## 6.5 Dune condition index

**Author, affiliation:** Al Alder (Cawthron), Anna Berthelsen (Cawthron)

**Citation for this chapter**: Alder, A., Berthelsen, A. (2024). Dune condition index. *In:* Lohrer, D., et al. *Information Stocktakes of Fifty-Five Environmental Attributes across Air, Soil, Terrestrial, Freshwater, Estuaries and Coastal Waters Domains*. Prepared by NIWA, Manaaki Whenua Landare Research, Cawthron Institute, and Environet Limited for the Ministry for the Environment. NIWA report no. 2024216HN (project MFE24203, June 2024). [https://environment.govt.nz/publications/information-stocktakes-of-fifty-five-environmental-attributes]

**Preamble:** Aotearoa has multiple types of dune systems that are broadly characterised based on the origin of sand, location (e.g., coastal vs. terrestrial), and the physical activity that led to the structure of these systems (e.g., active[1], stable[2], volcanic[3], inland[4]). While all dune systems in Aotearoa are important and endangered, we interpret this attribute to predominantly refer to coastal active and/or stable sand dunes as these systems have received the greatest share of attention relating to ecological integrity and because our professional expertise is within the estuaries and coastal waters domain. However, the issues and pressures related to the decrease in coastal dune condition can be broadly applied to all dune systems. Also note that dune 'condition index' encompasses dune 'extent' given extent is one indicator of dune condition.

**State of knowledge of the "Dune condition index" attribute:** Overall, we consider the state of knowledge for the dune condition index attribute to be 'Good / established but incomplete' (though this may need to be changed to Poor / inconclusive or Medium / unresolved if considering all dune systems). Internationally and nationally, there is excellent evidence relating dune condition to ecological integrity. New Zealand-specific data that quantifies stressor impacts on 'dune condition index' and associated ecosystem services are good, and management interventions for coastal dunes are well known (though this may not be the case for volcanic or inland dune systems). Nationally, a standardised protocol exists for monitoring coastal dune condition, however to our knowledge this has only been adopted for a handful of councils and data on tipping points are lacking. Monitoring of dune condition is also carried out haphazardly across the country, leading to a lack of national-scale data for baseline and comparison of changes to dune condition.

### Part A—Attribute and method

#### A1. How does the attribute relate to ecological integrity ~~or human health~~?

There is excellent evidence globally and in Aotearoa New Zealand (hereafter Aotearoa) to show that dune condition, which relates to dune extent among other measures, is closely tied with ecological

---

[1] See link: Active sand dunes » Manaaki Whenua (landcareresearch.co.nz)
[2] See link: Stable sand dunes » Manaaki Whenua (landcareresearch.co.nz)
[3] See link: Volcanic dunes » Manaaki Whenua (landcareresearch.co.nz)
[4] See link: Inland sand dunes » Manaaki Whenua (landcareresearch.co.nz)

integrity. Dunes are highly energetic habitats that contribute to coastal protection[1-3], support endemic biodiversity[4-6], and biocultural practices[7, 8]. Dunes are a common feature of the landscape throughout Aotearoa but may be most conspicuous along coastlines[1]. Their existence at the land-sea interface makes them important for terrestrial, freshwater, estuarine and nearshore coastal ecosystems.

Nationally, dune habitats are endangered (for all dune types) and support various threatened and critically endangered plant and animal species including a number of arachnid[4], lizard[9], and bird species[5, 10, 11]. Dunes serve several physical functions that support the ecological integrity of coastal systems, such as shoreline protection from storm surges, coastal erosion and flooding[1, 3, 12]. The presence of intact dunes supports the existence of a number of unique and often sensitive habitats such as dune slacks[2], dune deflation hollows[3], and/or damp sand plains[4]. Additionally, dunes play a crucial role in nutrient cycling (e.g.,[13]), soil formation (e.g.,[14]), and water regulation (e.g., [15]).

**A2. What is the evidence of impact on (a) ecological integrity ~~or (b) human health~~? What is the spatial extent and magnitude of degradation?**

Globally and nationally, there is substantial evidence of the impact of degraded dune condition on the ecological integrity of coastal systems (e.g., globally[16-22], for Aotearoa[12, 23-27]). The loss of native dune species from stressors like coastal development, beach renourishment programs, fire, recreation, invasive species has led to the fragmentation and loss of coastal dunes, has led to a severe reduction in both dune condition and extent (i.e., between 60 and 80%, [28, 29]). Notably, this has impacted the national-scale loss or severe reduction of dune habitat for various threatened, endangered and critically-endangered spider and bird species, such as the Katipō spider (*Latrodectus katipo*) and the New Zealand Fairy Tern (*Sternula nereis davisae*), respectively[4, 5, 30]. In addition, the incursion of invasive plant (e.g., Marram grass, *Ammophila arenaria*, [31, 32]) and animal species (e.g., rabbits, [33]) has led to the displacement and loss of native dune flora (e.g., Pīngao, *Ficinia spiralis*; Spinifex, *Spinifex sericeus*), altering dune structure and promoting coastal recession and the loss of native bird nesting habitat [30, 34-39].

**A3. What has been the pace and trajectory of change in this attribute, and what do we expect in the future 10 - 30 years under the status quo? Are impacts reversible or irreversible (within a generation)?**

Dune condition has declined significantly over time, particularly due to the loss of native vegetation due to historic land reclamation (for agriculture, forestry, and/or development, [40]), coastal infrastructure development / hardening (e.g., groins, seawalls, and dykes, [41-43]), livestock grazing [33, 44], recreation [45], and invasive species [31, 32]. It is likely that over the next 10 – 30 years, the interactions among sustained stressors will continue to reduce dune condition, which also directly threatens the habitats supported by dune systems (e.g., dune slacks, dune deflation hollows, and/or damp sand plains).

