A multi-proxy reconstruction of a fossil (*ca* 900 AD) ecosystem in the Dutch coastal dune area (Noordwijk, The Netherlands)

Dedicated to Hans Vader †

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In this study we use an exceptional outcrop (Van Limburg Stirumvalley outcrop: VLS) located in the dunes of the western Netherlands, to give a multi-proxy reconstruction of an early medieval (*ca* 900 AD) ecosystem. We document diverse biota with species, including Eurasian eagle-owl *Bubo bubo* (Linnaeus, 1758), brown bear *Ursus arctos* Linnaeus, 1758, wild boar *Sus scrofa* Linnaeus, 1758, red deer *Cervus elaphus* Linnaeus, 1758 and blind worm *Anguis fragilis* Linnaeus, 1758, that were thought to have vanished from the western Netherlands well before Roman times. Our findings show that the Dutch dune areas harboured a very different ecosystem compared to today's, and give a glimpse of the high biodiversity which existed before the landscape changed due to natural causes and human intervention. At least for pockets in the Dutch dune landscape, that change appears to have been much later then hitherto proposed. The VLS outcrop shows a variety of plants and animal species that should be considered in dune rewilding and restoration programmes.

KEY WORDS: *Anguis fragilis, Bubo bubo*, Early Middle Ages, *Lacerta* sp., molluscs, Older Dunes, plants, ecosystem reconstruction, *Spermodea lamellata, Ursus arctos*

Introduction

The Dutch coast has a dynamic history (Vos, 2015). During the beginning of the Holocene, the current North Sea was dry, but gradually came under the influence of the sea due to a rising sea level. The eastern border of the North Sea reached the current coastal area of Holland around 7500 BP and afterwards also inundated large areas east of it. Between 5000 and 2500 BP, the coast expanded seaward. Marshes, salt marshes and beach barriers arose with low dunes on them. These dunes are called the Older Dunes. Over the centuries, mainly after the ending of sand transport from the West in Roman times, various vegetations and their associated fauna developed undisturbed on these Older Dunes. Due to its higher position in relation to the sea and the marshes, the area was also attractive to humans. From the Stone Age onwards, settlements are present. Well known is the presence of Romans in the River Rhine estuary (14 km south of our site). But only from the Early Middle Ages the dune area became (temporarily) inhabited at many places.

The area discussed in the current paper is situated in the municipality of Noordwijk; with the centre coordinates 52.3222/4.5064 (Dutch Rijksdriehoekscoördinaten: 94,950/481,965). It is located in the middle of a large dune area, 1 km from the North Sea coast. These dunes are known as the Amsterdamse Waterleidingduinen (AWD). As a result of landscape restoration in the beginning of the 21st century, soil sections and old dune strata were exposed. On several sites geological and archaeological observations were made (Vader, 2007; Vossen, 2007). The exposed strata date to the Older Dunes, medieval horizons, and the Younger Dunes (Jelgersma *et al*., 1970). After the construction work in 2006-2007, a bare stretch of 7500 m² of sand in the northern part of the area remained: the Van Limburg Stirumvalley (VLS; Figs 1 and Pl. 1, fig. 1). Here, wind erosion exposed light brown palaeosoils with shells, bones and a peat layer. We sampled these sediments extensively and here discuss all animal and plants remains that were found. Some preliminary results have already been published elsewhere (Kuijper, 2016; Kuijper *et al*., 2016; Vader, 2019). In addition, the results of other research in this dune area are used. Vader realised the value of this area and started collecting bones.

Geology and history

In the present-day lithostratigraphical classification the coastal sandy dune deposits are part of the Naaldwijk Formation and the interjacent peat layers are part of the Nieuwkoop Formation (TNO-GDN, 2021). The formerly formally recognised Older Dunes and Younger Dunes are now classified as Schoorl Member within the Naaldwijk Formation, but the older names are still in use (Vos, 2015).

