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Author:
Jenks, G.
Associate
CLIMsystems Ltd.
Hamilton
New Zealand

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CLIMsystems Ltd
9 Achilles Rise
Flagstaff
Hamilton 3210
New Zealand
www.climsystems.com
info@climsystems.com

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AFFECTING THE FUNCTIONAL CAPACITY OF COASTAL DUNE ECOSYSTEMS 1 - Utilising New Zealand Coastal Dune Degradation Records as a Proxy for Analogous Global Impacts.

Greg Jenks, Associate – CLIMsystems Ltd and Senior Ecologist and Coastal Restoration Specialist International Global Change Institute, Hamilton, New Zealand.

ABSTRACT:

Anthropogenic degradation of New Zealand (NZ) coastal sand dune ecosystems is relatively recent, from geological, evolutionary and global perspectives. Impacts upon the functional capacity of these naturally protective coastal ecosystems have been both comprehensive and prodigious. Where recorded, NZ historic narratives provide unique insights into a plethora of disastrous activities in a world of analogous, but similarly poorly documented effects. The actuality of historic settlement and the closely related agricultural influences on dune lands continues to threaten many coastal margins globally. Modern effects include untenable spiralling of coastal populations habitually with inadequate setbacks and/or sustainable management of the coastal buffer, plus consequential proliferation of detrimental construction of extraneous revetments. More recent are concerns regarding the scale and compounding effects of climate change and rising seas on these decreasingly slim slivers from disaster – our coastal dunes. Erosion threats and their genuine origins while both commonly significant; remain inadequately recognised and sufficiently comprehended. This NZ experience simply and effectively represents similar deleterious impacts on often undervalued and locally indigenous C_4 halophyte dune vegetation commonly observed on global coastal margins.

KEYWORDS: Coastal sand dunes, human impact, degradation, coastal erosion, C_4 halophyte vegetation, dune functional capacity, dune ecosystems.

INTRODUCTION: The prevailing traditional view of the state of many coastal margins.

This nation possesses more than 40 perfectly adapted plant species (frequently endemic) capable of successful habitation in coastal dune sands. These naturally evolved species existed in successional zones - from foredunes through mid-dunes and on to increasingly complex back-dune climax-forests. Each landward succession revealed enhanced biodiversity gains, as humus, nutrients and shelter were added by the pioneer inhabitants of the previous more-seaward zone. These three distinct zones also had their own attendant and often similarly endemic faunal inhabitants; many now lost from this environment, including the unique 10cm diameter carnivorous NZ land snails (*Powelliphanta spp*), and the iconic flightless kiwi, of the genus *Apteryx*. Coastal dune ecosystems are the extreme seaward edge of all terrestrial existence.

The majority of the indigenous plants discussed above are generalist back-dune plant species, with a smaller number of sand-tolerant mid-dune species, then finally to the four species of truly unique specialist and sand-obligate front dune plants. These latter four are halophyte species that also possess extraordinary and evolutionary-advanced dry-environment C_4 attributes – *Spinifex sericeus, Ficinia spiralis, Poa billardierei,* and *Euphorbia glauca.* These front-dune species are particularly effective at trapping sand during and between oceanic storms (by reducing wind speed and arresting saltation) to effectively rebuild dunes and beaches following erosion events. Coastal margins plus their attendant faunal and floral occupants have fluctuated frequently, forced by the effects of preceding natural climate and sea-level changes. But these natural coastal defence systems have endured - evolving to maintain a protective role for landward zones incapable of buffering oceanic storms – a worthy model of continuing landscapes where evolutionary processes can still progress as a constant existence on radically fluctuating coastal margins.

However, human-induced impacts over recent centuries seriously threaten these critical, functional, sand-trapping and dune-building front-dune plants. The anthropogenic effects on natural populations have long been severe - commonly their conservation status is now listed as: “At Risk – Declining”.

NZ coastal dune ecosystems have experienced degradation pressures relatively recently on a geological time-scale; subsequent to the 14th Century arrival of Polynesian settlers – the last great global migration - *"New Zealand … was difficult to reach and return from and was, correspondingly, the last major temperate land mass in the world to be settled by humans"* (Irwin 2010). The unprecedented impacts from these people, plus their later European counterparts, have been both uncompromising and extensive. However, changes forced by these two waves of colonist populations have also created opportunities to monitor a sequence of mammalian impacts in a land formerly occupied almost solely by birds, reptiles and invertebrates.

These coastal impacts are not borne by NZ alone however; one of the earliest acknowledged inscribed records of coastal dune disruption comes from 16th century Denmark - where remarkably familiar anthropogenic impacts forced stabilisation attempts (and the world's first Sand Drift Act) to be initiated by King Christian II in 1539 Denmark (McKelvey 1999). His action was prompted by the common agricultural effects of dune grazing and removal of coastal vegetation for thatching roofs of dwellings. Consequently, history plus observation confirms that the most regularly damaged element of natural dunes – locally indigenous and highly adapted C_4 halophyte coastal vegetation – is also conclusively the most critical and most habitually compromised components of dynamic equilibriums on sandy coastlines globally. Halophyte C_4 plants evolved in many nations over millennia (probably initiated during the Oligocene epoch, 23-34 million years BP, when the C_4 innovation commenced) and these advanced species now possess competitive advantages over all other terrestrial plants to actively and effectively contribute to functional coastal stabilisation and so offer significant protection roles. But this innovative advantage has long been swept aside as a 'superfluous nuisance'. Inopportunely, this critical and functional vegetation complex (a leading example of convergent evolution) is often the most common coastal component to be unwisely and regularly impacted by human activity.

Dune erosion, often erroneously labelled as 'natural', is 'simply' now the expected casualty or consequence of increases in storm events and their arguably increased severity due to climate change: for example – increasingly frequent ex-tropical cyclonic storms in NZ and Australia, Superstorm Sandy in USA (Lehmann 2012) and Super Typhoon Haiyan (the Philippines Nov 2013).