While the multitude of stressors are actively interacting to reduce dune condition (to varying magnitudes based on location), most can be considered reversible and many are being managed, to

[1] Other dune types exist throughout Aotearoa, such as volcanic dunes formed from volcanic sediments and inland dunes formed from riverine sediments. Generally, these dunes are uncommon, in part due to decades of land-use change, which have made them endangered and critically endangered nationally.
[2] See link: Dune slacks » Manaaki Whenua (landcareresearch.co.nz)
[3] See link: Dune deflation hollows » Manaaki Whenua (landcareresearch.co.nz)
[4] See link: Damp sand plains » Manaaki Whenua (landcareresearch.co.nz)

some degree, by locally-led management and restoration programs (e.g., [46-48]). However, many of these dunes (especially near urban or developed areas) are generally in a degraded condition (e.g., moderate to poor, [39]). Furthermore, natural dune recovery is highly variable, depends on sediment supply, the presence of stabilising native plant species, reduced physical disturbance (i.e., from humans, livestock, and/or pest species) and may not fully recover without additional interventions, such as planting of native flora (which can take up to 2 years for rearing plant propagules[49, 50]). This means that retaining or improving dune condition will be heavily dependent on effective legislative action that affords dunes adequate protection, monitoring, risk mitigation, and restoration where needed.

Climate change is also predicted to impact dune condition and stressors associated with this are expected to exacerbate over the next 10-30 years[51]. See Section D3 for climate change impacts and management actions.

**A4-(i) What monitoring is currently done and how is it reported? (e.g., is there a standard, and how consistently is it used, who is monitoring for what purpose)? Is there a consensus on the most appropriate measurement method?**

The use of a dune condition index has recently been included in State of the Environment monitoring for a number of councils throughout Aotearoa[39, 52]. The condition index used by these councils includes indicators for pressures to dune systems (e.g., livestock, mammalian pest species, human impact) and the ecological state of dunes (e.g., indigenous animal dominance, indigenous and non-indigenous land cover). Each indicator is given a score between zero and five with a low score representing negative condition (e.g., low indigenous vegetation cover, high foot traffic) and a high score representing positive condition (e.g., high indigenous vegetation cover, limited physical disturbance). The scores are then added up and compared against a possible maximum score to determine overall condition. Internationally, dune vulnerability indices have been developed, some of which have been used for forecasting tipping points in future climate-change related scenarios[20-22, 51, 53-56].

Some work has trialled the use of remote sensing (e.g., aerial and satellite images) to estimate dune condition, however, there often remains a need to ground-truth these data to accurately characterise native plant cover[57-59]. However, technological advances may help improve the accuracy of this type of data collection with time (e.g., as suggested for UAVs, [60]).

**A4-(ii) Are there any implementation issues such as accessing privately owned land to collect repeat samples for regulatory informing purposes?**

Dune condition monitoring methods generally require on-the-ground fieldwork for accurate surveys of indigenous vegetation cover. Access is a key consideration given that some dunelands are located on private lands and are therefore subject to the landowner's property and/or customary rights (e.g., for sites within or near Marae domains or Urupā). Accessing private property without the owner's consent can be considered trespassing (if not tapu), so clear communication, establishing good relationships, and addressing any concerns or impacts on the landowner's property or operations will be necessary. Formal access agreements or contracts may need to be established. It is possible that some dunes are not able to be permitted during certain times of year due to ecological factors such as nesting of rare birds.

Various health and safety factors also need to be considered in relation to fieldwork. These include access to the dunes and whether a 4-wheel drive vehicle is required for transport. Depending on the monitoring method being used, technical expertise such as plant species/taxa identification may also be required.

**A4-(iii) What are the costs associated with monitoring the attribute? This includes up-front costs to set up for monitoring (e.g., purchase of equipment) and on-going operational costs (e.g., analysis of samples).**

We anticipate that the main cost to undertake monitoring dune condition is paying field staff for their time. The costs associated with ground-truthing are likely similar to those proposed for surveying estuaries. For example, in 2002 the approximate cost to survey one estuary (for all substrate and vegetation types; this could be analogous to dune extent) following NEMP was estimated to be between $15,000 to $30,000[61]. However, this cost was dependent on the size of estuary (*or dune system*) and whether suitable aerial photographs were available or needed to be obtained for the survey. The approximate cost now (to account for inflation and technological expenses) will likely be higher. Additional costs will relate to personnel time spent reporting results, however, key equipment may also include GPS ($300 - $800), camera and / or cell phone ($100 - $600), clip boards, transects, plant ID guides, and if mapping dune extent as part of the condition index as is currently done, ARC GIS or equivalent software ($100 - $3800)[62].

**A5. Are there examples of this being monitored by Iwi/Māori? If so, by who and how?**

To our knowledge, Māori indicators for dune condition monitoring mainly relate to the presence of native flora (e.g., such as Pingao) and fauna (e.g., such as geckos[1]). We are currently unaware of any Iwi/Māori-led initiatives to monitor dune condition specifically. However, there are several Iwi-led projects to monitor and restore dune wetlands (e.g., [8, 63]). Furthermore, a number of Marae are situated within or near dune systems (e.g., [2,3,4,5]), so it is possible that these Iwi are monitoring dune condition locally, especially with respect to anthropogenic disturbances[6].

**A6. Are there known correlations or relationships between this attribute and other attribute(s), and what are the nature of these relationships?** [Discuss similarities, links, or correlations with other listed attributes. Could the correlated attributes be grouped?]

Active and stable dunes are part of larger, continuous coastal habitats. This means that unobstructed connections with other habitats leads to higher habitat quality and ecological functions than isolated or fragmented dunes, all of which relates to 'dune extent' (encompassed under dune condition) and 'landscape connectivity'. Dunes that offer limited 'access to natural areas' (specifically in relation to human disturbance) may also have less impacted condition and support more diverse, native ecological communities. However, this does not exclude the potential impacts of stressors on adjacent attributes such as 'wetland extent' or 'surface water flow alteration', which can also influence 'indigenous plant dominance'.

