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Resilience of Meta-Stable Landscapes? The Non-Linear Response of Late Glacial Aeolian Landforms to Prehistoric Reclamation along Dutch River Valleys

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Archaeology; drift sand; erosion; Holocene; late prehistory, reclamation; aeolian geomorphology.

1 Introduction

During the Holocene, Late Glacial aeolian deposits throughout the European sand belt were reactivated as sand drifts.[1] The well-documented lack of synchronicity in the temporal and spatial distribution of Holocene dune activity clearly argues against any single major external force as the main trigger of this reactivation process, but rather points towards localised nuclei and human impact.[2] In the Netherlands, most sand drifts date from the high- to post-medieval period.[3] Their formation was probably connected to an intensification of land use in settlement peripheries (*outfields*), but contextual evidence for this is scarce.[4]

In recent years, archaeological excavations have produced a growing body of evidence for the existence of prehistoric sand drifts along terraced Dutch river valleys (Fig. 1). The archaeological context of these sand drifts strongly suggests that they are (largely) anthropogenic in origin and that they were originally situated in settlement *infields.* We conclude that early reclamations of dune fields along river valleys had disproportionately large consequences, as they exposed a landscape in a state of incipient instability to erosion and 'desertification.'

2 Observations

2.1 Meuse Valley

Archaeological excavations within a major dune field near Wijchen revealed two prehistoric sites covered by drift sand. At the site of Wijchen-Martensterrein (Fig. 1: WMa), the major drift sand phase left an unstratified aeolian deposit of up to 3m thick which separated Middle from Late Neolithic deposits (Fig. 2; see Tab. 1: 1,2).[5] Intense sand drifting can be associated with the earliest agricultural phase of the Middle Neolithic. An arable layer dated archaeologically to the Late Neolithic and Early Bronze Age forms the topsoil of the aeolian deposit, an indication that the sand drift had by then stabilised.

1 e.g., Koster 1982; Hilgers 2007; Tolksdorf and Kaiser 2012.
2 Castel 1991; Hilgers 2007; Tolksdorf and Kaiser 2012.
3 Koster 1978; Castel 1991; Koster, Castel, and Nap 1993.
4 Jungerius and Riksen 2010, 66.
5 Verhelst 2011.

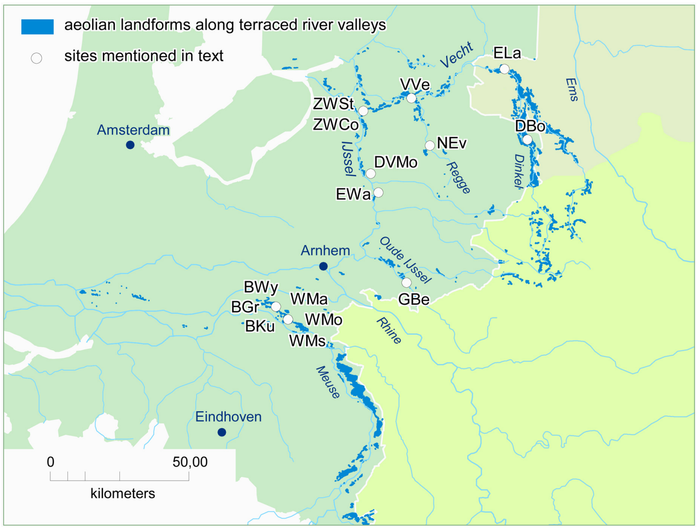

Fig. 1 | Dunes along terraced river valleys in the Netherlands, with site names mentioned in the text.

Agricultural activity from the Middle Bronze Age onwards sparked off a renewed phase of sand drifting characterised by several sedimentation phases (including the Late Bronze Age [3,4] and Middle Roman period [c. AD 200] periods), but these events only resulted in locally restricted and thin drift sand deposits. A similar example of intense first-phase sand drifting is found nearby, at the Meshallen site (WMs). Here, a substantial accumulation of drift sand (up to 1.5m of largely unstratified deposits) was archaeologically dated as being younger than c. 1100 BC.[6]

2.2 IJssel Valley

At the Epse-Waterdijk site (EWa), reactivated Late Glacial sand dunes form an extensive, up to 1.5m thick deposit.[7] This drift sand was deposited on top of an Early Bronze Age field and accumulated in the course of the Middle or Late Bronze Age (5). At Deventer-Molenbelt (DVMo), an arable layer, buried by moderate drift sands and archaeologically dated to the Iron Age, forms the topsoil of a thicker accumulation of drift sand,[8] presumably dating from the Middle or Late Bronze Age (6,7). At both sites, the largely unstratified deposits suggest short-lived but intense events. Elsewhere along the IJssel Valley, other late prehistoric sand drifts were found at the Zwolle-Stadshagen site (ZWSt[9]). Radiocarbon dates indicate that these sand drifts date to the Middle Bronze Age (8,9).