The Younger Dunes were formed after circa 1000 AD by sand blowing in from the West. This sand covered the Older Dunes (with on top a soil = horizon C of Jelgersma *et al.*, 1970; Pl. 1, fig. 2), but the wind also eroded high parts of the underlying dunes before they were overblown. However, the low, moist parts with peat layers were buried without erosion. These Older Dunes with a relief of a few metres were formed long before the deposition of the Younger Dunes and formed coastal dunes on beach barriers with elongated depressions between them. These dunes largely stopped moving and forming before Roman times. For about 1200 years, undisturbed vegetation developed on dry and wet soil, and in aquatic habitats. Due to the height differences of several metres, in the lower parts dune lakes, pools and marshes formed, while forests grew on the higher parts. Small dune streams drained surface water. Pollen analyses of peat show that tree cover (birch, oak, alder, willow, beech) increased between 175 BC and 900 AD. Especially at the end of the 8th–end of the 9th century the beech increased markedly. At the same time, groundwater levels rose and there was a lot of open water in the dunes. In the entire dune region between Velsen and Noordwijk, a practically continuous forest area developed. The presence of full-grown oak and beech trees is attested through finds of wood and seeds in buried soils and peat layers at the top of the Older Dunes. Part of this forest was situated in the border area between the counties Rijnland and Kennemerland and thus remained untouched for a long time (Jelgersma *et al.*, 1970: fig. 31). It is estimated that this dune area spanned several hundred square kilometres.

