# Implications of environmental change for dune mobility in the Netherlands

*Sebastiaan M. Arens, Quirinus L. Slings, Luc HWT Geelen and Harrie G.J.M. Van der Hagen*

Bureau for Beach and Dune Research Amsterdam, The Netherlands

nv PWN Drinking Water Company Velserbroek, The Netherlands

Research & Development, Waternet Vogelenzang, The Netherlands

Dune Water Company Voorburg, The Netherlands

ABSTRACT

In this paper we discuss mechanisms for dune mobility and stability, with special reference to the Netherlands. Currently in the Netherlands, as in other parts of western Europe, dunes are in a phase of stabilization, which results in loss of biodiversity. Provides durable dune mobility a solution to maintain biodiversity? Is durable dune mobility realistic under the current climatic and environmental changes?

KEY WORDS: Coastal dunes; dune mobility; aeolian dynamics; Netherlands; restoration projects

## INTRODUCTION

Coastal dunes in the Netherlands comprise important, multifunctional landscapes. They harbour many rare species, of both flora and fauna, protect the hinterland from flooding, provide us with drinking water and serve as recreational space. Sustainable management off this landscape demands a thorough understanding of the system. Of many coastal dune systems in the world, the exact origin is unknown. In literature, several hypotheses for the origin of mobile dunes are explained. One hypothesis argues that the origin of coastal dunes is related to large scale coastal processes, leading to massive input of sand onto the coastal system. In this case, the birth of coastal dunes is the result of sand supply. Another hypothesis claims that large scale mobile dunes must be related to remobilization of older systems due to coastal erosion. Finally, a third hypothesis attributes dune mobility to human activity, caused by destruction of vegetation through wood gathering for fuel, overgrazing and other exploiting activities.

Most coastal dune systems in western Europe presently are in a phase of stabilization. Again, the true reason is not well understood. Stabilization of these systems may occur because of stabilizing efforts of man during centuries, reduced anthropogenic pressure or climatic change. Due to stabilization, pioneer stages are becoming rare, causing biodiversity to decrease in many dune systems. Managers try to counteract these negative effects, for example by removing vegetation in order to set vegetation succession back, or by restoration of mobile dunes. The question here is whether stabilization can be turned down in a durable way, or if managers will be forced to fight stabilization "for ever". What are the key factors in dune mobility or dune stability?

In this paper, we discuss mechanisms of dune mobility, impacts of environmental and climatic change and tools available for managers to keep biodiversity in their dune systems intact.

## MOBILITY VERSUS STABILITY: THE STRUGGLE OF VEGETATION AGAINST SAND

Dunes all over the world experience alternating phases of mobility and stability (e.g. McFadgen, 1985, 1994; Arbogast et al, 2002; Tsoar and Blumberg, 2002; Clemmensen and Murray, 2006). Also within a system, mobile and stable phases can coexist (Barbosa and Dominguez, 2004; Tsoar, 2005; Yizhaq et al, 2007). The state of the system is determined by climatic parameters and the availability of sand.

More specific, three major driving forces can be recognized (cf. Hesp and Thom, 1990): wind energy, growing capacity of vegetation and sand availability (Fig. 1). Transitions from one phase to the other are driven by changes in climate, sand supply or human impact. In essence, the problem of mobility versus stability can be reduced to the struggle of vegetation against sand.

Wind energy and growing characteristics of vegetation are governed by climate. For example, increased storminess will increase the available wind energy for aeolian transport, and therefore enhance dune mobility. Increased rainfall and a rise of the average temperature will favour vegetation growth, and tend to direct the state of the system to stabilization. Several studies point to increasing mobility of dune systems due to climate change, especially in areas where aridity is increasing (Lancaster, 1997; Forman et al., 2001; Thomas et al., 2005). None mention the probable reduction in dune mobility in areas with increasing rainfall, and the resulting loss of biodiversity.