[1] See link: Mana whenua guidance key to reptile surveillance - OurAuckland (aucklandcouncil.govt.nz)
[2] See link: Northland marae's concern for wāhi tapu – Te Ao Māori News (teaonews.co.nz)
[3] See link: Te Henga | Maori Maps
[4] See link: Māori cultural sites among most vulnerable to climate change, rising sea levels | Newshub
[5] See link: Bikers tear up eroding Kāwhia Beach dunes, threatening Marae | Stuff
[6] See link: Landowner agrees not to dig Karikari Peninsula's wāhi tapu sand dunes | RNZ News

Dunes are often found between multiple ecosystems, meaning there will likely be a crossover in monitoring methods for 'salt marsh quality and extent', 'seagrass quality and extent', 'lowland forest extent', 'mangrove extent and quality', and, to some extent 'beach litter'. In addition, the 'wetland condition index' is applicable to dune-associated wetlands, such as dune swales [64].

## Part B—Current state and allocation options

### B1. What is the current state of the attribute?

There is substantial evidence that dunes have been lost throughout Aotearoa since initial surveys of dune systems in the early 1900s [23, 25-27, 29, 45, 65-68]. The current state of dune condition is understood at some regional levels (e.g., Hawkes Bay Region [37, 69]) and is reasonably well-understood nationally (e.g., for extent [28, 29, 70]). However, there is some indication that with the spread and intensification of human activity around Aotearoa means that the current (as of 2024) condition of dune systems is likely poor[71].

### B2. Are there known natural reference states described for New Zealand that could inform management or allocation options?

Dune systems that have retained their historical condition and that have limited to no introduced plant species or evidence of human-induced impacts (e.g., vehicular trampling, livestock grazing) could be considered a reference state. Dunes found in remote, protected locations such as those within or in association with national parks national parks may best serve as examples of natural states with limited to no impact from human-induced stressors. However, sites within remote, protected areas may still contain stressors like introduced weeds and mammals and may still be subject to climate change impacts.

Additionally, the United Nations Statistics division has developed a System of Environmental – Economic Accounting, Ecosystem Accounting (SEEA-EA)[1] that assesses a suite of landscape characteristics to quantify ecosystem condition / integrity. The indicators for this are derived from a number of variables in relation to specific reference states for the system in question, e.g., [72]. In the case of dune systems, these indicators include abiotic (e.g., geomorphic alignment of shoreline, number of extreme wave events, and chemical attributes[2]) and biotic (e.g., proportion of native:non-native species, presence of exotic woody species, and the presence of functional, sand-binding species) and were designed to reflect dune condition. Ryan et al. (2023; [72]) implemented this system to provide an updated narrative of dune state throughout Aotearoa and have suggested its use for the development of a globally relevant monitoring framework.

### B3. Are there any existing numeric or narrative bands described for this attribute? Are there any levels used in other jurisdictions that could inform bands? (e.g., US EPA, Biodiversity Convention, ANZECC, Regional Council set limit)

[1] System of Environmental Economic Accounting | UN
[2] Though this is data deficient for dune systems throughout Aotearoa.

See section A4-(i) for more information on how current dune condition indices are calculated in New Zealand. Additionally, the narrative bands used to monitor wetland condition index (which includes dune wetlands) could be modified to inform bands for dune extent[73].

**B4. Are there any known thresholds or tipping points that relate to specific effects on ecological integrity or ~~human health~~?**

Tipping points for dune condition (in respect to dune extent) have been reported internationally for coastal systems (e.g., 0.25 m of sea level rise, [51, 54, 56]), but data for Aotearoa is lacking. The tipping points reported internationally depend on factors such as dune condition, sediment budget, wind intensity, frequency of storm events, and sea level rise (e.g., [51, 56]). For example, increases in variables such as wind speeds, wave action and sea level rise can increase dune erosion resulting in a deficit of sand trapping, which can signal ongoing loss of dune extent, and as a result, condition[74]. Recently, the use of spatial modelling has been employed to forecast future 'tipping-point'[1] scenarios for dune condition in response to climate-change, human use, and/or geologic activity[75-77].

**B5. Are there lag times and legacy effects? What are the nature of these and how do they impact state and trend assessment? Furthermore, are there any naturally occurring processes, including long-term cycles, that may influence the state and trend assessments?**

Lag time between stressor and impact on dune condition will be site- and stressor-dependent. For example, there may limited to no lag time in cases of direct impact and severe physical damage, such as coastal development or recreational vehicles[76]. Alternatively, lag times are expected from the impacts of stressors such as sea level rise due to relatively slow encroachment. Additionally, there are lag times expected from the impact of non-indigenous plant species where there will be a time when these exist as seeds/seedlings before becoming established and spreading. There may also be lag times following coastal development and/or alterations to hydrological flow regimes, which can influence sediment budgets for dune systems[78].

**B6. What tikanga Māori and mātauranga Māori could inform bands or allocation options? How? For example, by contributing to defining minimally disturbed conditions, or unacceptable degradation.**

Mātauranga Māori is inherently place-based and so needs to be considered within a local context. Dunes are valued by Māori as important systems that provide resources for cultural practices (e.g., collecting Pīngao for weaving) and as habitat for taonga species. Indigenous indicators (i.e., specific tohu and/or taonga species) could be used to inform bands/allocation options.

## <u>Part C—Management levers and context</u>

**C1. What is the relationship between the state of the environment and stresses on that state? Can this relationship be quantified?**

In cases where dunes are lost, for example from agricultural, forestry, or infrastructure development, there is an obvious and direct detrimental relationship between the stressor and dune condition [40]. Furthermore, there is also some information for Aotearoa documenting the relationship between

[1] Though not all spatial modelling studies have explicitly referred to these scenarios as 'tipping points'.

dune condition and other physical stressors such as vehicle damage, livestock grazing, trampling, and invasive species incursions[25, 31, 45, 67, 76, 79]. These relationships are currently being quantified as: presence / absence of stressors and certain flora and fauna; % cover / area accessed or disturbed (e.g., as reported by [52, 80]); and in some cases as ratios between native:non-native plant dominance (e.g., for SEE-EA in [72]).

However, there are still challenges associated with disentangling interactions among multiple stressors, respective lag times, additional legacy affects, and overall dune condition. In addition, the impact of stressors on ecosystems is usually highly context-specific (i.e., place and history are very important) and so effective management and needs to understand and allow for that context.

