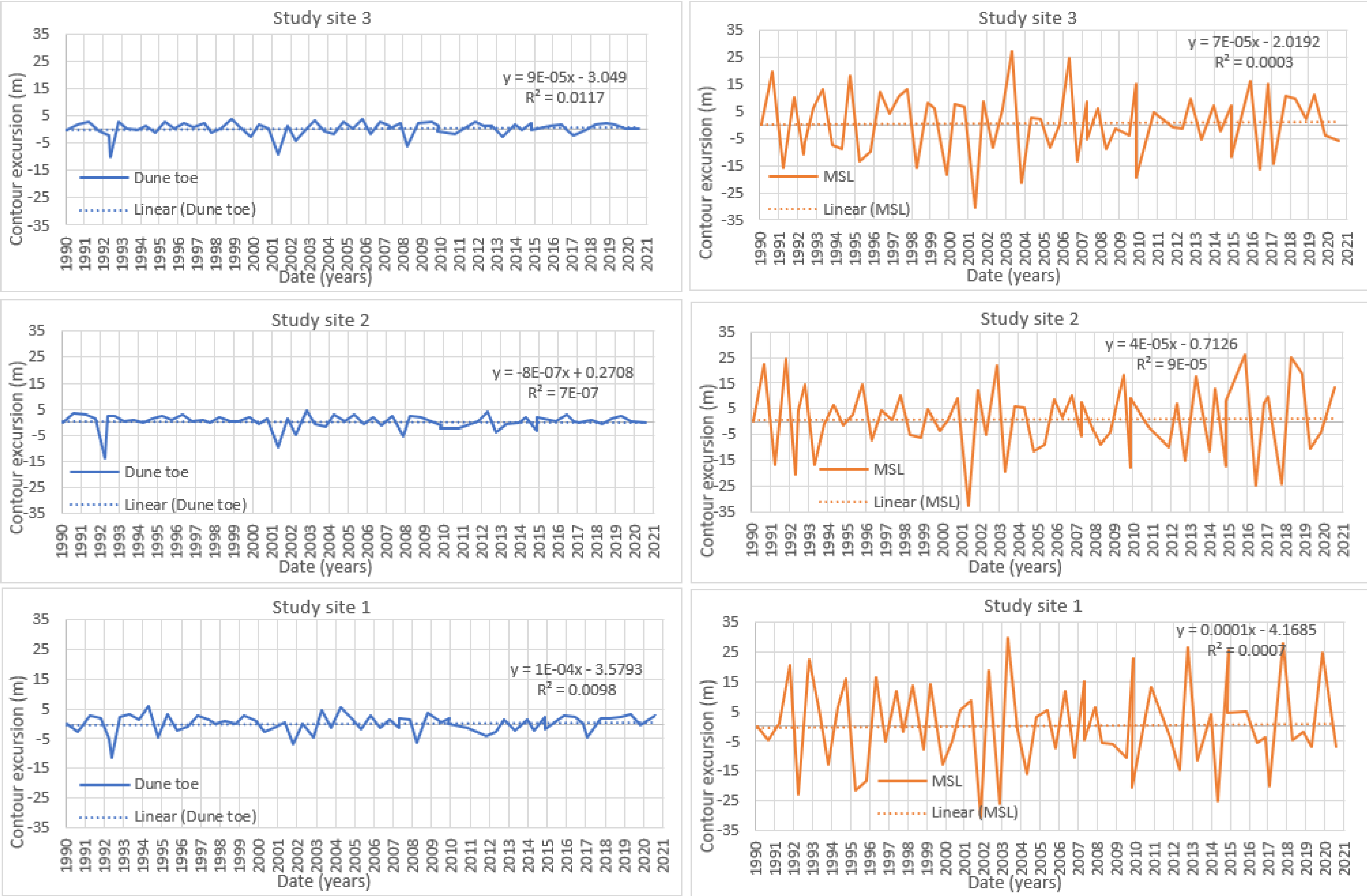


Figure C2- Dune (left) and beach (right) volume changes from 1990 to 2020 for study sites 1 (a & d), 2 (b & e) and 3 (c & f) in this order (raw data sourced from ECan, (2020))