There is currently common acceptance and even celebration of the existing degraded state for our many desecrated dune systems (along with fatuous statements like 'our iconic' coastlines), without adequate or serious consideration of the principal causal problem - human-induced destruction of natural ecosystem function – and this problem has principally and insidiously introduced many of our existing and disconcerting coastal erosion issues. Contemporary conclusions reached about dune instability problems often merely reflect flawed modern concepts and a disregard of the real consequences of this folly, for example *"… there is nothing wrong with the natural processes of dune blow-outs…* (Hume 1999). In actuality many dune 'blowouts' should now be considered as entirely <u>unnatural and significantly damaging.</u> As a consequence, these abnormal processes simply generate additional and compounding negative influences on dune integrity and beach sediment budgets within their degraded beach zones, from where often immense volumes of wind-blown sand have been removed for many decades or more. These facts, explored later in this paper, should naturally lead to a reconsideration of the primary causal factors of coastal erosion in NZ, and in a wider global context.

The above narrow but pervading view on beach erosion most likely originated because many of the world's dune systems have long been inappropriately altered and their natural function degraded by a variety of familiar, historic but poorly recorded and poorly grasped human impacts. These most often have been prompted by superficially 'acceptable' and even normalised practices - such as grazing by farm animals, the deleterious effects of introduced feral herbivores - or the burning and removal of natural dune vegetation for other anthropological purposes (McKelvey 1999).

However some 'early' observations of unnatural sand movements (on a human time-scale) have been documented in NZ, due partly to the relatively late colonisation of this nation. The botanist Dr.

Leonard Cockayne wrote in 1908 *"The wind blowing inland from the foreshore carries with it, according to its velocity, more or less sand."* (Sale 1985). However, these reports and those from other early interested parties (e.g. The New Zealand Institute) were merely observations of simple factual events, rather than deeper analyses or recognition of the prevailing and pivotal coastal processes. And these 20th century observations were in essence simply reflecting abnormal processes induced by earlier human destruction of the naturally evolved and functionally superior indigenous dune vegetation.

Modern coastal science and its resultant measurements, observations, assumptions and illustrative formulae of the prevailing (and often mistakenly-assumed) 'natural' coastal processes and geomorphic responses have been developed over only the preceding *c.*60-70 years. But over this very recent period in our coastal history, many dune systems were already clearly suffering from a lengthy legacy of human-induced impacts, and their truly-natural protective processes were consequently entirely compromised. This new science can thus only report on dune processes pertaining to these mere coastal artefacts, as the originally functional dune forms are long destroyed.

Therefore many of the conclusions concerning current beach state and 'normal' dune responses are plainly based on coastal systems where often severe and unnatural erosion has been provoked solely by previous anthropogenic activities, and this abnormal and detrimental behaviour is controlling the assumed-to-be natural contemporary coastal processes; while normal sand accumulation and dune accretion regimes have been dangerously disrupted. This regrettable situation has led to most NZ (and international) coastal science studies being based erroneously upon the coastal processes appropriate only to our commonly and alarmingly *degraded dunes suffering from cumulative unnatural human impacts*.

The resulting state of many dune margins is anything but natural, and that fact must be conceded so we can effectively ensure its recognition and so make real progress on reversing these impacts.

Those many seemingly innocent but persistently destructive impacts have compounded to create a catastrophic continuum of coastal degradations. Conversely, simple, affordable and assiduous restoration of the original and functional C_4 halophyte dune flora species convincingly reverses many historic and seriously deleterious biodiversity impacts, and such restoration increasingly invalidates notions that beach erosion is always 'natural' in origin.

Therefore most global dunes, barely persisting today and increasingly expected to buffer the frequent storms and new climate change impacts are, by comparison, merely mounds of loose fragments of sand, diffidently bound (if at all) by a motley hodgepodge of mediocre, naturalised and poor-performing weed species readily modified by the grazing of introduced domestic and feral mammals, and these tragically ineffectual plant species are also frequently destroyed by simple inundation with sea water (e.g. marram, lupins, pampas grass, kikuyu, Indian doab etc.). Reality suggests that there should be no shock or surprise when these impacted mounds (contemporary and even iconic 'dunes' as they are presently titled) increasingly suffer from continuing episodes of extensive 'natural' erosion.

While sea-level rise is identified as an underlying cause of retreating international shorelines, the induced loss of natural and highly specialised sand-trapping C_4 halophyte plant species is increasingly considered as the primary and most common source of this observed global erosion trend (Nicholls et al 2007; Jenks et al 2005). Climate change impacts are merely compounding this earlier induced degradation. These same species additionally need to be increasingly acknowledged for their superior functionality and contributions to critically natural coastal processes.

The existing and clear record of 19th and 20th century NZ dune degradation (much longer in many other nations) is explored; along with the real impacts of this degradation, along with early and failed band-aid technologies aimed at (unsuccessfully) repairing this acknowledged damage.

This paper thus questions the veracity of many orthodox assumptions relating to modern coastal process models, as these have literally been founded on the grossly exaggerated and poor behavioural patterns of existing and long-degraded dune systems. This is a time for fresh thought and a new acceptance of the roles and ecosystem services supplied by natural coastal sand ecosystems – a new 21st century paradigm for coastal management. One example of this new paradigm comes from Australia - The Sunshine Coast Waterways and Coastal Management Strategy (2011-2021) acknowledges that coastal foreshores (when dominated by C_4 halophyte species) are often overlooked as a protection mechanism to the adjacent built environment. It states that well vegetated coastal dunes have *"a tremendous capacity to absorb wave energy and thereby protect roads and buildings from inundation."*

THE ERA OF DOCUMENTED DUNE DEGRADATION IN NEW ZEALAND

Many of NZ's large-scale and increasingly challenging coastal attrition and beach erosion dilemmas affecting our coastal communities have expediently been based on assumptions that these problems are prompted by simple and inescapable 'natural' erosion. And further, that this 'menace' must therefore be halted, usually with flawed and expensive manufactured devices. However the true foundations of these destructive anthropogenic impacts in fact date from the 14th century (McGlone et al, 2005). These early impacts were subsequently accelerated and compounded by European settlement during the 19th and 20th centuries. The deleterious effects generated in this latter period were quantified by an extensive coastal survey, and later presented to parliament in 1911 by Dr. Leonard Cockayne within his *'Report on the Dune-Areas of New Zealand'* (Cockayne 1911).