**C2. Are there interventions/mechanisms being used to affect this attribute? What evidence is there to show that they are/are not being implemented and being effective?**

Key management interventions include duneland protection and the elimination or reduction of stressors. From a policy perspective, the RMA (1991) is a key piece of legislation that sets out how we should manage our environment. In addition, the New Zealand Coastal Policy Statement guides councils in their day-to-day management of the coastal environment, which specifically includes dune systems[2]. There are various other relevant government-related directions and management implementations, for example for biosecurity, climate change, wildlife, threatened species and national parks. Some local governments have also instituted specific bylaws for the protection and recovery of dune systems (e.g., vehicle use bylaw, [81]).

A number of councils have active dune management / restoration plans, which may be part of larger shoreline management schemes (e.g., Northland, Auckland, Waikato, Hawkes Bay, Tasman, and Nelson[1]). For example, dune habitats are commonly roped / fenced off to exclude public access along many public beaches throughout Aotearoa to allow for dune recovery / persistence[2, 82]. These rope systems and associated signage discourage the public from trampling sensitive dune fauna and increase awareness of the ecological function of dunes (e.g., as nesting habitat for rare and endemic seabirds[5, 30]).

Active dune restoration is another management intervention that can be carried out to improve quality of dune condition by community groups, councils, DOC, iwi/hapū or others interested in recovering dune habitat [e.g., [62, 83]. For example, a number of coastal care groups (e.g., Coastal Restoration Trust of New Zealand) are actively involved in re-vegetating dune systems with native flora (e.g., [83]). Dune species are grown in some commercial/specialised nurseries and are widely available for these kinds of restoration projects. Furthermore, there have been several guides produced to inform the use of various species used in dune restoration to inform restoration efforts [e.g., see[38, 49, 50, 84-87]]. There is also potential to consider dune restoration for flood and sea level rise mitigation as suggested by [88].

**C2-(i). Local government driven**

A number of local government-driven initiatives are present throughout Aotearoa aimed at restoring dune habitat. Some examples include the restoration of endemic dune species such as Pīngao and spinifex at sites around Timaru [47]; urban dune habitats along the Coromandel coastline [46]; and Ngarahae Bay, West Coast North Island [48], to name a select few. Additional projects can be found at

[1] https://www.doc.govt.nz/get-involved/run-a-project/restoration-advice/dune-restoration/

the websites for the Coastal Restoration Trust of New Zealand[1], Waikato Regional Council Coastcare groups[2], and for international projects, in [89].

**C2-(ii). Central government driven**

Central government can provide key funding for the protection, conservation and restoration of dunelands. For example, the recently completed NZ SeaRise Te Tai Pari O Aotearoa[3] project that projects sea level rise around New Zealand could be used to help prioritise future restoration projects at vulnerable coastal areas. There is also potential to consider dune restoration for shoreline management and/or conservation plans supported by the Department of Conservation (e.g., the Auckland Regional Council Shoreline Adaptation Programme[4]; Rakiura Conservation Management Strategy[90]).

**C2-(iii). Iwi/hapū driven**

We understand that Māori could offer protection to dune habitats through rāhui (e.g., Pakiri Beach, Auckland[5]). We are also aware of a small number of Iwi-led restoration projects for dune adjacent habitats (e.g., dune wetlands, [8, 63]). Also refer to footnotes 14-19 for articles related to interventions being used to improve / protect dune condition.

**C2-(iv). NGO, community driven**

A number of community-driven dune restoration projects exist throughout Aotearoa. A notable NGO is the Coastal Restoration Trust of New Zealand (previously called The Dune Restoration Trust of New Zealand), which has developed a comprehensive guide and monitoring scheme for dune restoration projects throughout the country[83]. This guide has been, or is being, used by several partner councils and government agencies (e.g., Christchurch City Council, Department of Conservation, Environment Canterbury Regional Council, Northland Regional Council, the Greater Wellington Regional Council)[6]. Additional projects include the Native Forest Restoration Trust[7], DUNE, the Whāngaimoana Dune Restoration Group, and Onetangi Beach Dune Restoration, to name a select few (for a comprehensive list of coastal restoration groups see footnote 24). International NGOs, such as The Nature Conservancy, are also active in New Zealand[8] and provide support for conservation initiatives and nature-based solutions, which can include increasing dune condition through planting of native vegetation.

**C2-(v). Internationally driven**

Restoring the vitality of degraded systems (which include dune ecosystems) is crucial for fulfilling the UN Sustainable Development Goals and for meeting the targets of the UN Decade (2021-2030) on Ecosystem Restoration (UN-DER). Under the Convention to Biological Diversity (CBD), Aotearoa is required to have a national biodiversity strategy and action plan through which obligations under the CBD are delivered. Aotearoa has international climate change obligations such as those under the Paris Agreement. We understand that Aotearoa has also signed other international agreements (e.g.,

---

[1] https://www.coastalrestorationtrust.org.nz/coast-care-groups/groups/
[2] https://storymaps.arcgis.com/stories/14b535daa5ae4aae820d1be774f740b7
[3] https://www.searise.nz/
[4] https://www.aucklandcouncil.govt.nz/plans-projects-policies-reports-bylaws/our-plans-strategies/topic-based-plans-strategies/environmental-plans-strategies/shoreline-adaptation-programme/Pages/shoreline-adaptation-plans.aspx
[5] https://www.localmatters.co.nz/news/tangata-whenua-closes-beach/
[6] See link: Research Partners • Coastal Restoration Trust of New Zealand
[7] https://www.nfrt.org.nz/reserves/oreti-totara-dune-forest/
[8] https://www.nature.org/en-us/about-us/where-we-work/asia-pacific/new-zealand/stories-in-new-zealand/our-work-in-new-zealand/

Free Trade) that require conditions around environmental management to be upheld. Additionally, the Ramsar Convention of which Aotearoa is a signatory meaning it plays a part in the international effort to conserve wetlands, which includes dune slacks and lakes[91].

