6.2 Dune extent

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

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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 of coastal dune extent can be broadly applied to all dune systems. Also note that dune 'extent' is encompassed under dune 'condition index' given extent is one indicator of dune condition.

State of knowledge of the "Dune Extent" attribute: Overall, we consider the state of knowledge for the dune extent 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 extent to ecological integrity. New Zealand-specific data that quantifies stressor impacts on 'dune extent' 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 for monitoring coastal dune condition exists (which encompasses dune extent), however to our knowledge this has only been adopted for a handful of councils and data on tipping points are lacking. Monitoring of dune extent is not routinely carried out across the country, leading to a lack of national-scale data for comparison of dune extent growth and/or loss.

Part A—Attribute and method

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

[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)

There is excellent evidence globally and in Aotearoa New Zealand (hereafter Aotearoa) to show that dune extent is closely tied with ecological 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[9] 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, coastal (and terrestrial) dune habitats are endangered and also support various threatened and critically endangered plant and animal species including a number of arachnid[4], lizard[10], and bird species[5, 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]. 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 strong evidence of the impact of degraded dune extent on the ecological integrity of coastal systems (e.g., globally[16-22], for Aotearoa[12, 23-27]). Fragmentation and loss of coastal dunes from stressors like coastal development, beach renourishment programs, fire, recreation, invasive species, and climate change has led to a severe reduction in dune 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]) and animal species (e.g., rabbits, [32]) 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, 33-38].

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)?

Both globally and nationally, coastal dune extent has declined significantly over time, particularly due to historic land reclamation (for agriculture, forestry, and/or development, [39, 40]), coastal infrastructure development / hardening (e.g., groins, seawalls, and dykes, [41-43]), livestock grazing [32, 40], recreation [44, 45], and invasive species [31]. Nationally, this is also the case for volcanic and inland dune systems, the latter of which were once regarded as 'useless sand wastes' (see the link at footnotes 3 and 4 for further details)[46-48]. It is likely that over the next 10 – 30 years, the interactions among sustained stressors will continue to reduce dune extent (for all types of dunes, globally and nationally), 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 extent (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.

some degree, by locally-led management and restoration programs (e.g., [49-51]). However, many of these dunes (especially near urban or developed areas) are generally in a degraded state (e.g., moderate to poor, [38]). 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[52, 53]). This means that retaining or improving dune extent 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 extent and stressors associated with this are expected to exacerbate over the next 10-30 years[54]. See Section D3 for climate change impacts and management actions. It should be noted that, internationally, the expansion of dune extent as a result of climate change may also be a wider sign of desertification (e.g.,[55]). However, we are not aware of any evidence of this occurring for Aotearoa.

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?

In Aotearoa, active dune extent has been determined (albeit infrequently) from coastal monitoring programmes, published topographic maps, aerial and satellite imagery mapping [29]. We are aware of one standardised monitoring protocol for dune extent throughout Aotearoa produced by the Coastal Restoration Trust of New Zealand[56-58]. This protocol is used by a handful of regional/city councils to determine the state and condition of dunes within their management areas (e.g., Greater Wellington[59], Bay of Plenty[56], Northland[1], Canterbury, Christchurch). Additional councils monitor dune condition as part of their state of environment monitoring, which includes pressures (e.g., livestock, mammalian pest species, human impact) and the ecological state of dune systems (e.g., indigenous animal dominance, indigenous and non-indigenous land cover; e.g., Hawkes Bay Regional Council [60]).

Some work has trialled the use of remote sensing (e.g., aerial and satellite images) to estimate dune extent (with respect to dune condition), however, there often remains a need to ground-truth these data as there is often interest to include the extent and coverage of native plant cover[61-63]. Furthermore, these broad scale mapping methods may be limited for identifying the spatial extent of active and stable sand dunes due to high variation in classification methods for land types, making accurate assessments of extent difficult (e.g., [64, 65]). However, technological advances may help improve the accuracy of this type of data collection with time (e.g., as suggested for UAVs, [66]).

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

In general, mapping dune extent can be achieved through remote sensing platforms (for more see section A4-[i] and [62]). For this, there is a need for technical expertise such as mapping/GIS skills. However, some extent monitoring methods may require on-the-ground fieldwork (i.e., for ground-truthing). For ground-truthing, 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.,

[1] See link: Coastal State of the Environment monitoring - Northland Regional Council (nrc.govt.nz)

for sites within or near Marae or Urupā). Accessing private property without the owner's consent can be considered trespassing, 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 permitted to be accessed 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).