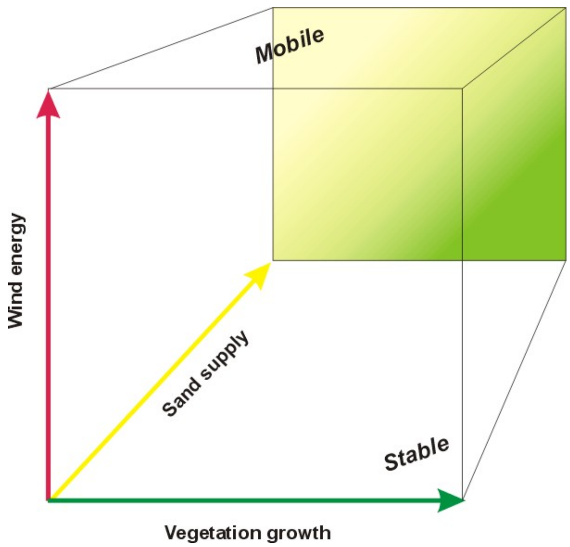


Fig. 1. Driving forces in dune development. After Hesp & Thom (1990).

Sand supply is governed by coastal processes or the input of sediment by rivers. Humans may directly or indirectly influence sand supply, with important consequences for the dune system, as will be discussed below.

Which changes have occurred to the Dutch coastal dunes in the past centuries and what was their impact on dune mobility?

DUNE MOBILITY IN THE NETHERLANDS

The Younger Dunes in the Netherlands developed in several phases of major dune mobility, roughly between 800 and 1600 AD (Jelgersma et al., 1970; Klijn, 1990). The exact mechanisms are not well understood. Klijn (1990) and Jelgersma et al. (1970) mention storm activity, coastal erosion and exploitation by man as probable causes. But the main question remains about the origin of the sand that built up the Younger dunes: which process triggered the invasion of these massive amounts? A study by Pool and van der Valk (1988) pointed out that during development of the Younger Dunes as much as 50 $m^3$/m.yr of sand was stored in the dunes, during several hundreds of years and along several km's. These amounts exceed the present day transport by an order of magnitude. Probably the input of sand was related to processes on the shoreface, resulting in a steepening of the shoreface, thereby providing large quantities of sand to the beach (Zagwijn, 1986). Storm surges in the $10^{th}$-$16^{th}$ century caused large scale coastal erosion and a probable remobilisation of sand. Whether there is a relation with supply of sediment by the large rivers is unclear. Climate variation might have played a role, with periods of increased storminess and severe droughts as trigger for dune mobilization. A recent study in the Dutch Delta area (Beekman, 2006) relates massive phases of dune building to coastal erosion, triggered by changes in coastal inlets.

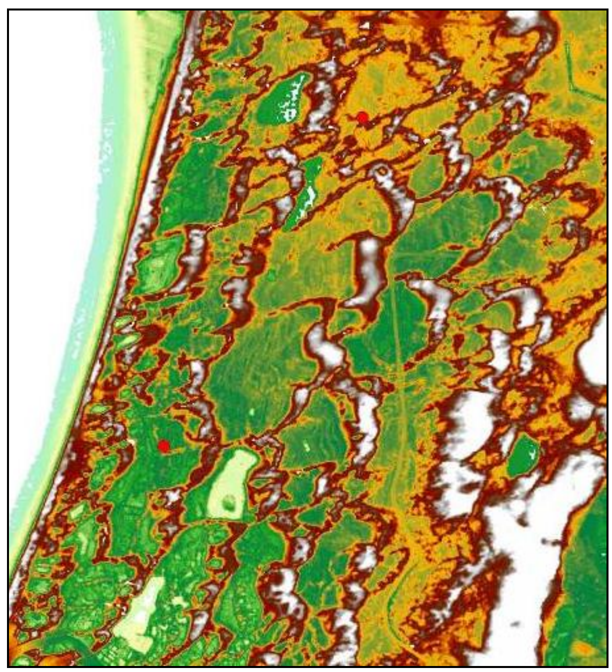

Figure 2. The coastal dunes of Kennemerland. Source data PWN.