For a small nation New Zealand has *"one of the longest coastlines of any country in the world, at more than 18,000km*" (MfE 2007), so the rapid loss of natural dune stability and function was, and still is, a problem of substantial proportions. Close scrutiny of Cockayne's 1911 report reveals unambiguous, remarkably large scale and nationwide dune degradation focusing principally on the European settlement period, and that dissertation specifically refers to the serious demise of both integrity and natural function of dunes throughout this nation, plus impacts on the role of the very sensitive and protective foredune zone. However, unlike similar events in other parts of the globe (McKelvey 1999), the relatively late European colonisation of NZ (in the early to mid-19th century) allows suitable, but still limited, scientific inquiry of the degradational effects of fire and introduction of mammalian herbivores into the natural dune environment, previously devoid of these damaging animals. Members of The New Zealand Institute (later the Royal Society of NZ) became involved in *"objective observations and informed opinions … facing settlers as a whole* (McKelvey 1999)*. These included the threat of moving sands"* exposed and set loose by humans and their introduced mammals. Regrettably the passage of time has relegated these and other important early observations to dusty back-room shelves.

Dr. Leonard Cockayne's parliamentary report opened with unequivocal observations and early germane concepts of dune function and the apparent consequences of escalating degradation of the *'formerly-stable'* NZ dunes "*coastal dunes…form a natural defence to the land against the encroachment of the sea, and, their movement inland is a national concern… while yearly further destruction takes place, the evil … becoming more difficult to suppress".* (Cockayne 1911)

THE LONGER LEGACY OF ANTHROPOGENIC DUNE DEGRADATION IMPACTS

While the effects of 19th century colonial settlement are unequivocally recorded by Cockayne, Polynesian settlers also created much earlier and poorly acknowledged impacts: *"It is probable that Maori … weakened the coastal vegetation initially with their use of fire to encourage the growth of bracken fern, a major source of starch in their diet."* (McKelvey 1999). This assertion is confirmed by McGlone "… *Maori relied on bracken rhizome starch as a major element of their diet ….* ", and continues with other effects of this early Polynesian settlement period "*The dominance of bracken over very large areas was mainly a result of burning to create open landscapes…* " (McGlone 2005).

This first wave of human settlement clearly created major ecological destruction through removal of many native forest systems, including the often drier and hence more flammable coastal dune forests. These effects have been described thus: "*Late-Holocene pollen and charcoal records from New Zealand provide striking evidence for initial Polynesian* [Māori] *arrival being strongly associated with widespread burning and loss of native forest. These forests had no previous history of fire and thus showed little resilience to the introduction of a new disturbance."* (McWethy et al 2009). The potency of this impact remained for a considerable period and covered much of this country "*Over much of the North Island the bracken dominance established during the early Maori deforestation phase was maintained up until the European pastoral and forestry era*… ", and "*Early fires (pre-600 years BP) have been recorded in pollen diagrams from Northland to Southland.*" (McGlone 2005).

In the far north, evidence of historic Maori occupation (including discovery of large wood-chopping adzes) was widespread on the subsequently unstable sand dunes that extending up to 5 kilometres inland from Ninety Mile Beach. Archaeological sites on back-dune areas included charcoal and relict wood from many now absent native coastal climax-forest species such as kauri (*Agathis australis*), taraire (*Beilschmiedia tarairi*), puriri (*Vitex lucens*), pohutukawa (*Metrosideros excelsa*), matai (*Prumnopitys taxifolia*), tanekaha (*Phyllocladus trichomanoides*), and associated species such as monoao (*Halocarpus kirkii*), and kapuka (*Griselinia littoralis*). Shells of NZ landsnails (<u>*Powelliphanta spp*</u>) extracted from coastal middens support the conclusion that, prior to human arrival; these extensive mid and back-dune areas had been naturally stable and dominated by extensive ancient coastal podocarp and broadleaf climax-forests. These stable dune areas were subsequently sites of extensive habitation (Coster 1983:182-3, 1989). The coastal midden sites occupy only a limited time range, from the late 15th to the early 17th centuries (300-500 years BP), suggesting common occupation of the stable Holocene dunes, a natural state that rapidly broke down under the combined influence of burning and the ensuing horticultural use. As a consequence of destructive ecosystem impacts from 2 centuries of occupation, these dunes were simply abandoned and permanent occupation turned instead to more stable high points along the coast.

For NZ's early Polynesian settlers *"The Oceanic environment presented a number of major challenges for human settlement which were successfully overcome ... <u>through modification of island ecosystems to provide a stable resource base.</u>"* (Smith and Jones 2005)

These people behaved like new settlers anywhere: essentially devoted to modifying the environment to suit their most pressing needs *"The most significant change in the environment say 1000 years ago was not in climate … but the effect of the arrival in New Zealand of the first major tide of human settlement".* (Sale 1985).

Dr. Ernst Dieffenbach visited NZ in 1841 and recorded his observations thus: *"The sand, driven by strong westerly gales … has made great encroachments upon the land ... Evidence that this overwhelming sand drift is of modern date* [prior to 1841] *and is owing to the destruction of the forest may be seen on the western coast."* (Sale 1985).

Given the vast scale and enormity of those early and devastating impacts it should come as no surprise that, while sailing from North Cape south past Ninety Mile Beach in January 1770, Captain James Cook described this area on his chart as the *"Desert Coast"* and further wrote *"Everywhere is a barren shore"*. His botanist Joseph Banks inscribed in his diary that the land appeared *"almost entirely occupied by vast sands*". (Sale 1985). That degraded condition and Banks' consequential dramatic conclusions reached *c.*250 years BP were obviously prompted by even earlier ubiquitous and damaging human actions, i.e. those anthropogenic actions preceding 1770.

Consequently, centuries of such activities on our natural dune lands means that examples of indigenous climax forests remaining on coastal sand are now extremely rare. A recent estimate puts this problem into context: *"more than **99% of indigenous forest** on stabilised sand dunes had been removed"* (Williams 2010. pers. comm.).