2.3 Oude IJssel Valley

At the Gaanderen-Beekstraat site (GBe), drift sand was deposited on top of a fossil plough soil which has been dated archaeologically to the Late Neolithic/Early Bronze Age. The oldest settlement traces in its topsoil presumably date from the Late Iron Age.[10]

6 Heirbout, Hendriks, and Hermsen 2010.
7 Appels 2002; Appels 2002.
8 Hermsen 2005.
9 Kooistra 2004; Hamming 2008.
10 Veldman and Kenemans 2005.

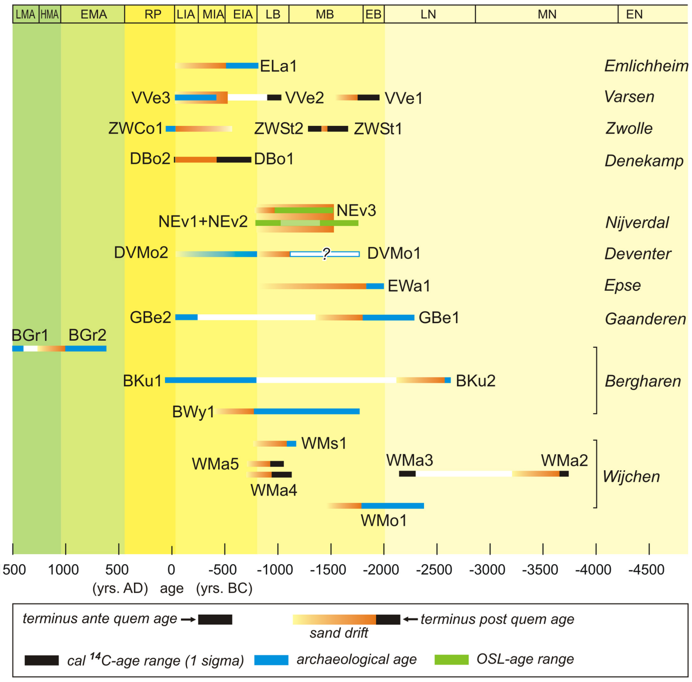

Fig. 2 | Boxplot of radiocarbon-, OSL- and archaeologically dated sand drifts mentioned in the text (terminus post quem, - ante quem and depositional ages). Archaeological periods abbreviated: EN, MN, LN (Early, Middle, Late Neolithic); EB, MB, LB (Early, Middle, Late Bronze age); EIA, MIA, LIA (Early, Middle, Late Iron age); RP (Roman period); EMA, HMA, LMA (Early, High, Late Middle Ages).

2.4 Regge Valley

The archaeological Nijverdal-Eversberg site (NEv) is situated on top of a Late Glacial dune field along the Regge Valley. Settlement traces date back to the Middle and Late Neolithic, Bronze Age and Iron Age.[11] Along the fringes of the dune field, up to 0.5m of drift sand deposits accumulated on top of a 0.4–0.5m-thick arable layer, OSL-dated 1570–1010 BC (10). Micromorphological analysis indicates that the arable layer reached this considerable size because drift sand accumulated whilst the field was in use.[12] OSL samples taken from the drift sand produced a date of 1760 to 1020 BC (11,12: Middle to Late Bronze Age), which corresponds to the date of the buried arable layer. Apparently, Bronze Age farmers abandoned their fields as wind erosion and sand accumulation further intensified.[13]

2.5 Vecht Valley

The high-relief dune fields along the lower Vecht Valley (G: *Vechte*) have been inhabited since early prehistory.[14] During the Iron Age, settlement density increased significantly.[15] The Varsen-Varseneres site (VVe) is located on a prominent sandy ridge. Holocene dune reactivation began with minor accumulations of windblown sediment, which produced a radiocarbon date of 1896–1773 BC (13) and were deposited on top of an intact older soil.[16] These oldest drift sand deposits were then covered by a massive, c. 1m-thick accumulation of dune sand, which has been dated archeologically to the Middle to Late Iron Age (14)

11 Gerrets, Opbroek, and Williams 2012.
12 Bos and Zuidhoff 2012.
13 Bos and Zuidhoff 2012.
14 e.g., Johansen and Stapert 2000.
15 Beek 2009; Beek and Groenewoudt (in press).
16 Hielkema (in press).

and early Roman period.[17] After a period of relative inactivity, these sand drifts were again covered by a thin layer of drift sand, followed much later by the accumulation of a *plaggen* soil.