## Part D—Impact analysis

### D1. What would be the environmental impacts of not managing this attribute?

Failing to manage dune condition poses a significant threat to coastal environments, triggering a cascade of ecological problems. For example, increased physical disturbance from vehicle traffic or livestock grazing can lead to the loss of endemic, sand-trapping flora, which can lead to a severe reduction of condition and eventually loss of dunes. With this comes a loss of coastal protection and habitat for critically endangered endemic species, which is partially reflected in the decline of bird populations[10]. The incursion of invasive flora species, like Marram grass, can over-stabilise dunes, upsetting coastal sediment budgets through increased erosion, leading to increased degradation of adjacent shoreline habitats (e.g., [31, 32]).

Additionally, the loss of dunes can allow for saltwater intrusion into coastal aquifers and wetlands, which can substantially alter ecosystems, leading to further loss of endemic species[92]. This influx of sea water may disrupt the delicate balance of coastal marine life and can sever vital links in the coastal marine food web, which can have cascading impacts on the overall health, biodiversity, and thus ecological integrity of coastal ecosystems[72, 93].

### D2. Where and on who would the economic impacts likely be felt? (e.g., Horticulture in Hawke's Bay, Electricity generation, Housing availability and supply in Auckland)

The economic impacts are likely to be felt among coastal infrastructure development and tourism sectors. Reductions in dune condition could lead to a loss of habitat for critically endangered bird species, which limits coastal tourism opportunities for certain groups (e.g., birders) and local businesses (e.g., [94]). Reductions in dune condition can also limit their protective capacity as natural buffers that absorb wave energy and lessen the impact of tidal flooding and storm surges[3, 12, 23, 77]. The loss of dunes exposes coastlines to increased erosion, leading to a retreat of beaches, coastal wetlands, and lowland forest, which may lead to a heightened risk of damage to coastal infrastructure and sensitive adjacent habitats such as dune slacks[18, 21, 95].

Reductions in dune condition can also impact the loss of culturally important sites, such as Marae and / or Urupā[1,][96]. The loss of dune systems can directly influence tikanga practices, which can diminish mana over associated resources and / or areas [97-99].

### D3. How will this attribute be affected by climate change? What will that require in terms of management response to mitigate this?

Sea level rise and increased storm frequency is expected to lead to the erosion and loss of dune habitat [92, 93, 100, 101]. Sea level rise may also result in reduction in dune extent, and thus condition, due to 'coastal squeeze' if habitat is not available for it to migrate to due to the presence of roads, urban

[1] See link: Tairāwhiti marae facing 'devastating' loss of urupā as heavy rain lashes Gisborne region | Stuff

areas, stopbanks, or agricultural land directly inland from current dunes [89, 102]. Increased storm frequency will likely lead to increased flooding, which will likely impact coastal sediment budgets and coastal erosion processes[95, 103]. Changes to vegetative cover, at times due to increasing temperature, can alter dune faunal community structure and lead to further range shifts and incursions of invasive species. Increased intensity of fires as a result of climate related issues, such as drought poses an additional risk to the recovery of dune species, however there is some indication that this does not contribute to dune instability [104, 105]. In addition, increasing temperatures may also reduce below-ground biomass for certain dune vegetation species, which can reduce dune accretion and subsequent stabilisation (e.g., as seen in China[106]).

**Reference list:**

[1] Dahm, J. and G. Jenks, *Community-based dune management for the mitigation of coastal hazards and climate change effects: A guide for local authorities*. 2005, Eco Nomos Ltd. p. 1-36.

[2] Conservation, D.o., *New Zealand coastal policy statement 2010*. 2010, Department of Conservation. p. 1-30.

[3] Feagin, R.A., et al., *Going with the flow or against the grain? The promise of vegetation for protecting beaches, dunes, and barrier islands from erosion.* Frontiers in Ecology and the Environment, 2015. **13**(4): p. 203-210.

[4] Patrick, B., *Conservation status of the New Zealand red katipo spider (Latrodectus katipo Powell, 1871)*, in *Science for conservation*. 2002, Department of Conservation: Wellington, New Zealand. p. 1-9.

[5] Ferreira, S.M., et al., *Conservation of the endangered New Zealand fairy tern.* Biological Conservation, 2005. **125**(3): p. 345-354.

[6] Küchly, H. and S. Hartley, *Monitoring coastal sand dune vegetation communities for conservation*. 2006, Victoria University of New Zealand: Wellington, New Zealand. p. 1-86.

[7] Bergin, D., et al., *Pingao Golden Sand Sedge: sustainable harvesting of Pingao for weaving*. 2011, Coastal Restoration Trust of New Zealand: Online. p. 1-8.

[8] Huia Christine Spinks, A., *Restoring the Mauri of Coastal Dune Lake Ecosystems: The case study of Lake Waiorongomai, Ōtaki Aotearoa / New Zealand*, in *Resource and Environmental Planning*. 2018, Massey University: Palmerston North, New Zealand. p. 1-653.

[9] Conservation, D.o., *Coastal foredunes in Wellington*. 2003, Department of Conservation: Wellington, New Zealand. p. 1-4.

[10] Robertson, H.A., et al., *Conservation status of birds in Aotearoa New Zealand, 2021*. 2021, Department of Conservation: Wellington, New Zealand. p. 1-47.

[11] Moore, P.J., et al., Dune restoration in northern Chatham Island A trial to enhance nesting opportunities for Chatham Island oystercatchers (Haematopus chathamensis). 2012, Department of Conservation: Wellington, New Zealand. p. 1-69.

[12] Bergin, D., et al., *Climate change effects and the importance of sand dunes*. 2011, Coastal Restoration Trust of New Zealand: Online. p. 1-8.

[13] Read, D.J., *Mycorrhizas and nutrient cycling in sand dune ecosystems.* Proceedings of the Royal Society of Edinburgh. Section B. Biological Sciences, 2011. **96**: p. 89-110.

[14] Sevink, J., *Soil development in the coastal dunes and its relation to climate.* Landscape Ecology, 1991. **6**(1-2): p. 49-56.

[15] Kocurek, G., et al., *Dune and dune-field development on Padre Island, Texas, with implications for interdune deposition and water-table-controlled accumulation.* Journal of Sedimentary Research, 1992. **62**(4): p. 622-635.