Much of this damaging activity occurred prior to any European settlement. The limited recovery from these early fires induced a proliferation of pioneer plant species, principally indigenous grasses, shrubs and small trees as diminished derivatives of the earlier burnt climax coastal dune-forest species, thus representing a semi-natural colonising vegetation response to earlier degradations of this once natural and functional ecosystem. (Coster 2012. pers. comm.)

And then the second wave of human settlement arrived (largely from Great Britain), bringing its own and substantially increased agrarian impacts and practices. Similarly harmful agricultural effects are still observed in contemporary United Kingdom – including open and unhindered grazing of dune lands (figure 1). Many NZ (and global) indigenous dune species were (and still are) very palatable to the many herbivores introduced by these new settlers, and therefore extremely vulnerable to the next wave of destructive impacts. Before useful inland roads could be established, beaches and dunes were widely used as for grazing plus droving and transport routes (Sale 1985). The numerous but already modified assemblage of indigenous dune plants (the colonising grasses, shrubs and small trees mentioned earlier) now provided ideal forage supplies for these new grazing mammals prior to the clearance of inland forests and subsequent introduction of farm pasture species. Reports from this period indicate that some initial recovery from Polynesian impacts had occurred and that *"the sand country was fairly stable at the time of European settlement"* (McKelvey 1999).

Figure 1: Persistent grazing of open dune lands has removed all indigenous C_4 halophyte dune plant species, leaving only these non-halophyte and non-functional pastures, John o' Groats, Scotland. July 2011.

However, this situation was not to persist: *"It soon became clear… that the indigenous plant cover of grasses, shrubs and small trees holding the coastal sands was particularly vulnerable to the grazing of sheep and cattle introduced by settlers … and the associated burning to induce more grass ..."* Reports also revealed that the essential and indigenous spinifex *"was completely grazed out along* *the Manawatu coast ..."* (Esler 1970). Regrettably, the Manawatu region did not bear these impacts exclusively. During this period the cumulative area affected was *"about 40,000ha in 1880; by 1909 the estimate had risen to over 120,000ha"* (McKelvey 1999) amounting to a catastrophic 95% of the estimated area of all dunelands in 1911 New Zealand (129,000ha). This was a young country, and for a second time, the most recent settlers evidently had a very limited awareness of the real effects of their many early and deleterious actions.

It should be a matter of national regret that this second wave of anthropogenic degradation of NZ's dunelands was almost completely 'successful' this time, after only 80 years of renewed human mismanagement. Regretfully this damaging conduct was actively <u>promoted</u> by our early colonial governments. In 1881 the extensively moving sand dunes between Paekakariki and Wanganui were *"a consequence of coastal Crown land being leased for cattle and sheep grazing. Crown lands leased for grazing included many of the worst problems."* (Cockayne 1911).

This young and recently colonised country was now suffering the many ravages of dune and beach modification instigated solely by anthropological settlement *"… human beings, in general, are a new kind of animal on the planet, one prone to ruining ecosystems and destroying their own futures."* (Flannery 1994). Ecosystem destruction is again not unique to NZ of course; this is a common phenomenon globally that affects even widely dispersed, distant and improbable lands like Ascension Island, a tiny isolated speck in the mid-Atlantic Ocean. *"This island originally had its own native flora until Portuguese explorers released goats in the 1500's which ate most of it. The later introduction of rabbits, sheep, cats, rats and donkeys ... further marginalised the original flora and fauna. By 1843 the island was barren … "* (Wikipedia 2014)

The dunefields of NZ responded in a manner similar to those of Europe and many other nations, when exposed to comparable and damaging treatment (McKelvey 1999). The now loose *"sand menace"* emanating from formerly and naturally stable dunes was being actively and rapidly relocated inland by the strong and frequent coastal winds, with beach sediment being carried up to 20km inland in Manawatu (at Rangiotu). In Waikanae a church was completely buried by deep volumes of moving sand *"It did not take long; <u>by 1849</u> the sand had progressed sufficiently to block the windows on one side …"* This church was later abandoned and then completely buried in beach sand and only unearthed again in *"1961 by workmen forming a road in a new subdivision."* (McKelvey 1999).

In 1872 the drifting sands of Taranaki were *"increasing the areas of sand desert there"*, and dangerously at Kaipara in 1873 *"advancing … dunes 90m high"* reportedly fatally overwhelmed a sleeping child in their inexorable path (Cockayne 1911). As loose sand began its destructive march inland, purely now at the whim of the wind, the most immediate nationwide concern was the unnatural large-scale burial and consequent loss of recently cleared and now productive pastures, inundation of new houses, and disruption of early road and rail transport (Cockayne 1911). These effects were relatively rapid and clearly obvious. Much more sinister, and 'less important' at the time was the <u>consequential and currently still unrecognised loss</u> of vast volumes of the functionally important sand resource from previously natural beach systems, losses that now lowered beach levels and induced the nation-wide **disruption of natural coastal processes, including increasing forfeiture of the storm buffer function.** These losses of sand and normal dune function have consequently and insidiously induced many of the beach degradation and coastal erosion problems observed today, and in so doing, have damaged the functional capacity of natural dunes and caused a calamitous cascade of unexpected consequences.

A further consequence of persistent dune degradation is the unnatural effects on cross-shore and long-shore sediment exchange processes. Those 'insidious' impacts are applicable to many of the damaged local and global coastal dune ecosystems: *"The progressive transport of sediment from the beach into an alongshore current quickly reduced the limited amount of beach sand and created an offshore current flow (effectively a large mega rip) … similar to those reported elsewhere."* (Jackson 2012)

And so the prevailing state of NZ dune-fields more precisely reflect a long legacy of cumulative human modifications rather than truly natural (and functional) landscapes, and are *"an exceptional example of a developed Pacific 'travelling landscape' tradition – defined by human modification through clearing, cultivation … erosion, loss of soil fertility – resulting in more cultural than natural landscapes."* (Smith & Jones 2005)

A MARGINALISED ECOSYSTEM

*"Maintenance of sand dunes along the coast is a critical part of the management strategy, with the dunes being valued for their natural habitat and as an essential coastal buffer. <u>Most of the dunes are however an artifact</u> …" (*Short 2012).