The late prehistoric settlement at Emlichheim-Lamberg (ELa; Germany) is more or less contemporary with Varsen-Varseneres. As was the case at Nijverdal-Eversberg, the plough soil on the fields around Emlichheim-Lamberg attained a considerable thickness (up to 0.5m) due to the continuous accumulation of drift sand. The settlement and fields were abandoned in the Early Iron Age following a catastrophic erosion episode which buried the site beneath as much as 5m of drift sand.[18] This catastrophic erosion was probably anthropogenic in origin.

2.6 Dinkel Valley

The sand drifts at the Denekamp-De Borchert site (DBo) are roughly contemporary with Varsen-Varseneres and Emlichheim-Lamberg. At Denekamp-De Borchert, Late Glacial cover sand was blown into an inactive channel of the River Dinkel. The deposits have been dated to somewhere between 763–409 BC (15) and AD 50 (16).[19]

3 Discussion

3.1 Are the Observed First-Phase Sand Drifts Anthropogenic?

In all these cases, sand drifting is a phenomenon clearly tied to settlement *infields*, and all observed instances correspond to, or immediately follow upon, phases of agricultural activity. Several of the sites presented in this paper (Wijchen, Denekamp, Emlichheim) have produced excellently preserved hoof prints and plough marks directly beneath drift sand deposits. In our opinion, this is a strong indication that farmers were forced to move their fields as these were being destroyed by drift sand. Dunes along riverbanks were preferred settlement locations during prehistory,[20] and there is strong archaeological evidence for intensive late prehistoric land use and settlement.[21] As in the studies by Hilgers[22] and Tolksdorf and Kaiser,[23] dates of prehistoric sand drifts cluster between 1500 and 1000 BC, i.e. Middle to Late Bronze Age. Many archaeological sites representing settlements or farmland were covered by aeolian sand at that time.[24] Archaeological evidence shows that around 1500 BC, settlement mobility decreased and agricultural land use intensified.[25]

17 Verlinde 1972.
18 Maschmeyer 1991.
19 Verlinde 2004; Verlinde 2006.
20 e.g., Street et al. 2001; Verhart and Arts 2005.
21 e.g., Beek and Groenewoudt (in press).
22 Hilgers 2007.
23 Tolksdorf and Kaiser 2012.
24 e.g., Waterbolk 1961; Hammen and Bakker 1971; Verlinde 1972; Gijn and Waterbolk 1984; Maschmeyer 1991; Groenewoudt et al. 2007; Beek 2009.
25 Arnoldussen and Fontijn 2006.

How Can the Substantial Scale and Incidental Nature of the Observed Sand Drifts Be Explained, and why Do the Sand Drifts along Terraced Dutch River Valleys Predate those in Cover Sand Areas?

The Late Neolithic appears to have been the first period of sudden and intensive dune reactivation (2500–2000 BC[26]), which is usually linked to the intensification of agricultural activity[27] and woodland clearance in the European Plain.[28] However plausible intensification may be as a partial explanation, it does not fully explain the timing, distribution and intensity of the observed sand drifts. Here, conditions prior to reclamation seem to have been influential. As early as the late Atlantic (c. 4500 BC; Early Neolithic), a natural process of podzolisation and soil depletion set in, which affected the nutrient-poor aeolian soils alongside river valleys, such as those of the dune fields of Wijchen (Teunissen[29]: pollen zone HV4b/5). This onset of soil depletion amply predates the early reclamation phase, and also precedes the depletion of the more fertile and loamy cover sand soils.[30] It is thus quite possible that natural soil depletion prior to the arrival of the earliest farmers had brought the high-relief sand dunes alongside the river valleys into a state of what geomorphologists call "incipient instability."[31] This condition is intrinsic to geomorpological systems where substantial changes in an external variable[32] are not always required for a geomorphic threshold to be exceeded, and for a significant geomorphic event to ensue.[33] This would help to explain our observation that on several sites only moderate sand drifting has been observed following more severe first-phase erosion, although environmental pressure at these sites became more profound. In our opinion, the abrupt erosional and depositional prehistoric events at e.g.Wijchen-Martensterrein (Middle Neolithic), Nijverdal-Eversberg (Middle or Late Bronze Age), Epse-Waterdijk (Middle or Late Bronze Age), Wijchen-Meshalle, Deventer-Molenbelt (Late Bronze Age?) and Emlichheim-Lamberg (Early Iron Age) should be interpreted as non-linear geomorphic responses to relatively small anthropogenic perturbations.