The present morphology of the dunes reflects the extent and vigour of dune mobility in the past. Most of our dunes consist of large series of parabolic dunes, increasing in dimension from west (coastline) to east, alternated by large deflation plains and ending up in a huge precipitation ridge in the east (Figure 2). The maximum width of the dune belt is approximately 4.5km. The height of the dunes ranges between 10 and 50m.

This specific setting of series makes us believe that parabolic dunes started as blowouts in the foredunes, gradually released from the foredune when growing larger and moving inland, coalescing to larger systems moving further inland, and finally ending up in a precipitation ridge. The main origin of the parabolic dunes then is related to processes at the foredunes. However, human influence cannot be ignored. From several sources we know that at least until the 19th century dune mobility in many locations was related to human disturbance, mainly gathering of wood for fuel, branches, marram grass etc, overgrazing and digging out of rabbits. Also there is evidence that the size of the precipitation ridge, which locally exceeds 50m DOD, is caused by plantation of trees by humans who would stop the gradual invasion of sand, at least since around 1600. Several paintings from the 17th century show severely eroding coastlines, but also strong abuse of the foredunes (Giepmans et al., 2004). Many stories tell of villages swallowed by the sea or buried under sand (Rentenaar, 1977). The present coastline is situated several 100s to 1000s of metres east of the coastline before the building of the Younger Dunes. We believe that the sand of the Younger Dunes was derived from this vast coastal erosion, while much of its present morphology is in someway related to human activity.

Nowadays, the system has changed completely. Since centuries, man has put efforts in stabilizing dunes by planting pine trees and marram grass. From the start of the 19th century this gradually resulted in decreasing dynamics in the dunes. At the end of the 19th century large areas of dunes were still mobile. By the end of the 20th century, only a small percentage of the surface was left bare.

Figure 3 summarises most environmental and climatic factors that have exerted some influence on dune mobility in the Netherlands. On the left are those factors which enhance stability, on the right those factors that enhance mobility. Between 1000AD and now, many of the factors on the right have decreased in importance (most of all coastal erosion and exploitation by man). Especially in the last century, many of the factors on the left have increased in importance, due to several causes. As a result, the dunes in the Netherlands are forced into the direction of stability.

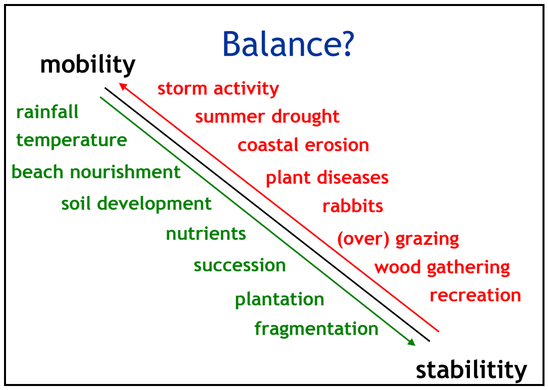


Figure 3. Impact of environmental stress factors on dune mobility and stability.

Despite predictions of increased storm activity due to global warming, the Netherlands have experienced considerably less storms since 1990, resulting in reduced coastal erosion and aeolian activity. Rain fall and temperature are steadily increasing over the last century, with positive impacts on growing capacity of vegetation. The growing season over the last decades has extended with approximately one month. Vegetation growth is further stimulated by Nitrogen input from air pollution. Exploitation of dunes by man has ceased. Because of increasing vegetation, organic matter in soils is accumulating. The rabbit population decreased enormously because of myxomatosis and VHS. Meanwhile, vegetation succession continues, as time goes by. All these factors together have resulted in an incredible increase in biomass.

Around 1990 coastal defence strategies changed. Since then, beach nourishments are applied on a very large scale, to counteract erosion processes, and fixate the coastline at its position. There are signs that this inhibits the interaction between beach, foredunes and inner dunes, limits the input of fresh sand into the inner dunes, and causes a further fixation of the coastal dune landscape. Also stimulated by the lack of big storms, large parts of the coastline are now covered with newly built dune ridges (Fig. 4). Gentle sand input of around 5-15m$^3$/m.yr is not sufficient to kill vegetation, but on the contrary helps Marram grass to grow vigorously.