One of the consequences of degradation has been the rise of concepts used to explain away the phenomenon of beach erosion – where large quantities of sand resource have been taken offshore from eroding beaches and subsequently moved mysteriously elsewhere through long-shore drift, or parabathic movement. This theory was used here in an attempt to describe the frequent coastal attrition problems observed in many locations, like the eroding beaches on East Coast Bay of Plenty. The localised concept theorises that sand moves in a continuous 'stream' from Waihi Beach (in the north) and subsequently also from nearby Matakana Island, Mount Maunganui, Papamoa etc. down the coast in a south-east direction towards Opotiki. This concept losses veracity however, as large volumes of similar grain-size sediment are not subsequently deposited near to coastal Opotiki (Figure 2). Rather, sand is now returning to very beaches on which the erosion originally occurred (Waihi, Matakana Island, Mount Maunganui etc.), and returning rapidly through natural diabathic exchange processes following assiduous restoration of their affected dunes with indigenous plants – *"The published rates of net littoral drift* [parabathic movement], *and also directions, appear to be too high and <u>inconsistent with observed patterns of erosion and accretion</u>."* (Healy and de Lange 2014).

This fresh information may also have implications for the analogous "river of sand" moving north adjacent to the degraded New South Wales and Queensland beaches, on the eastern coast of Australia (estimated to be *c.* 500,000m^3 p.a.).

Modernised and more convincing perceptions of the actuality of diabathic and parabathic sub-aerial littoral processes clarify the genuine origins of immense volumes of fresh sand now rebuilding significant dune width and dune volume following restoration of the indigenous dune plant species. We ignore these revelations at our peril and must consequently update our appreciation of modern, affordable and truly sustainable options for dune ecosystem management, while also recognising the relentless, real and compounding effects of damaging dune degradation. This dune renovation topic will be reported in a following and supporting paper - "Affecting the Functional Capacity of Coastal Dune Ecosystems 2 - Utilising New Zealand Coastal Dune ***Restoration*** Records as a Proxy for Analogous Global ***Responses***" - where transformation of human-induced impacts will be discussed, changing relict dunes dominated by ineffectual weed species into functional dunescapes dominated again by indigenous flora (and fauna). This definitive action dramatically increases the functional capacity of these protective coastal dune systems.

The erroneous and assumed-to-be 'natural processes' acting on coastal margins today are merely a litany of inconvenient truths resulting from centuries of unrecognised degradational impacts on natural dune flora (and fauna), plus attendant and now predictable aberrant beach behaviour, now widely accepted as the current 'norm'. Nothing **natural** is at work in this **existing** and **pervasive scenario**.

Figure 2: An example of the damaging and dangerous effects of unsuitable vegetation, dune mismanagement and erroneous assumptions of sand circulation – Hukuwai Beach contemporary, Opotiki, NZ.

The community plus various government and NGO agencies are rightfully concerned over the large–scale loss of natural wetlands: *"around 90% of New Zealand's wetlands have been drained or otherwise destroyed in the last 150 years"* (NIWA 2010). However, coastal ecosystems have been damaged on a similar or, in all probability, an even larger scale by anthropogenic impacts. And it can be argued that we must increasingly depend on the superior function of naturally vegetated coastal dunes for their many economically advantageous and appreciated ecosystem services, particularly now with the effects of climate change and rising sea levels. Restoration of natural dune function can be considered an impeccable adaptation response to these impacts. Conversely, sea walls and sand renourishment projects are neither affordable nor sustainable options for all the coastal settlements exposed to these damaging effects: *"Successive hard engineering 'solutions' prompted through public pressure and engineers keen to do business, have been largely ineffective as they fail to address the root causes of erosion … "* (Jackson 2012)

EARLY BAND-AID 'SOLUTIONS'

Dune protection and replanting measures are also not new; as seen with early restoration attempts by Denmark's King Christian II (McKelvey 1999). Similar techniques and stabilising materials employed to inhibit challenging dune erosion problems in 16th century Europe were also erroneously presented for 'solving' the dune drift problems in 20th century NZ.

Replanting of our increasingly problematic and wind-eroded dunes was commenced soon after the consequences of early beach mis-management practices became obvious *"the planting of* [European] *marram beginning in the 1890's have … done much to reshape the coastal strip"* (Esler 1970).

The NZ Sand Drift Bill was first introduced in 1902 by the Native Minister, James Carroll, and sand stabilisation programmes used in Europe were discussed and then recommended. However the government member for Northern Maori was not enthusiastic about using introduced marram grass, *Ammophila arenaria,* even though it was *"the world's best known and most widespread sand plant"* (Esler 1970). The minister claimed that northern sand was different, *"being lighter and unable to be stopped by marram grass or any other of the stabilising plants suggested"* (McKelvey 1999). This was an enlightened suggestion as marram grass does have serious failings when compared to NZ's indigenous dune plants, such as sensitivity to salt-water inundation and susceptibility to wind erosion, discussed in further detail below.

General consolidation of statutes occurred and the Sand-drift Act 1908 came into being. This may be one of the first 'user-pays' devices in NZ law, as costs for any proposed stabilisation scheme were apportioned to the affected landowners or occupiers. There was no commitment for government to incur any expense, even though early government policies had clearly at least contributed to the earlier destruction of dunes, and so *"It was an ineffective statute, producing no sand-reclamation projects….it became clearer that* *the magnitude of the problem was beyond the scope of the Sand-drift Act.*" (McKelvey 1999)

However, Cockayne's subsequent 1911 report changed the direction of dune reclamation for the ensuing 80 years or more, where further effort was recommended and plants from all four corners of the globe were introduced to provide the 'quick-fix' solution so frantically sought. In those ruinous days' time was of the essence. While our native dune plants were described by Cockayne as being *"of much interest ... and also of quite remarkable form … their value as sand-fixers is by no means generally appreciated"*, the necessary propagation techniques for these indigenous plant species remained completely enigmatic. This respected and renowned botanist simply did not have the luxury of time in his and the colonial government's haste to commence rapid resolution of the desperate demands regarding the clear and increasingly close calamity.