[16] Everard, M., L. Jones, and B. Watts, *Have we neglected the societal importance of sand dunes? An ecosystem services perspective.* Aquatic Conservation: Marine and Freshwater Ecosystems, 2010. **20**(4): p. 476-487.

[17] Pintó, J., C. Martí, and R.M. Fraguell, *Assessing Current Conditions of Coastal Dune Systems of Mediterranean Developed Shores.* Journal of Coastal Research, 2014. **30**(4): p. 832-842.

[18] Pinna, M.S., et al., *Assessing the potential for restoring Mediterranean coastal dunes under pressure from tourism.* Journal of Coastal Conservation, 2022. **26**(3): p. 1-14.

[19] Williams, A.T. and P. Davies, *Coastal dunes of Wales; vulnerability and protection.* Journal of Coastal Conservation, 2001. **7**: p. 145-154.

[20] Sancho, F., F.S. Oliveira, and P. Freire, *Coastal dunes vulnerability indexes: a new proposal and aplication to Ria Formosa coast (Portugal).* Coastal Engineering, 2012: p. 1-12.

[21] Ciccarelli, D., et al., *Development of a coastal dune vulnerability index for Mediterranean ecosystems: A useful tool for coastal managers?* Estuarine, Coastal, and Shelf Science, 2017. **187**: p. 84-95.

[22] Bertoni, D., et al., *Implementing a Coastal Dune Vulnerability Index (CDVI) to support coastal management in different settings (Brazil and Italy).* Ocean & Coastal Management, 2019. **180**: p. 104916.

[23] Bergin, D., et al., *Why do we need to restore our coastal dunes?* 2011, Coastal Restoration Trust of New Zealand: Online. p. 1-4.

[24] Council, N.R., *Northland's Coast and Us: Our dunes*. 2024.

[25] Jamieson, S.L., *Sand dune restoration in New Zealand: methods, motives, and monitoring*, in *School of Biological Sciences*. 2010, Victoria University Wellington: Wellington, New Zealand. p. 1-169.

[26] Walls, G., *Simply sand? Ocean Beach dunes, Hawkes Bay*. 1998, Department of Conservation: Wellington, New Zealand. p. 1-17.

[27] Holdaway, R.J., S.K. Wiser, and P.A. Williams, *Status assessment of New Zealand's naturally uncommon ecosystems.* Conservation Biology, 2012. **26**(4): p. 619-29.

[28] Ryan, C., et al., *Ecosystem integrity of active sand dunes: A case study to implement and test the SEEA-EA global standard, from Aotearoa New Zealand.* Ecological Indicators, 2023. **149**: p. 1-14.

[29] NZ, S. *Active sand dune extent*. New Zealand’s environmental reporting series: Our land 2024 2024 [cited 2024 11-5-24]; Available from: https://www.stats.govt.nz/indicators/active-sand-dune-extent/.

[30] Brooks, J., et al., *Issues and options for the conservation and recovery of the critically endangered New Zealand Fairy Tern*. 2011, Royal Forest & Bird Protection Society of New Zealand. p. 1-54.

[31] Rapson, G.L., A.L. Murphy, and A.R. Smith, *Invasive species over-stabilise the vegetation of a mobile dunefield, Manawatū, New Zealand, disrupting natural succession.* Vegetation Classification and Survey, 2023. **4**: p. 343-360.

[32] Hilton, M.J., *The loss of New Zealand's active dunes and the spread of marram grass (Ammophila arenaria).* New Zealand Geographer, 2006. **62**(2): p. 105-120.

[33] Gadgil, R.L. and F.J. Ede, *Application of scientific principles to sand dune stabilization in New Zealand: past progress and future needs.* Land Degradation & Development, 1998. **9**(2): p. 131-142.

[34] Bergin, D., et al., *Pingao Golden Sand Sedge: ecology, distribution and habitat*. 2011, Coastal Restoration Trust of New Zealand: Online. p. 1-8.

[35] Bergin, D., et al., *Spinifex Kowhangatara: Ecology, habitat and growth*. 2011, Coastal Restoration Trust of New Zealand: Online. p. 1-12.

[36] Smith, S.M., R.B. Allen, and B.K. Daly, *Soil-vegetation relationships on a sequence of sand dunes, Tautuku Beach, South-east Otago, New Zealand.* Journal of the Royal Society of New Zealand, 1985. **15**(3): p. 295-312.

[37] Madarasz-Smith, A. and B. Shanahan, *State of the Hawke's Bay Coastal Marine Environment: 2013 to 2018*. 2020, Hawkes Bay Regional Council. p. 1-136.

[38] Bergin, D., et al., *Weed control: options for planting natives on sand dunes*. 2011, Coastal Restoration Trust of New Zealand. p. 1-4.

[39] Uys, R. and P. Crisp, *Duneland Health State of the Environment monitoring programme: Annual Data Report 2017/18 and 2018/19*, in *Duneland Health State of the Environment monitoring programme*. 2019, Greater Wellington Regional Council: Wellington, New Zealand. p. 1-30.

[40] Whitehead, P.S., *Sand dune reclamation in New Zealand.* New Zealand Journal of Forestry, 1964. **9.2**: p. 146-153.

[41] Comfort, J.A. and M.B. Single, *Literature review on the effects of seawalls on beaches*. 1997, Department of Conservation: Wellington, New Zealand. p. 1-10.

[42] García-Mora, M.R., et al., *A coastal dune vulnerability classification. A case study of the SW Iberian Peninsula.* Journal of Coastal Research, 2001: p. 802-811.

[43] Matias, A., et al., *Development of indices for the evaluation of dune recovery techniques.* Coastal Engineering, 2004. **51**(3): p. 261-276.

[44] Gao, J., D.M. Kennedy, and T.M. Konlechner, *Coastal dune mobility over the past century: A global review.* Progress in Physical Geography: Earth and Environment, 2020. **44**(6): p. 814-836.

[45] Bergin, D., et al., *Effects of vehicles on sand dunes*. 2011, Coastal Restoration Trust of New Zealand: Online. p. 1-12.