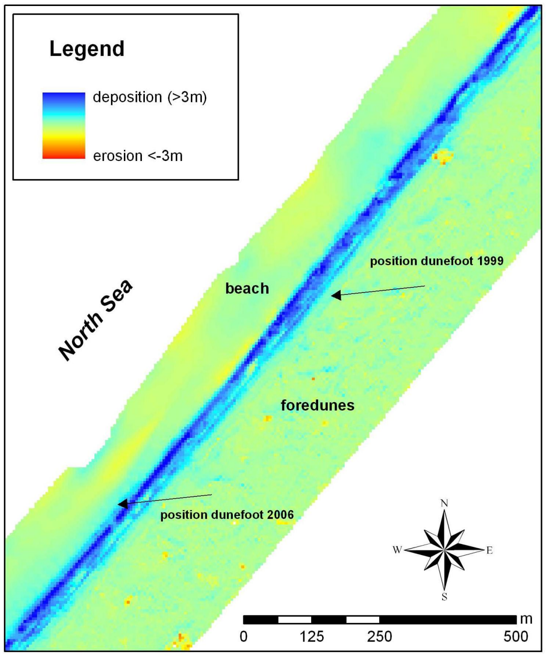


Fig. 4. Small scale dune building due to beach nourishment. North of Scheveningen, province of South-Holland. Source data Rijkswaterstaat.

Some current developments might favour aeolian processes and locally give rise to new phases of dune mobility. Increased summer droughts are expected, and occasionally observed, like in the summer of 2006. There are signs that the combination of higher temperatures and increased rainfall intensities results in higher levels of water erosion, which enables new development of blowouts. Grazing as a management tool replaces the former activity of rabbits. In some areas, dynamic preservation of the coast (Hillen and Roelse, 1995) gives room to natural processes. In places where beach nourishment is applied less strictly, occasional foredune erosion leads to promising new developments. For example, the foredunes along the coast of North-Holland have changed drastically within a decade by the development of breaches and blowouts. Before 1998 development of blowouts was prevented by the managers. Since the application of "dynamic preservation" at this part of the coastline, numerous blowouts have been developing (Fig. **5**). In other parts of the coast, with the same change in management attitude, nothing happens. It is important to find out why these differences in development occur.

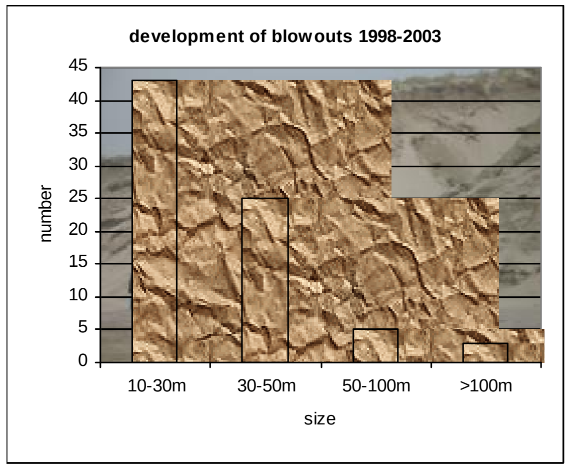


Fig. 5. Development of number of blowouts in the Northholland Dune Reserve since 1998.

## RESTORATION OF DUNE MOBILITY IN THE NETHERLANDS

Presently, because of stabilisation, many of the dunes tend to end up in the same climax vegetation, dominated by shrubs. On average, biodiversity is decreasing (Arens and Geelen, 2006). New ways of management are being developed to maintain biodiversity, or increase where possible. Which factors can be manipulated in such a way that the system will be forced back into a durable state of mobility? Is this possible at all? In the last decade, several experiments have been started in order to restore large scale mobility. The main idea is that if we succeed in restoring dune mobility, nature itself will keep biodiversity on the same level, by creating freshly deflated valleys through deflation on the upwind side, with opportunities for pioneer species and destroying climax vegetation by burial of sand on the downwind side (Arens et al., 2004). With a

Fig. 6. Foredune remobilisation, Terschelling, Wadden Islands. Photograph R. Haring.

certain percentage of mobile dunes within the area, permanent renewal of pioneer stages and rejuvenation of the landscape is ensured.