In response to these demands, Cockayne was obliged to recommend the widespread use and introduction of foreign plant species, including *'Marram-grass and tree-lupin as plants for dune fixing'.*

In summary, this simple need for urgency and expediency was due to three principal factors:

1. The impacts from the vast scale of dune disruption in NZ (>120,000ha, or **>95%** of NZ's total dune land extent).
2. Ease of propagation of Marram (simple division) and lupin (easily from seed).
3. A prevailing helplessness to successfully propagate indigenous dune plant species.

Marram had long before been introduced and naturalised in areas of New Zealand *"by 1872 it had become established on the Miramar Peninsula, Wellington."* (McKelvey 1999) It was a simple matter then to propagate from these existing stocks, and in 1913 to commence trial plantings *"at two locations where the problems were patently serious … at the mouths of the Rangitikei and Waikato Rivers."*

Some haphazard planting programmes were attempted through the next two decades, *"by 1922 only about 65 ha of marram had been planted at Waipu ... by 1924 about the same area at Woodhill.* (McKelvey 1999)

Large work schemes of the Great Depression kick-started the more familiar and vast-scale marram planting programmes, *"as the sand dunes drifted out of control..."* Starting in 1932 in the Far North (figure 3), work programmes then continued down through Muriwai, Rangitikei, Manawatu and down to New Brighton in the South Island and beyond. (McKelvey 1999)

Figure 3: The immense scale of planting introduced marram by machine to 'stabilise' or 'fix' obviously and severely degraded NZ dune lands *c.*1963.

In addition to use of marram and lupin, vast legions of other adventive species (now recognised as similarly unsuitable) were hastily introduced in the almost feverish gaol of controlling and containing this unprecedented and destructive *"sand menace".* These included invasive species like Sydney golden wattle *(Acacia longifolia var. sophorae),* Australian coastal tea-tree *(Leptospermum laevigatum),* South African iceplant *(Carpobrotus edulis),* along with a plethora of imported *Pinus spp.* and other invasive species like Lyme Grass (*Leymus arenarius*), East African kikuyu (*Pennisetum clandestinum*), *Gazania spp*, *Arctotis spp*, and Indian doab (*Cynodon dactylon*) etc.

A report on coastal erosion in the Bay of Plenty helpfully recognised that vegetation cover is an essential ingredient for dune stability "*...if a dense, diverse vegetation cover exists, the dune will probably regain its full stature much sooner."* (Healy *et al* 1977). Despite this early and commendable recognition of a useful role for plants, this observation was written before the failings of the introduced species were fully comprehended, as Healy's recommendations included the use of sown "*marram … and kikuyu grass to stabilise it*."

While many of the introduced species are variably tolerant of salt spray and some provided the 'band-aid' effect so urgently required to control aeolian components of the sand-drift predicament sought by Cockayne (and others), all of these foreign species possess one critical and fatal flaw: **not one of them is tolerant of regular salt-water inundation (i.e. none are halophyte species).**

Salt-water tolerance is an **unequivocally essential** natural attribute for any foredune plant, not only to endure in this hostile environment, but to subsequently enable effective trapping and accumulation of sand on front dune slopes where spring tides and frequent storm surges naturally ensure regular and comprehensive inundation by sea water. Marram in its native Europe is not naturally present on foredune slopes *"Marram grass is tolerant of salt spray* ***but not immersion****, and should be planted above the expected run-up limit of storm waves."* (Wallingford 2000). Even when used above this unsuitable run-up zone, marram is still very prone to wind erosion *"marram dominated dunes remain unstable…...due to the exposure of sand between the clumps of vegetation."* This effect is also clearly and frequently observed as a serious concern wherever marram has, or is still inappropriately used in NZ. Therefore use of this plant for control of sand movement should have been **a temporary measure at best**, but never an end point. However this indeed was the case throughout the ensuing decades, and this species is still inadvisably utilised in many coastal foredunes to this day. **The same critical flaw is shared by all the plant species** introduced to NZ for dune stabilisation roles**.**

Extensive plantings of marram and other introduced species continued with large-scale work programmes beyond 1985 (Sale 1985). These vast revegetation projects using exotic species only, undeniably *moderated* the degree of inland dune migration (and consequential wind erosion of coastal lands, blowouts etc.), but the many abnormal attrition problems were not completely resolved. The toe of **all** marram-dominated dunes remain barren of vegetation (as a consequence of the damaging contact with seawater), a factor that **guarantees** continuing dune-base erosion. Loose sand from the beach berm and dune toe is readily and frequently lost from the beach compartment – being blown up the steep and densely vegetated slope, often finding a resting place only on or landward of the relatively calm crest (lee slope) of these dunes, and/or taken offshore by sub-aerial cross and along-shore exchange processes (diabathic and subsequently parabathic), through the turbulence induced by reflective wave action. This habit ensures front slopes of marram dunes remain over-steep and unstable, frequently also with inadequate incipient dune formation, while dune crests grow in height at the expense of protective width. This effect is clearly illustrated by the unnaturally >20m high Oreti Beach dunes (figure 4), and the 11-18m high dunes at New Brighton, Christchurch. The tall but narrow marram-dominated New Brighton dunes have their crests regularly reduced by earth-moving machines to the lower height of 8 metres above sea level. by the regional council (Environment Canterbury), responding to the demands of nearby and thus detrimentally affected communities (Cope *pers. comm.).*

Figure 4: Unnaturally elevated and unstable marram dunes at Oreti Beach, Southland, NZ.