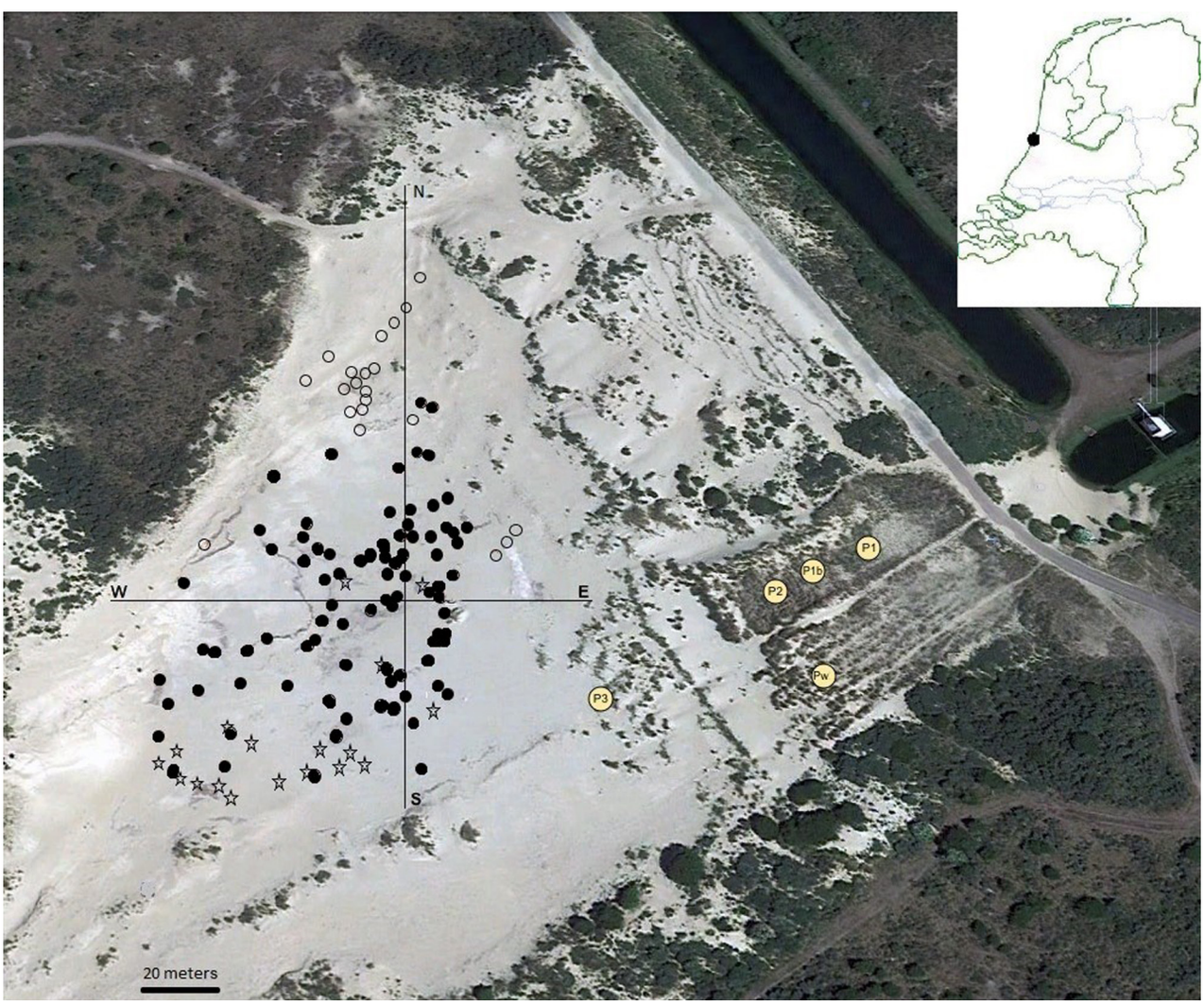

Figure 1. Aerial view of the study area, the Van Limburg Stirumvalley outcrop (inset: location within the Netherlands) with sample locations (circle: black = Older Dunes, transparent = Younger Dunes), tree stumps (star) and geological sections (big circle). Straight lines indicate the location of the elevation data (NS = Fig. 4 and WE). (Source: Google Maps, 2015).

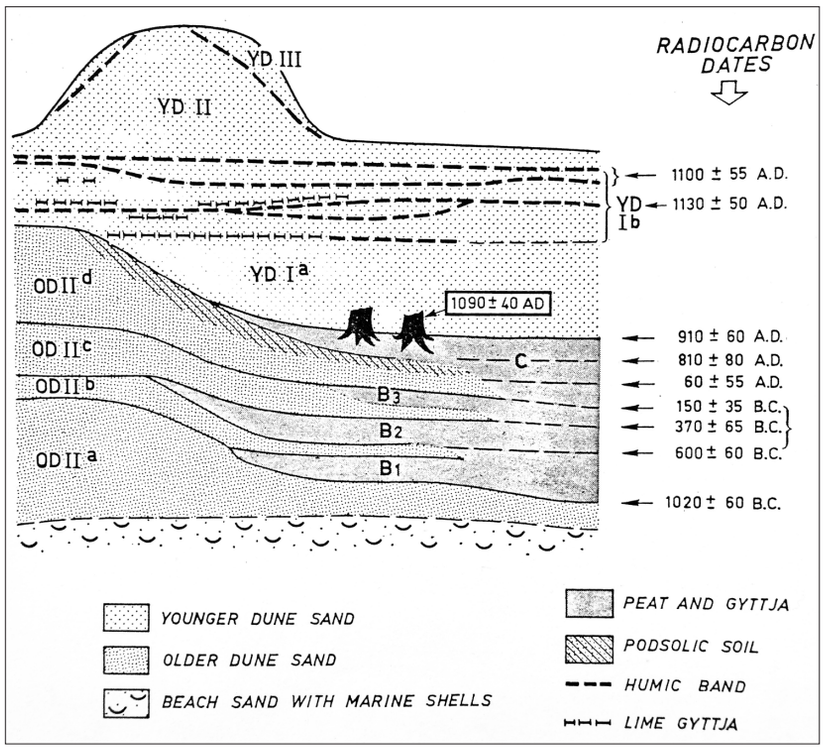

Figure 2. Outline of strata in the Amsterdamse Waterleidingduinen. On top of the Older Dunes (OD) a (podsolic) soil or a peat layer in the low parts is present. This horizon (C) separates the OD from the Younger Dunes (YD) (after Jelgersma *et al*., 1970: fig. 5).