Earlier experiments with foredune displacement proved that restoration of large scale dynamics can be achieved in the foredunes by means of simple interventions. In the province of North-Holland removal of vegetation and the digging of some trenches in the direction of the wind caused the foredune to move inland, with measured sand transport rates of about 45 $m^3$/m.yr, mainly derived from redistribution of foredune sand. Similar results were obtained on the Wadden Island of Terschelling (Fig. 6), but here the sand input is derived from the beach as well.

Restoration of dune mobility in the inner dunes appears to be much more complicated. Monitoring of these experiments indicates that restoration is not immediately successful (Arens et al., 2004, 2005; Arens and Geelen, 2006). Even after ten years, we cannot conclude that restoration works or fails. Removal of vegetation and soil leads to a sudden and dramatic increase in aeolian dynamics (*Fig. 7*, top), but restabilisation from root remnants causes important problems (*Fig. 7*, bottom). The formation of a desert pavement of blown out (dead) roots prevents further erosion. After a restoration intervention, a certain form of maintenance for a number of years might be necessary. Further monitoring in the coming decades will reveal if these experiments are successful in the long run.

It has become clear that we do not yet know all ins and outs of durable dune mobility. Therefore we have tried to unravel the complex mechanisms of dune mobility and stabilization, and the main factors that play a role. Only if we understand this well, we will be able to design the best strategy for management, by which natural processes are stimulated to shape and reshape the landscape, with as less human interference as possible.

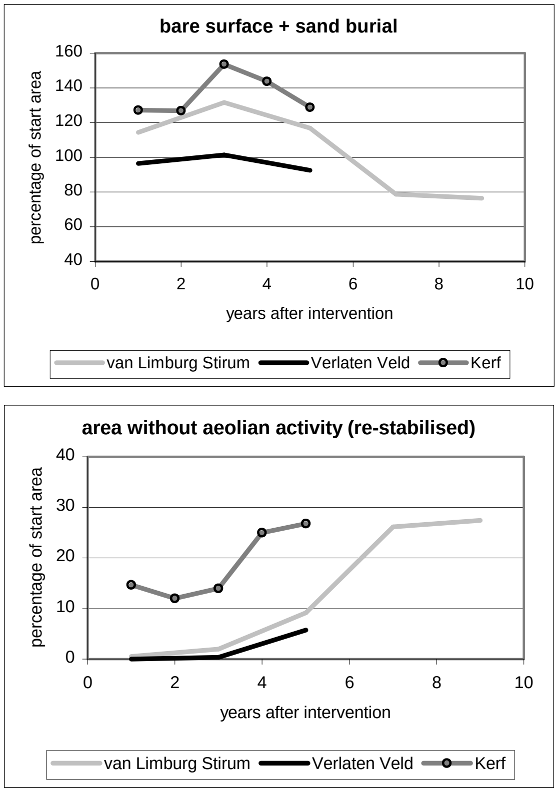


Fig. 7. Changes in dynamic and stabilised surfaces for 3 restoration projects

## DISCUSSION

Conclusions from the literature, and local developments in the Netherlands and other sites in western Europe have convinced us of the necessity to incorporate beach and foredune dynamics in restoration projects. Be it by erosion or excessive sand supply, the foredunes should act as some transfer system between beach and dunes. This might be the key for a durable development. In our situation, coastal erosion, breakdown of the foredune and remobilisation of sand is considered as the engine for large scale dune mobility. Mobility due to climatic change is unlikely to happen within the next decades, but might happen in the long run (>2040). Mobility due to massive supply of sand to the beach is unrealistic. Dimensions of beach nourishments might be oversized to enable transgressive dune development, but the costs will be enormous. Better results could be achieved on parts of the coast with enough space for a natural development. Allowing foredune erosion and consequently dune remobilisation at these places might "restart the engine". Fig. 8 shows an example from the mouth of the river Authie, in northwestern France. Severe coastal erosion remobilises the foredunes. The covering pine forest is completely destroyed by sand blasting and salt spray. The dune front remains bare for at least a couple of year, sand is available for wind erosion, and the dune invades the hinterland.