Most costs of monitoring dune extent will relate to personnel time spent collecting data, mapping and reporting results, which can cost more than tens of thousands of dollars of labour time depending on size of the dune (estimated pricing for remote mapping of vegetation structural classes for unmapped dune systems, [61]). Key equipment includes a computer set-up with sufficient computational power to support ARC GIS or equivalent software (estimated as $1000 - $3800 total).

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[67]. 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 differ.

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

Māori indicators for dune monitoring mainly relate to the presence of native flora (e.g., such as Pīngao) and fauna [102].

We are currently unaware of any monitoring of dune extent being undertaken by iwi/hapū/rūnanga.

A6. Are there known correlations or relationships between this attribute and other attribute(s), and what are the nature of these relationships?

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 condition index' and 'landscape connectivity'. Dunes that offer limited 'access to natural areas' (specifically in relation to human disturbance) may also have less impact to extent and support more diverse 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 influence the formation of dunes.

Dunes are often found between multiple ecosystems, meaning there will likely be a crossover in monitoring methods for 'dune condition', 'salt marsh quality', 'seagrass quality', 'lowland forest

extent', 'mangrove extent and quality', and, to some extent 'beach litter'. In addition, the 'wetland condition index' and 'wetland extent' are applicable to dune-associated wetlands, such as dune swales [68, 69]. Provided there is sufficient data resolution to assess dune condition (i.e., that can suitably measure indigenous vs non-indigenous species), methods for monitoring 'indigenous plant dominance' in the terrestrial domain may also overlap with those used to measure dune extent.

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, 44, 70-72]. The current state of dune extent is well understood at some regional levels (e.g., Hawkes Bay Region [36, 73]) and is reasonably well understood nationally (e.g., [28, 29, 74]). However, there is some indication that, with the spread and intensification of human activity around Aotearoa, the current (as of 2024) extent of dune systems remains unknown (as suggested by [28]).

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

The active nature of sand dunes (i.e., resulting from processes of accretion and erosion) means that assessing natural reference states for dune extent is likely difficult, if not impossible, due to the inherently variable nature of dune systems. However, 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 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.

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)

To our knowledge, there are no known numeric or narrative bands that specifically describe dune extent. The use of a dune condition index (which includes aspects related to dune extent) has recently been included in State of the Environment monitoring for a number of councils throughout Aotearoa[38, 60]. 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. Additionally, the narrative bands used to monitor wetland condition index (which includes dune wetlands) could be modified to inform bands for dune extent[69].

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

Tipping points for dune extent have been reported internationally for coastal systems (e.g., 0.25 m of sea level rise, [54, 75, 76]), 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., [54, 76]). 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 [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[78]. 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[79].

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. In addition to discussing this attribute directly with iwi/hapū/rūnanga, there is likely to be tikanga and mātauranga Māori relevant to informing bands, allocation options, minimally disturbed conditions and/or unacceptable degradation in treaty settlements, cultural impact assessments, environment court submissions, iwi environmental management and climate change plans.

Part C—Management levers and context

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 can be an obvious and direct detrimental relationship between the stressor and dune extent [39]. Furthermore, there is also some information for Aotearoa documenting the relationship between dune extent and other physical stressors such as vehicle damage, livestock grazing, trampling, and invasive species incursions[25, 31, 44, 72, 78, 80]. However, there are still challenges associated with disentangling interactions among multiple stressors, respective lag times, additional legacy affects, and overall dune extent. 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?

C2-(i). Local government driven

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]).

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]).

Active dune restoration is another management intervention that can be carried out to improve dune extent by community groups, councils, DOC, iwi/hapū or others interested in recovering dune habitat [e.g., [56, 58]. 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., [58]). Dune species are grown in some commercial/specialised nurseries and are widely available for these kinds of restoration projects. There is also potential to consider dune restoration to enhance dune extent for flood and sea level rise mitigation as suggested by [83].