The sum of all these impacting factors is the creation of a dangerous tipping point: where dune erosion now dominates coastal processes and natural accretion is hindered at most beach locations. Consequently, the excesses of at least the last 600 – 1,000 years of human history can currently be measured by the rather ‘successful’ and complete disruption of the previously natural beach and dune processes on the extensive coastal zone surrounding this nation, in one of our most critical and increasingly significant ecosystems; the exceedingly effective storm defence ecosystem that is, or was, the coastal buffer – sand dunes. And this brings into focus another common problem – the lengthy history of these impacts - they all occurred in a time beyond the experience or memory of any living person. So this long history of disruption (on a human time-scale) has given rise to a number of misconceptions, where processes once considered 'natural' are simply a litany of dangerous degradational impacts overlying the actual realities of truly natural 'cut and fill' dune processes.

These early, inappropriate, unnatural and flawed revegetation responses have also led to NZ's now relict dunes being described as "fixed" or "active" systems (Hilton et al 2000). The term "fixed" describes dunes planted in haste during the colonial sand menace era, with incongruous species like marram and the plethora of other adventive plants. "Fixed" infers these coastal systems may have also been 'repaired'. This 'repair' initially did induce an improved degree of stability, as demanded by the early 20th century populace, but this colonial-era 'repair' also forced further and truly remarkable losses of dune biodiversity.

"Active" dunes are discussed in the "*Inventory of New Zealand's active dunelands*" (Hilton *et al* 2000) where the authors state *"The main cause of the decline in area of active duneland has been the stabilisation, then afforestation, of active dunelands".* While that statement is generally supported and can be regarded as factual, the authors continue with another observation - "*Most dune restoration programs … aim to re-establish foredunes for the purpose of coastal hazard management, rather than the conservation of dune function or dune flora*". Indeed, a focus of some early restoration work was "*coastal hazard management*" (certainly a commendable enterprise), but many of the current innovative and sustainable ecosystem restoration projects are working assiduously to also include "*the conservation of dune function or dune flora"* through carefully considered biodiversity enhancement projects. This can be simply demonstrated by the many collaborative programmes with the more progressive members of academia and ecological consultants producing a selection exceeding 35 indigenous dune plant species for restoration of biodiversity on successional dunes zones in the BOP region of NZ. However, the proselytising assertion by Hilton *et al* that contemporary eradication of *"marram grass on Stewart Island ... stands as perhaps the most significant dune conservation initiatives to date ..."* has conversely been quite egregious in effect – and regrettably responsible for initiating the newest large mobile dunefield in this nation, observable even by satellite imagery. This mobile 'active' dune in Doughboy Bay is now impacting on an inland perched stream and wetland system nearby. This modern problem was induced by imprudent aerial-spraying of a marram-destroying herbicide (in about 2000), and the subsequent on-going grazing of emergent colonising native dune plant seedlings by locally plentiful feral deer. This lamentable modern impact shares more commonality with the degraded dunes common one century ago than contemporary practices of coastal conservation and ecosystem restoration.

In reality, active dunes are simply degraded and now relict dunes, stressed by the impacts of man and his animals, where natural vegetation has been obsessively burned and native plant colonisation denied by the proliferation of mammalian herbivores (rabbits, hares, goats, sheep, cattle, pigs, deer, horses etc). Consequently, "active" dunes remain mostly as mere reflections of these immense impacts (earlier or modern, or both), with artificial limitations being wrought by a range of introduced and frequently-feral grazing mammals. These dunes are additionally prone to further problematic and unnaturally-induced aeolian AND consequential wave erosion. On occasion, beaches possessing such dunes are described with incongruous and sentimental overtones, including the perversely emotive expression '*iconic*' and even described as possessing *'natural character'*. The NZ Coastal Policy Statement 2010 contains such idiosyncrasies, like those in Objective 2 *"To preserve the natural character of the coastal environment and protect natural features and landscape values … ".* This prescriptive policy clearly obliges coastal management authorities to retain the 'natural character' of their coastal margins and thereby protect this unfortunate and desolately unnatural state: "*3.3 OBJECTIVES - 3.3.1 To preserve the natural character of the coastal environment by protecting the coastal marine area from inappropriate … use and development …"* (Auckland Regional Coastal Plan 2004). There is remarkably little that is truly **natural** about **that** character.

This reality is brought into sharp focus by renowned botanist A. E. Esler with his comments on similar degradational problems "*At that point* [in 1858] *the landscape ceased to be uniquely NZ and started to* *resemble other temperate parts of the world wherever man took his populations, practices and plants*." (Esler 2004) Only relict and severely damaged dunes remain in existence today; degraded and reduced in functional capacity now to be mere shadows of their former biologically diverse and dependable selves, failing to provide their critically important protection role as naturally effective coastal buffers by accreting sand naturally between normal erosion events, where necessary.

Healy and de Lange (2014) have usefully updated prevailing concepts concerning subaerial sand movement in NZ, while enriching our perceptions of the existing and factual diabathic (cross-shore exchange) and parabathic (alongshore transport) littoral processes. Human-induced erosion of sand dunes (and consequently their attendant beaches) can affect this movement of sediment, as sand relocated to off-shore storm bars by wave erosion of affected dunes can then be entrained by ocean currents for abnormally long periods (without suitable plant species to trap and stabilise these sediments when returned to degraded beach berms), and this consequently induces excessive and aberrant relocation of ocean-entrained sand through parabathic movement. Additionally where sediment is returned to its native beach berm, the existing despoiled condition of these foredunes also frequently induces aeolian removal of sediment landward from the beach compartment, further exacerbating the problem of unnatural erosion.

Following dune restoration with indigenous vegetation, any useful and 'new' sand returned by cross-shore exchange processes is now convincingly trapped and stored by this halophytic C_4 vegetation – so the true natural diabathic processes are restored also. This new reality is now supportively recognised by Healy and de Lange in the recent paper above.

Beach erosion has long been considered to be an aberrant and obstinate problem, suited only to being 'solved' by engineers with substantial investment in combative constructions. But as multitudes of these intrusive structures have continued to fall short of their often highly-promoted roles and promises of security, there is increasing clarity that beach erosion continues despite the presence of these 'protective' devices, albeit at possibly a slower pace. Damaging wave reflection is induced by all such artifices, and this reflective turbulence simply removes further sediment with each backwash. *"Wright concluded that beaches in front of seawalls were consistently narrower or absent in comparison to the adjacent unwalled beaches. Beach degradation and loss in front of seawalls is attributed to three mechanisms (Pilkey and Wright 1988): passive loss, placement loss, and active loss."* (Jackson et al. 2012). These structures only provide temporary protection for landward coastal infrastructure, and are incapable of dealing with the root causes of the problem – the poorly documented impacts of dune degradation over many centuries - **and its reversal**.