More knowledge is needed on the transfer mechanisms. It is clear that wave erosion releases sand for subsequent aeolian transportation, and that a very large supply of sand from the beach kills vegetation and results in mobility as well. But gentle supply leads to enhanced vegetation growth and blocks the transfer. Is there some equilibrium? Can we manipulate the system in such a way that both wave erosion and (gentle) sand supply keep the transfer function intact?

A smart design of nourishments might give room for coastal erosion, creating "windows" in the foredunes where sand can be transported inland. For example, a nourishment could be started after a few years of foredune breaching. Then, some extra amounts of sand could be nourished to feed the dune system. In the past, coastal defence engineers considered any landward transport of sand as a loss for the defence system. Nowadays, with sea level rise, any input of sediment into our country should be regarded as a welcome help to keep our heads above the water.

The discussion of dune mobility and stability, and environmental and climatic control has brought us to the conclusion that dunes in general reflect two different settings. In desert dunes (mostly continental dunes), there is an almost 1:1 link between dune mobility and climate. Vegetation growth is fully governed by climate (and humans). With a deterioration of climate (or increased exploitation), vegetation disappears and dunes become mobile. These dunes respond directly to climatic change.

In many of the coastal dunes in the world climate is not arid or semi-arid, but temperate and/or humid. Although these dunes only can develop under the guarantee of wind, the other decisive factor is sand supply. Without sand supply, these dunes finally will stabilise. Sand supply can either

Fig. 8. “Restarting the engine”. An example from northwestern France, mouth of the Authie.

be from shoreface to beach, resulting in burial of vegetation that cannot cope with deposition rates, or the release of previously deposited sand by erosion. Under climatic conditions with limited possibilities for plant growth, small amounts of sand suffice. Under climatic conditions favourable for vegetation growth (like ours), large amounts of sand are needed. Bare foredune cliffs of 15-25m height in combination with the right winds, can produce these amounts of sand. The response of these systems to (delicate) climatic change is much more complicated.

## CONCLUSIONS

Coastal dunes alternate between phases of mobility and stability. A conceptual model is presented in which the main factors influencing either mobility or stability and their complex interactions are described. Climatic factors impose their influence through two of the driving forces: wind energy and vegetation. Environmental factors, often influenced by man, affect vegetation growth and sand availability in several ways. Both climatic and man induced changes can alter the state of the system. For managers, it is important to know how they can interfere with these factors, to achieve their management goals.

In the Netherlands dune mobility seems to be related to sand supply. Under the current conditions, a huge supply is needed to overcome fixation by vegetation. Removing of vegetation alone is probably not sufficient. Some help from the sea will sustain a more durable development.

## REFERENCES

Arbogast, AF, Hansen, EC and Van Oort, MD (2002). “Reconstructing the geomorphic evolution of large coastal dunes along the southeastern shore of Lake Michigan,” *Geomorphology* Vol 46, pp 241-255.

Arens, SM, Slings, QL and De Vries, CN (2004).

"Mobility of a remobilised parabolic dune in Kennemerland, The Netherlands". *Geomorphology*, Vol 59, pp175-188.

Arens, SM, Geelen, LHWT Slings QL and Wondergem, HE (2005). "Restoration of dune mobility in the Netherlands," In: Herrier, J.-L. et al. (eds), *Proceedings: Dunes and Estuaries 2005*. International Conference on Nature Restoration Practices in European Coastal Habitats, Koksijde, Belgium, 19-23 September 2005. VLIZ Special Publication, 19, pp 129-138.

Arens, SM and Geelen, LHWT (2006). "Dune landscape rejuvenation by intended destabilisation in the Amsterdam Water Supply Dunes," *Journal of Coastal Research*, Vol 23, pp 1094-1107.