[46] Bergin, D., et al., *Restoring degraded urban dunes case study - Eastern Coromandel*. 2011, Coastal Restoration Trust of New Zealand: Online.

[47] Bergin, D., et al., *Establishing Natives on sand dunes case study - Caroline Bay, Timaru*. 2011, Coastal Restoration Trust of New Zealand: Online. p. 1-12.

[48] Bergin, D., et al., *Restoring windblown dunes using native plants: Difficult sites case study - Ngarahae Bay, west coast North Island*. 2011, Coastal Restoration Trust of New Zealand: Online. p. 1-12.

[49] Bergin, D., et al., *Pingao Golden Sand Sedge: guidelines for seed collection, propagation and establishment*. 2011, Coastal Restoration Trust of New Zealand: Online. p. 1-12.

[50] Bergin, D., et al., *Spinifex Kowhangatara: guidelines for seed collection, propagation and establishment*. 2011, Coastal Restoration Trust of New Zealand: Online. p. 1-12.

[51] Sharples, C., et al., *Ocean Beach, Tasmania: A swell-dominated shoreline reaches climate-induced recessional tipping point?* Marine Geology, 2020. **419**.

[52] Madarasz-Smith, A. and B. Shanahan, *State of the Hawke's Bay coastal marine environment: 2013-2018*, H.B.R. Council, Editor. 2020, Hawkes Bay Regional Council: Napier, New Zealand. p. 1-136.

[53] Judge, E.K., M.F. Overton, and J.S. Fisher, *Vulnerability indicators for coastal dunes.* Journal of Waterway, Port, and Ocean Engineering, 2003. **129**(6): p. 270-278.

[54] Barnard, P.L., et al., *Multiple climate change-driven tipping points for coastal systems.* Scientific Reports, 2021. **11**(1): p. 1-13.

[55] Cohn, N., et al., *Simulating tipping points in future dune states with dune response tool.* Coastal Sediments 2023: The Proceedings of the Coastal Sediments 2023, 2023: p. 596-608.

[56] Kwadijk, J.C.J., et al., *Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands.* Wiley interdisciplinary reviews: climate change, 2010. **1**(5): p. 729-740.

[57] Schattschneider, J. and L. Floerl, *Evaluation of suitability of satellite and aerial imagery as data sources for dune vegetation classification, mapping, and monitoring*. 2022, Cawthron Institute: Nelson, New Zealand. p. 1-20.

[58] Bilkey, J., *Sand dune vegetation monitoring and assessment using UAV remote sensing: A case study for Karekare Beach, Auckland Region, New Zealand*, in *School of Science*. 2022, Auckland University of Technology. p. 1-102.

[59] Carboni, M., M.L. Carranza, and A. Acosta, *Assessing conservation status on coastal dunes: A multiscale approach.* Landscape and Urban Planning, 2009. **91**(1): p. 17-25.

[60] Cruz, C., et al., *Assessing the effectiveness of UAV data for accurate coastal dune habitat mapping.* European Journal of Remote Sensing, 2023. **56**(1): p. 1-18.

[61] Robertson, B.M., et al., *Estuarine Environmental Assessment and Monitoring: A National Protocol*, in *PART C:*

*Application of the Estuarine Monitoring Protocol*. 2002, Cawthron Institute. p. 1-47.

[62] Bergin, D. and M. Bergin, *Development of community-based monitoring methods for coastal dunes of the Bay of Plenty Region*. 2018, Environmental Restoration Ltd. p. 1-36.

[63] Smith, H., *Hei whenua ora: hapū and iwi approaches for reinstating valued ecosystems within cultural landscape*, in *Te Pūtahi ā Toi, School of Māori Studies*. 2007, Massey University: Palmerston North, New Zealand. p. 1-12.

[64] Clarkson, B.R., et al., *Handbook for monitoring wetland condition*. 2003: Ministry for the Environment. 1-73.

[65] Hilton, M., U. Macauley, and R. Henderson, *Inventory of New Zealand's active dunelands*. 2000, Department of Conservation. p. 1-34.

[66] Selby, M.J., *The Relationships Between Land Use and Erosion in the Central North Island, New Zealand.* Journal of Hydrology (New Zealand), 1972. **11**(2): p. 73-87.

[67] Bergin, D., et al., *Human modification of New Zealand coastal dune ecosystems*. 2011, Coastal Restoration Trust of New Zealand: Online. p. 1-12.

[68] Cockayne, L., *Report on the dune-areas of New Zealand, their geology, botany and reclamation.* 1911, Department of Lands: Wellington, New Zealand. p. 1-76.

[69] Council, H.B.R., *State of the Environment Report Card 2018: How do our sand dunes stack up?* 2018, Hawkes Bay Regional Council: Online. p. 1-2.

[70] Environment, M.f.t. and S. NZ, *Our marine environment 2022*, in *New Zealand's Environmental Reporting Series*. 2022, Ministry for the Environment: Wellington, New Zealand. p. 1-29.

[71] Keith, H., et al., *A conceptual framework and practical structure for implementing ecosystem condition accounts.* One Ecosystem, 2020. **5**: p. 1-55.

[72] Ryan, C., et al., *Ecosystem integrity of active sand dunes: A case study to implement and test the SEEA-EA global standard, from Aotearoa New Zealand.* Ecological Indicators, 2023. **149**.

[73] Clarkson, B.R., et al., *Handbook for monitoring wetland condition*. 2004, Ministry for the Environment: Hamilton, New Zealand. p. 73.

[74] Sharples, C., et al., *Ocean Beach, Tasmania: A swell-dominated shoreline reaches climate-induced recessional tipping point?* Marine Geology, 2020. **419**: p. 1-14.

[75] Lam, D.K., T.K. Remmel, and T.D. Drezner, *Tracking Desertification in California Using Remote Sensing: A Sand Dune Encroachment Approach.* Remote Sensing, 2010. **3**(1): p. 1-13.

[76] Orchard, S., H.S. Fischman, and D.R. Schiel, *Managing beach access and vehicle impacts following reconfiguration of the landscape by a natural hazard event.* Ocean & Coastal Management, 2022. **220**: p. 1-32.