Conclusion

The archaeological context of prehistoric sand drifts along Dutch river valleys suggests that they are largely anthropogenic, and that their occurrence corresponds to phases of early agricultural activity. After the local introduction of agriculture, small, short-lived changes appear to have produced disproportionately large results. On the basis of the available data we propose the hypothesis that natural soil depletion prior to the start of reclamation may have been an important trigger of intense aeolian sediment relocation. As they were ploughing fields and creating pasture for cattle, early farmers tore up already impoverished soils and over-exposed the until then fixated Late Glacial sandy landscape below, thereby sparking off intense sand drifting. This observed non-linear response suggests a form of geomorphic change that does not correspond to proportionally large external forcings, but is instead characteristic of landforms in a state of incipient instability. As

26 Hilgers 2007.
27 Hilgers 2007; Tolksdorf and Kaiser 2012.
28 e.g., Casparie and Waateringe 1980; Teunissen 1990; Casparie 1992; Behre and Kučan 1994; Spek 2004; Groenewoudt et al. 2007.
29 Teunissen 1995.
30 Roymans and Gerritsen 2002; Spek 2004, 129.
31 Schumm 1979; Phillips 2006.
32 Cf. Koster 2009, 100; Jungerius and Riksen 2010, 66.
33 Schumm 1979.

a result, the first (substantial) reclamations on high-relief aeolian landforms had a far more dramatic effect than later reclamations on a larger scale and on the same sites. This questions the general assumption that the environmental impact of relatively small-scale prehistoric activities was limited.

Identifier	Lab. No.	Location (cf. Figs. 1,2)	Analytical result	Cal BC (1s) #	TPQ/ TAQ?
1	Beta-272007	Wma2	4880 ± 40 14C yr BP	3710–3630 BC**	TPQ
2	Beta-27005	Wma3	3770 ± 40 14C yr BP	2300–2040 BC	TAQ
3	Beta-267524	Wma4	2870 ± 40 14C yr BP	1200–900 BC	TPQ
4	Beta-267522	Wma5	2840 ± 40 14C yr BP	1050–920 BC	TPQ
5	n.a.	EWa1	Archaeological date	2000–800 BC	TPQ
6	n.a.	DVMo1	Archaeological date *	1800–850 BC	TPQ
7	n.a.	DVMo2	Archaeological date	750–15 BC	TAQ
8	KIA -19155	ZWSt1	3280 ± 45 14C yr BP	1611–1506 BC	TPQ
9	KIA–19154	ZWSt2	3154 ± 30 14C yr BP	1489–1386 BC **	TAQ
10	NLC-7611088	NEv3	OSL 3290 ± 280 yr BP	1570–1010 BC	
11	X5058	NEv1	OSL 3380 ± 330 yr BP ^{X,Y}	1710–1050 BC	
12	X5059	NEv2	OSL 3390 ± 370 yr BP ^{X,Y}	1760–1020 BC	
13	Poz-43205	VVe1	3520 ± 35 14C yr BP	1896–1773 BC	TPQ
14	Poz-43206	VVe2	2825 ± 35 14C yr BP	770–541 BC	TPQ
15	GrN-7451	DBo1	2465 ± 35 14C yr BP	763–409 BC	TPQ
16	n.a.	DBo2	Tree-ring date	55 ± 6 BC	TAQ

^{14}C calibration according to IntCal04

*Based on a nearby settlement on Holocene soil (Modderman 1955)

**2σ (95.4%) confidence interval

^{X} Replicate samples

^{Y} Dose rate values and OSL-ages have been calculated assuming initial water contents of 5–10% saturation, otherwise OSL-ages would date approx. 300 years younger (Bos and Zuidhoff 2012).

Tab. 1 | List of sand drift ages (terminus post quem and terminus ante quem dates unless otherwise stated).

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