These engineered structures are extraneous and expensive at NZ$1.5 to NZ$48 million per kilometre (Jenks *et al* 2007), and have two very germane limitations:

1. A limited lifetime of 20 to 40 years (Jenks *et al* 2007)
2. They cause further loss of beach amenity: *"A common result of seawall…. placement along the open coastline is the loss of beach fronting the structure*." (Commission on Engineering and Technical Systems 1987)

Updated but equally superficial 'natural' beach renourishment practices are instead currently favoured by the United States Army Corps of Engineers in efforts to vainly protect property too close to disaster. However these renourished beaches are not replanted with indigenous dune plants, and therefore are often regarded as temporary and sacrificial, despite costing more than NZ$4.3million/km (or NZ$4,300/metre) of beach. Hence this expensive sand is frequently removed and relocated by wave action, necessitating expensive replacement programmes with five year rotations (National Geographic 2013). This too is not a sustainable option as a sole solution in the long term: *"… because beach nourishment provides a sacrificial, rather than fixed barrier, any property damage mitigation, as well as recreational or ecological benefits it affords, are ephemeral."* (Coburn 2012)

The sum of all the above actions has been cumulative and categorical creation of **relict (or fossil) landscapes,** where evolutionary processes are terminated, either abruptly or over a period of time. However the significant distinguishing features of these relict dunes are often still visible in physical form, and fortuitously can still frequently be restored.

CONCLUSION

Natural, functional and resilient coastal sand dunes are one of the more important but conversely most habitually, historically and degraded ecosystems globally. Due to the long-standing and widely accepted practice of comprehensively degrading dune character for spurious anthropogenic purposes, the original functional capacity of natural dune ecosystems has long been severely compromised. Additionally, this loss of integrity and function is particularly poorly documented while simultaneously being increasingly critical for natural protection of expanding coastal populations from the ravages of coastal erosion, storm surges and impacts of sea level rise due to climate change.

The problem of our many relict dune landscapes is increasingly (if superficially) being recognised globally: "*Extreme weather, sea-level rise and degraded coastal ecosystems are placing people and property at greater risk of damage from coastal hazards*" (Arkema et al 2013) (see figure 5).

Protection suggestions by coastal engineers often loose veracity and relevance when beach systems are more appropriately returned to their approximately natural state. 'Doing something concrete', no matter how irrelevant the 'something' is to the problem at hand and to natural dune function, is still erroneously seen by many members of the general public and regulators as a 'suitable' discharge of responsibilities: *"The successive interventions involving hard coastal engineering … along with the ignorance of a local authority being under immense local pressure do something, has resulted in a series of damaging human impacts on natural coastal processes … "* (Jackson 2012)

However we now have affordable, reliable means to reproduce **continuing landscapes**: restoration of natural dunes and beaches that retain an active recreational role in contemporary society closely associated with traditional ways of life, and where evolutionary processes can still progress. These restored dunes thus exhibit significant material evidence of their continuing evolution over time, even when impacted by the effects of climate change.

Assiduous, successful and low-cost dune biodiversity restoration outcomes proven in NZ, including use of indigenous C_4 halophyte coastal plant species to rectify the many deleterious human-induced impacts described above, may also have extensive benefits for other nations experiencing similarly challenging effects in their coastal zones. Restoration of indigenous dune vegetation and natural protective function is not only possible; it is also the most cost-effective option for coastal protection available. Again, further details of these new practices (or paradigm) will be presented in a supplemental paper.

The challenge now before us is simply to decide which coastal management option to choose:

To continue lamenting ineptly when 'natural' storm erosion tears away more of our precious beach sand, and then react with expensive futility with beach nourishment or additional expensive seawalls and so promote further creation of *relict* (fossil) landscapes, OR

To recognise that due to the cumulative impacts of human history, modern beaches are now simply degraded coastal systems, and so treat these damaged but naturally evolved ecosystems with deserved admiration for their long-lost and increasingly accepted protective function, and then initiate proven and transformational restoration programmes (i.e. recreating *continuing* landscapes).

The choice is simple; we now can simply and honestly recognise the impacts described above and turn the clock back by merely employing an attitude change – a paradigm shift.

And the best option in this endeavour is agreeably the most sustainable, and significantly, is also the least-cost option known – less than 1% of seawall costs. (Jenks *et al* 2007). The final famous words come from Albert Einstein: ***"We can't solve problems by using the same kind of thinking we used when we created them."***

Figure 5: **Human-induced dune degradation, Padang Bai, Bali, Indonesia - April 2011.**

The pervasive problem of extensive anthropogenic modification of these dunes is now limiting their natural function and protection role. Degradation of locally indigenous beach vegetation exceeds 95% of the original cover here. Hence normal and expected spring tide surges now regularly inundate the nearby (and encroaching) road, as shown in this photo taken from an adjacent hotel roof. This serious and challenging concern is simply a problem of dune degradation fated by a long legacy of anthropogenic actions. Climate change and rising sea levels are merely a secondary effect and only serve to compound this existing and unrecognised adversity. NOTE: A proximate dune - only one headland away – is still dominated by natural indigenous vegetation with greater than 80% coverage (due to less human impact) maintains a dynamic and predictably protective dunefield exceeding 200m in width. The locally indigenous C_4 halophyte foredune vegetation complex includes the tropical spinifex (*Spinifex littoreus*), beach morning glory (*Ipomoea pes-caprae*), beach bean (*Canavalia rosea*), and beach pea (*Vigna marina*), backed by a suite of similarly indigenous mid-dune plants. This functional dune naturally protects adjacent productive land from the identical tidal and storm surges shown in figure 5, and importantly self-repairs after episodic and limited (by vegetation) erosion events.

The lesson for future deliberation is yet-again encapsulated right here - and will be further reported subsequently.

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