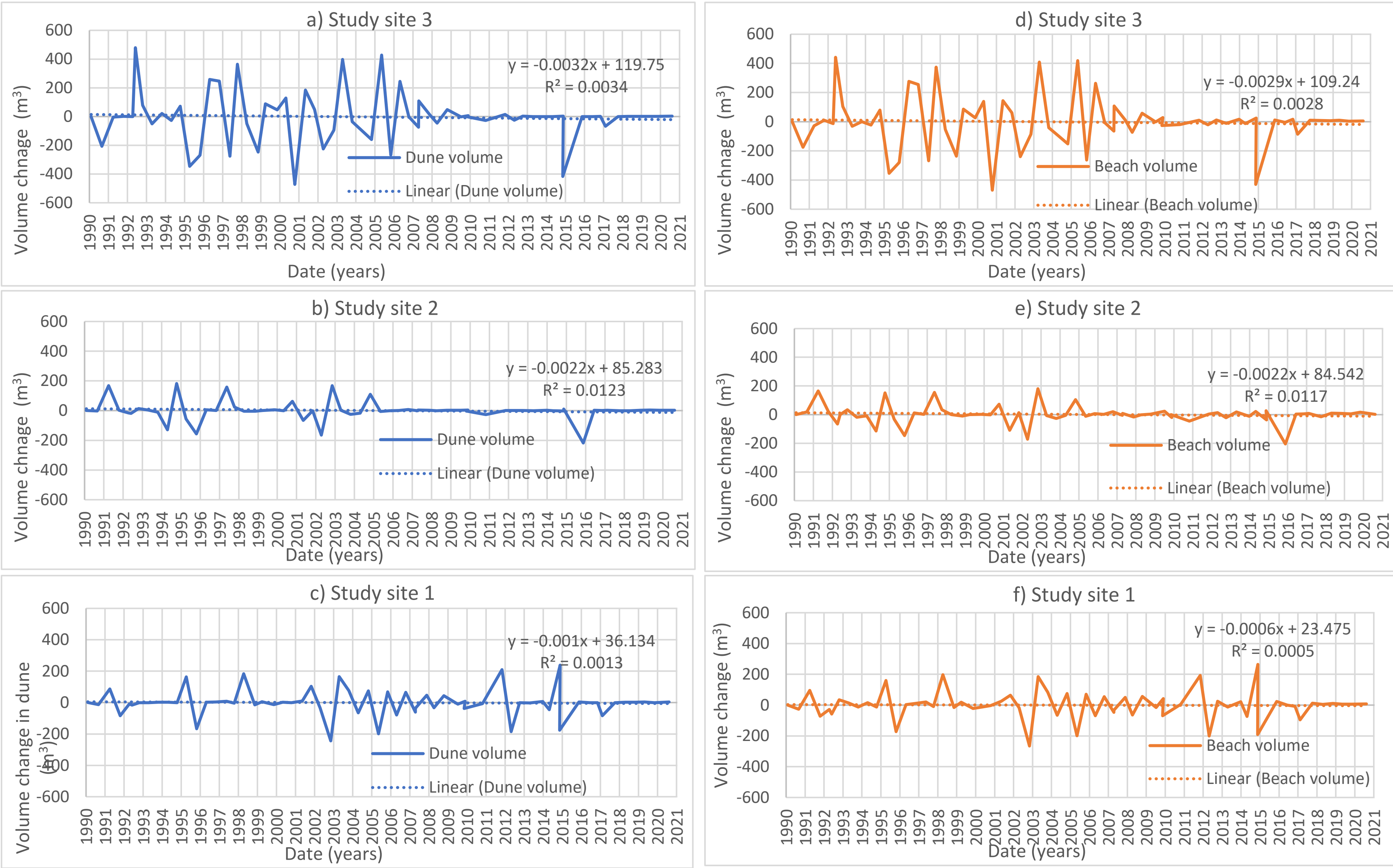
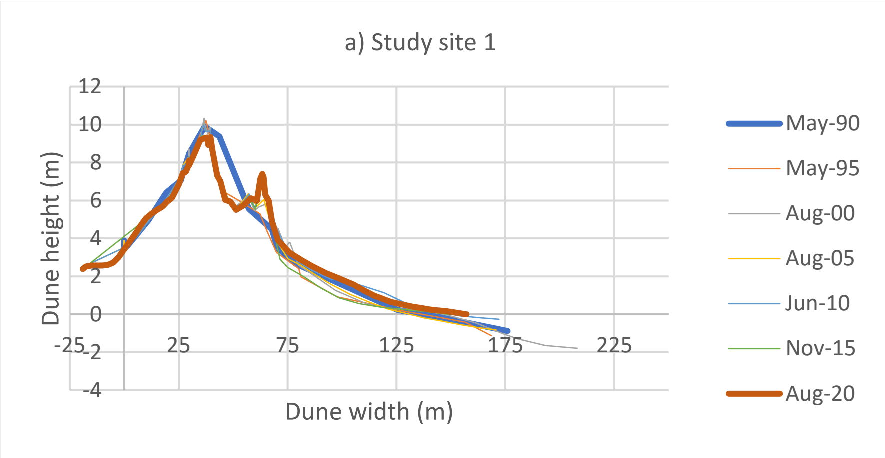
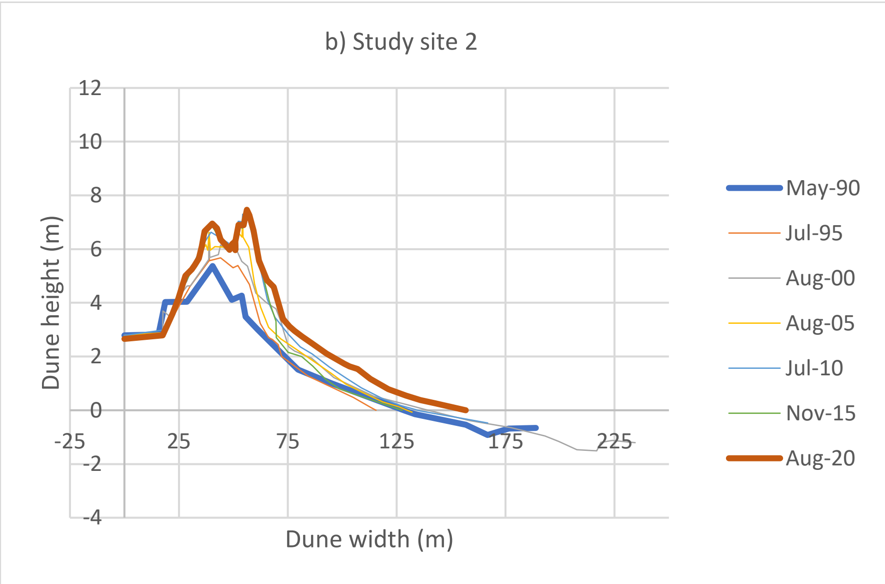
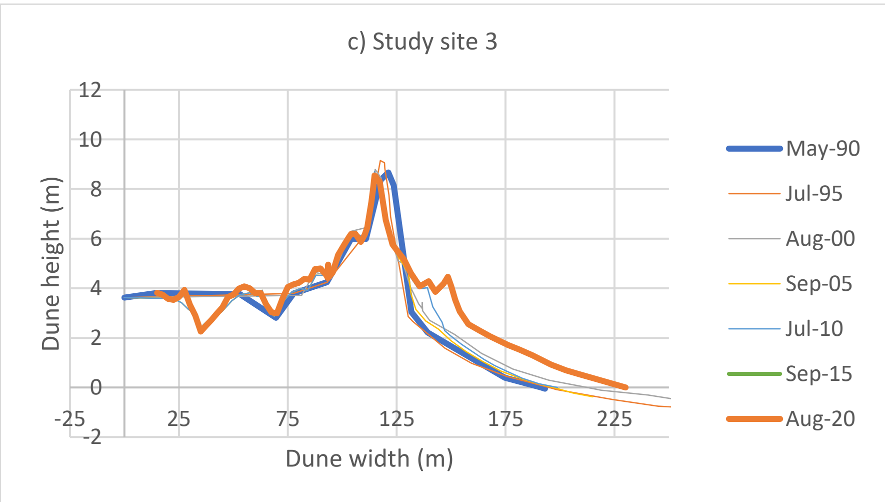