[77] Santos, V.M., et al., *Combining Numerical and Statistical Models to Predict Storm-Induced Dune Erosion.* Journal of Geophysical Research: Earth Surface, 2019. **124**(7): p. 1817-1834.

[78] Bergin, D., et al., *Shoreline changes at river and tidal entrances*. 2011, Coastal Restoration Trust of New Zealand: Online. p. 1-8.

[79] Pegman, M. and G.L. Rapson, *Plant succession and dune dynamics on actively prograding dunes, Whatipu Beach, northern New Zealand.* New Zealand Journal of Botany, 2005. **43**(1): p. 223-244.

[80] Uys, R. and P. Crisp, *Duneland health State of the Environment monitoring programme: annual data report 2017/18 and 2018/19*. 2019, Greater Wellington Regional Council: Wellington, New Zealand. p. 1-30.

[81] Council, M.R., *East coast beach vehicle bylaw*, M.R. Council, Editor. 2023. p. 1-24.

[82] Bergin, D., et al., *Accessways on coastal sand dunes*. 2011, Coastal Restoration Trust of New Zealand: Online. p. 1-12.

[83] Bergin, D., et al., *Restoration of Coastal Sand Dunes Using Native Plants: Technical Handbook*. 2011, Coastal Restoration Trust of New Zealand: Online.

[84] Bergin, D., et al., *Planting natives on sand dunes: getting started*. 2011, Coastal Restoration Trust of New Zealand: Online. p. 1-2.

[85] Bergin, D., et al., *Ground cover plants for the restoration of backdunes*. 2011, Coastal Restoration Trust of New Zealand: Online. p. 1-8.

[86] Bergin, D., et al., *Native trees and shrubs to use on backdunes*. 2011, Coastal Restoration Trust of New Zealand: Online. p. 1-8.

[87] Bergin, D., et al., *Restoration of Sand Daphne (Pimelea villosa) on coastal dunes - a plant in decline*. 2011, Coastal Restoration Trust of New Zealand: Online. p. 1-8.

[88] Fernández-Montblanc, T., E. Duo, and P. Ciavola, *Dune reconstruction and revegetation as a potential measure to decrease coastal erosion and flooding under extreme storm conditions.* Ocean & Coastal Management, 2020. **188**: p. 1-45.

[89] Martínez, M.L., J.B. Gallego-Fernández, and P.A. Hesp (Eds.), *Restoration of Coastal Dunes*. 2013: Springer. 344.

[90] Conservancy, S., *Stewart Island/Rakiura conservation management strategy and Rakiura National Park management plan*. 2012, Department of Conservation. p. 1-316.

[91] Denyer, K. and H.A. Robertson, *National guidelines for the assessment of potential Ramsar wetlands in New Zealand*. 2016, Department of Conservation: Wellington, New Zealand. p. 1-62.

[92] White, E. and D. Kaplan, *Restore or retreat? saltwater intrusion and water management in coastal wetlands.* Ecosystem Health and Sustainability, 2017. **3**(1): p. 1-18.

[93] Sorensen, R.M., R.N. Weisman, and G.P. Lennon, *Control of erosion, inundation, and salinity intrusion caused by sea level rise*, in *Greenhouse effect and sea level rise. A challenge for this generation.* 1984, Van Nostran Reinhold Company Inc: New York, United States. p. 1-27.

[94] Narayan, S., et al., *The Effectiveness, Costs and Coastal Protection Benefits of Natural and Nature-Based Defences.* PLoS One, 2016. **11**(5): p. 1-17.

[95] Van der Biest, K., et al., *Dune dynamics safeguard ecosystem services.* Ocean & Coastal Management, 2017. **149**: p. 148-158.

[96] Bailey-Winiata, A.P.S., *Understanding the potential exposure of coastal marae and urupā in Aotearoa New Zealand to sea level rise*, in *Earth Science*. 2021, The University of Waikato. p. 1-157.

[97] Awatere, S., et al., *He Huringa Āhuarangi, he Huringa Ao: A Changing Climate, a Changing World*. 2021, Ngā Pae o te Māramatanga: Online. p. 1-12.

[98] Harmsworth (Te Arawa, N.T., Ngāti Raukawa), Garth R. and S. Awatere (Ngāti Porou), *Indegenous Māori knowledge and perspectives of ecosystems*, in *Ecosystem services in New Zealand – conditions and trends*. 2013, Manaaki Whenua Press: Lincoln, New Zealand. p. 1-13.

[99] Environment, M.f.t. and S. NZ, *New Zealand's Environmental Reporting Series: Our land 2024*, in *New Zealand's Environmental Reporting Series*. 2024, Ministry for the Environment and Stats NZ: Online. p. 1-65.

[100] Ranwell, D.S. and R. Boar, *Coast dune management guide*. 1986, University of East Anglia: Norwich, United Kingdom. p. 1-116.

[101] Kwadijk, J.C.J., et al., *Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands.* WIREs Climate Change, 2010. **1**(5): p. 729-740.

[102] Pontee, N., *Defining coastal squeeze: A discussion.* Ocean & Coastal Management, 2013. **84**: p. 204-207.

[103] Ajedegba, J.O., H.L. Perotto-Baldivieso, and K.D. Jones, *Coastal Dune Vegetation Resilience on South Padre Island, Texas: A Spatiotemporal Evaluation of the Landscape Structure.* Journal of Coastal Research, 2019. **35**(3): p. 1-11.

[104] Shumack, S. and P. Hesse, *Assessing the geomorphic disturbance from fires on coastal dunes near Esperance, Western Australia: Implications for dune de-stabilisation.* Aeolian Research, 2018. **31**: p. 29-49.

[105] Shumack, S., P. Hesse, and L. Turner, *The impact of fire on sand dune stability: Surface coverage and biomass recovery after fires on Western Australian coastal dune systems from 1988 to 2016.* Geomorphology, 2017. **299**: p. 39-53.

[106] Luo, Y., et al., *Plant responses to warming and increased precipitation in three categories of dune stabilization in northeastern China.* Ecological Research, 2017. **32**(6): p. 887-898.