Barbosa, LM and Dominguez, JML (2004). "Coastal dune fields at the São Francisco river strandplain, Northeastern Brazil: morphology and environmental controls," *ESPL*, Vol 29, pp 443-456.

Beekman, F (2006). "De kop van Schouwen onder het zand. Duizend jaar duinvorming en duingebruik op een Zeeuws eiland". Thesis University of Amsterdam.

Clemmensen, LB and Murray, A (2006). "The termination of the last major phase of aeolian sand movement, coastal dunefields, Denmark," *ESPL*, Vol 31, pp 795-808.

Forman, SL, Oglesby, R and Webb, RS (2001). "Temporal and spatial patterns of Holocene dune activity on the Great Plains of North America: megadroughts and climate links," *Global and Planetary Change*, Vol 29, pp 1-29.

Giepmans, SE, Kos, A and Van ´t Zelfde, R (2004). "*Hollandse stranden in de Gouden Eeuw*," Katwijks Museum, 136 pp.

Hesp, PA and Thom, BG (1990). "Geomorphology and evolution of active transgressive dunefields," In: Nordstrom, KF, Psuty N and Carter, RWG (Eds), *Coastal dunes; form and process*. Wiley, New York, pp 253-288.

Hillen, R and Roelse, P (1995). "Dynamic Preservation of the Coastline," *Journal of Coastal Conservation*, Vol 1, pp 17-28.

Hugenholtz, CH and Wolfe, SA (2005). "Biogeomorphic model of dunefield activation and stabilization on the northern Great Plains," *Geomorphology*, Vol 70, pp 53-70.

Jelgersma, S., De Jong, J, Zagwijn, WH and Van Regteren Altena, JF (1970). "The coastal dunes of the western Netherlands; geology, vegetational history and archaeology". *Mededelingen Rijks Geologische Dienst, Nieuwe Serie*, Vol 21, pp 93-167.

Klijn, JA (1990). "The Younger Dunes in The Netherlands; chronology and causation". In: Bakker, ThW, Jungerius, PD and Klijn, JA (Eds), Dunes of the European coast; geomorphology – hydrology – soils. *Catena Supplement* 18, pp 89-100.

Lancaster, N (1997). "Response of eolian geomorphic systems to minor climate change: examples from the southern Californian deserts," *Geomorphology*, Vol 19, pp 333-347.

McFadgen, B (1985). "Late Holocene stratigraphy of coastal deposits between Auckland and Dunedin, New Zealand," *Journal of the Royal Society of New Zealand*, Vol 15, pp 27-65.

McFadgen, B (1994). "Archaeology and Holocene sand dune stratigraphy on Chatham Island," *Journal of the Royal Society of New Zealand*, Vol 24, pp 17-44.

Pool, MA and Van der Valk, L (1988). "Volumeberekening van het Hollandse en Zeeuwse Jonge Duinzand". Kustgenese Project, Taakgroep 1000, Rapport BP10705, RGD, Haarlem.

Rentenaar, R (1977). "De Nederlandse duinen in de middeleeuwse bronnen tot omstreeks 1300," *Geografisch Tijdschrif*,*t* Vol XI.

Thomas DSG, Knight, M and Wigs, GFS (2005). "Remobilization of southern African desert dune systems by twenty-first century global warming," *Nature*, Vol 435, pp 1218-1221.

Tsoar, H (2005). "Sand dunes mobility and stability in relation to climate," *Physica A*, Vol 357, pp50-56.

Tsoar, H and Blumberg, DG (2002). "Formation of parabolic dunes from barchan and transverse dunes along Israel's Mediterranean coast," *ESPL*, Vol 27, pp 1147-1161.

Yizhaq, H, Ashkenazy, Y and Tsoar, H (2007). "Why do active and stabilized dunes coexist under the same climatic conditions?" *Phys. Rev. Letters* Vol 98, pp 188001-04.

Zagwijn, WH (1986). "*Nederland in het Holoceen,*" Staatsdrukkerij, ´s-Gravenhage, 46pp.