Figure C3 - Beach profiles lines plotted at 5-year intervals for each study site

Note: study sites are shown in order from 1 (a), to 2 (b), and 3 (c). Beach profile data covers the 30 years record between May 1990 and August 2020, as measured by ECan (2020).







Appendix D- Aesthetic values raw observation and assessment data

Table D1- Site 1, 2 and 3 results for percentage vegetation cover and percentage of indigenous vegetation cover.

Note: (σ) is standard deviation

Site 1			Site 2			Site 3		
Quadrat	**% vegetation cover**	**% indigenous vegetation cover**	**Quadrat**	**% vegetation cover**	**% indigenous vegetation cover**	**Quadrat**	**% vegetation cover**	**% indigenous vegetation cover**
0	35	35	2	5	5	31	30	30
1	50	50	3	30	30	32	70	70
17	20	10	4	65	5	33	95	15
18	100	0	5	90	0	34	95	0
19	100	0	6	100	0	35	100	0
20	100	0	7	85	0	36	100	0
21	25	0	8	95	0	37	100	0
22	100	0	9	100	0	38	100	0
23	100	40	10	100	0	39	100	0
24	100	40	11	100	0	40	100	85
25	100	0	12	60	0	41	100	100
26	100	0	13	85	15	42	100	0
27	100	0	14	100	0	43	95	0
28	100	0	15	100	60	44	100	0
29	100	0	16	50	50	45	100	0
30	50	10	**Average**	**77.67**	**11**	46	100	0
Average	**80**	**11.56**	**σ**	**±29.69**	**±19.75**	47	100	40
σ	**±31.46**	**±18.23**	**Score**	**3**	**1**	48	100	0
Score	**3**	**1**				49	100	15
						50	100	70
						51	90	90
						52	100	0
						53	100	0
						54	100	0
						55	100	0
						56	100	0
						57	100	0
						58	100	0
						59	100	0
						60	100	0
						61	100	0
						62	100	0
						Average	**96.09**	**16.09**
						σ	**±13.30**	**±31.00**
						Score	**3**	**1**

Table D2- Results for the presence of built features (on the beach) & visibility of urban development from the beach (hinterland) for the three study sites

Site	Built features		Urban development	
	Number	Score	Number	Score
1	1	2	0	3
2	0	3	0	3
3	0	3	0	3

Table D3 - Quantity of observable litter present on 22/09/21 in the three study sites

	Site 1		Site 2		Site 3	
	Measured value	Score	Measured value	Score	Measured value	Score
Litter presence	2	2	2	2	0	3

Table D4- Visible beach width scores for the three study sites

	Site 1		Site 2		Site 3	
	Measured value	Score	Measured value	Score	Measured value	Score
Beach width	17	3	18	3	16	3