A number of local government-driven initiatives are present throughout Aotearoa aimed at restoring dune habitat. Examples include the restoration of endemic dune plant species such as pīngao and spinifex at sites around Timaru [50]; urban dune habitats along the Coromandel coastline [49]; and Ngarahae Bay, West Coast North Island [51]. Additional projects can be found at the websites for the Coastal Restoration Trust of New Zealand[2], Waikato Regional Council Coastcare groups[3], and in [84].

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[4] 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

[1] https://www.doc.govt.nz/get-involved/run-a-project/restoration-advice/dune-restoration/
[2] https://www.coastalrestorationtrust.org.nz/coast-care-groups/groups/
[3] https://storymaps.arcgis.com/stories/14b535daa5ae4aae820d1be774f740b7
[4] https://www.searise.nz/

Auckland Regional Council Shoreline Adaptation Programme[1]; Rakiura Conservation Management Strategy [85]).

C2-(iii). Iwi/hapū driven

We understand that Māori could offer protection to dune habitats through rāhui (e.g., Pakiri Beach, Auckland[2]). We are also aware of a small number of Iwi-led restoration projects for dune adjacent habitats (e.g., dune wetlands, [8, 86]). Iwi planning documents such as Environmental Management Plans and Climate Change Strategies/Plans may contain policies/objectives/methods seeking to influence dune quality outcomes for the benefit of current and future generations.

C2-(iv). NGO, community driven

A number of community-driven dune restoration projects exist throughout Aotearoa. A notable example includes the Coastal Restoration Trust of New Zealand, which has developed a comprehensive guide and monitoring scheme for dune restoration projects throughout the country[58]. Additional projects include the Native Forest Restoration Trust[3], 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 2 on previous page). International NGOs, such as The Nature Conservancy, are active in New Zealand[4] and provide support for conservation initiatives and nature-based solutions, which can include increasing dune extent 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 free trade agreements (e.g., Free Trade) that require conditions around environmental management to be upheld. Additionally, Aotearoa is a signatory of the Ramsar Convention meaning it plays a part in the international effort to conserve wetlands, which includes dune slacks and lakes[87].

Part D—Impact analysis

D1. What would be the environmental~~/human health~~ impacts of not managing this attribute?

Failing to manage dune extent poses a significant threat to coastal environments, triggering a cascade of ecological problems. For example, the loss of dunes can lead to a severe reduction or loss of coastal protection and habitat for critically endangered endemic species, which is reflected in the decline of bird populations[11]. Additionally, the loss of dunes can allow for saltwater intrusion into

[1] 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
[2] https://www.localmatters.co.nz/news/tangata-whenua-closes-beach/
[3] https://www.nfrt.org.nz/reserves/oreti-totara-dune-forest/
[4] https://www.nature.org/en-us/about-us/where-we-work/asia-pacific/new-zealand/stories-in-new-zealand/our-work-in-new-zealand/

coastal aquifers and wetlands, which can substantially alter ecosystems, leading to further loss of endemic species[88]. This influx of seawater 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 and biodiversity of coastal ecosystems[89]. Reduction in dune extent will also likely lead to increased degradation of adjacent shoreline habitats.

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 of dune loss are likely to be felt among coastal infrastructure development and tourism sectors. Reductions in dune extent 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., [90]). Reductions in extent of dunes can also limit their protective capacity as natural buffers that absorb wave energy and lessen the impact of storm surges[3, 12, 23, 91]. The loss of dunes exposes coastlines to increased erosion, leading to a retreat of beaches and a heightened risk of damage to coastal infrastructure and sensitive adjacent habitats such as dune slacks[18, 21, 92].

Many marae are at or near sea level, meaning a reduction in dune extent could severely increase the vulnerability of culturally-important sites, which also include urupā[1,][93]. The loss of dune systems and habitats associated with these systems can directly influence tikanga practices, such as kai gathering, which can diminish mana over associated resources and / or areas [94-96].

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 extent [88, 89, 97, 98]. Sea level rise may also result in reduction in dune extent due to 'coastal squeeze' if habitat is not available for it to migrate to due to the presence of roads, urban areas, stopbanks, or agricultural land directly inland from current dunes [84, 99]. Increased storm frequency will likely lead to increased flooding, which will likely impact coastal sediment budgets and coastal erosion processes [92, 100]. 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. In addition, increasing temperatures may also reduce below-ground biomass for certain dune vegetation species, which can reduce dune extent by diminishing accretion and subsequent stabilisation processes (e.g., as seen in China[101]).

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