Around 1100 AD a new overblowing phase started in the dunes, and with winds coming in from the West, the Younger Dunes were formed. Marshes were overblown and forest was buried under sand. The transition between Older and Younger Dunes is situated at about 4.5 m + NAP (NAP = Dutch Ordnance Level) (Blokzijl & Pruissers, 1989; Bosman & De Koning, 2005; Jelgersma *et al*., 1970; De Jong & Numan, 2002; Vossen, 2007). However, due to differences in altitude in the undulating old dune landscape and subsequent erosion, this can vary by several metres. Habitation remains from the Early Middle Ages were also found at this transition. In a dune area situated further to the North an estimate has been made of groundwater levels around 900 AD in the Older Dunes. They fluctuated around 3.5 m + NAP (Vos *et al*., 2010).

The situation in our study site at the northern tip of the Van Limburg Stirumvalley is in line with the results of the aforementioned publications. Specifically, we refer to the impression of the succession of the layers by Jelgersma *et al.* (1970), here reproduced in Fig. 2. In the deepest part of the Van Limburg Stirumvalley a layer (palaeosoil of light brown sand, sandy peatlayers and black peat) is present that is similar to horizon C of Jelgersma *et al.* (1970).

The surface of the valley shows that the palaeosoil, with many zoological and botanical remains, is situated in the deepest parts, between 3.60 and 4.50 m + NAP. A north – south surface elevation profile (Fig. 3) is presented (AHN3, 2020). From this altitude and the flora and fauna we conclude this is the soil in the top of the Older Dunes. Above this palaeosoil, many small marine shell remains were found, that were absent in the palaeosoil which is (partially) rich in calciumcarbonate. To test the

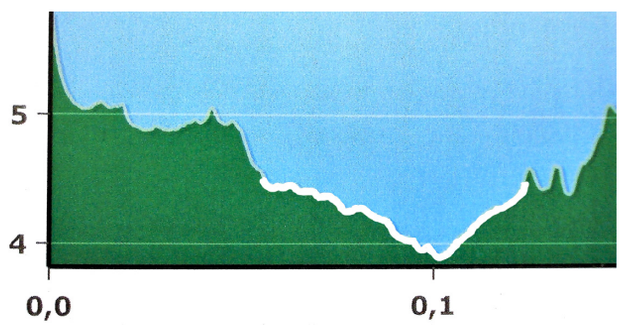

Figure 3. Surface height of the Van Limburg Stirumvalley outcrop from north to south (after AHN3, 2020). For location see Fig. 1 (N-S). Vertical: altitude in metres + NAP, horizontal: distance in kilometres. In white the brown palaeosoil in, and peaty layer on, the top of the Older Dunes is indicated.

above, an age determination was performed on a bone of a brown bear *Ursus arctos* Linnaeus, 1758 found in the brown soil. The ^{14}C dating was 1140 ± 30 BP (GrA-66477), calibrated: 880-970 cal AD (Kuijper *et al*., 2016). This date corresponds to the proposed age of the top of the Older Dunes.

Materials and Methods

At the start of the study in 2015, a barren sandy dune valley of about 50 x 150 m was present (Fig. 1 and Pl. 1, fig. 1). Loose sand on this surface was blown away by strong winds; this exposed several undisturbed deposits. After removing the debris from the surface, the undisturbed soilhorizon (Pl. 1, fig. 2) and peat layers (Pl. 1, fig. 3) could be sampled. The thickness of the palaeosoil ranged

from a few cm up to a maximum of 20 cm (Pl. 1, fig. 5). The aim was to sample the entire valley evenly. However, parts consisting of sand and peat were not sampled after small random tests showed these deposits were not fossiliferous. Sampling then focused on the fossil-bearing sediments, *i.e.* the palaeosoil. The exact sample locations were GPS recorded and many photographs were made. The altitude compared to NAP was determined using AHN3 (2020).

At each sample location, a volume of soil was collected, ranging between 0.5 litre and 10 litres. The standard volume aimed for was 2 litres. A total of 244 litres was analysed. The sediment was transported in plastic bags and sieved with tap water. The standard mesh size used was 0.5 mm; some material was sieved on 0.25 mm. This finer mesh did not provide any additional information. Residues from the upper and lower parts of the soil showed no differences and hence all results were pooled for analyses. The sieve residue (Pl. 1, fig. 6) was dried, divided into size fractions and analysed with the help of a binocular. A total of 111 localities (plotted in Fig. 1) was sampled and analysed. Some animal bones were collected in situ because they were partly visible on the surface after sand was blown away (Pl. 1, fig. 4; Pl. 3, fig. 1).

The collected material is stored in the Naturalis Biodiversity Center, Leiden, The Netherlands, the bones of a brown bear are in the collection of the Laboratory for Archaeozoological Studies of the Faculty of Archaeology, Leiden University, The Netherlands and some bones (collected by H. Vader) in the Provinciaal Archeologisch Depot Zuid-Holland, Alphen aan den Rijn, The Netherlands.

For the identification, information and ecology of the species found we used Broekhuizen *et al.*, 2016 (mammals); Creemers & van Delft, 2009 (amphibians and reptiles); Weeda *et al.*, 1985, 1988, 1991 (plants); Welter-Schultes, 2012 (molluscs) and different reference collections and own observations.

It is customary not to use species names for pollen and wood. For simplicity, for plant names author and year have been left out. In botanical literature author names are generally abbreviated and the year of publication is not used.

Results

General

Only one sample did not contain animal or plant remains. In the absence of shells, the soil was also found to be free of calciumcarbonate. However, 90 samples contained terrestrial and aquatic gastropod shells in varying amounts. Due to the fragility of the shells, fragmentation occurred during sampling, transport, and sieving. Occasional bone fragments or small bones were found in the soil samples. Large bones were visible on or in the soil.

The abundant sclerotia of a soil fungus, present in 80 soil samples, were striking. These samples, that mostly also contained remains of earth worms (Lumbricidae), appeared to be characteristic of the soil in the top of the Older Dunes. In the southern and middle part of the VLS some stumps and roots of trees were visible (plotted in Fig. 1). Evidence for reworking of fossils was not found.

Most results allow for a palaeoecological reconstruction on a local scale (molluscs, small mammals, amphibians, reptiles, worms, plants), but the remains of large mammals and birds provide information on a regional scale. There is a small chance that species have been transported to the VLS by carnivores (prey, owl pellets).

Molluscs (Mollusca)

The research focused on the land and freshwater molluscs; specifically on identifying species associations. The first results have been published previously (Kuijper, 2016). This rich fauna of terrestrial molluscs from the Older Dunes in the Netherlands was not reported before 2016. Additionally to the material retrieved from the soil samples, specimens were also collected from material concentrated by the wind and loose shells on the valley floor.

• Concentrated by the wind

The species in accumulated material in the surrounding dunes gave a first indication of the fauna in the sediments of the VLS. It is a mixture of molluscs from the Older Dunes, Younger Dunes and the recent fauna (Tables 1 and 2). Most remarkable was the presence of many shells of *Spermodea lamellata* (Jeffreys, 1830), which was also collected abundantly from *in situ* samples. This species, together with other forest species *Acanthinula aculeata* (O.F. Müller, 1774), *Vertigo pusilla* O.F. Müller, 1774, *Cochlodina laminata* (Montagu, 1803) and *Aegopinella nitidula* (Draparnaud, 1805) cannot live in the current conditions at the site, due to the present open and dry environment. The single specimen of the land snail *Truncatellina cylindrica* (A. Férussac, 1807) can be both fossil or recent, while *Helicella itala* (Linnaeus, 1758) lived in this area until recently; the age of the specimens collected is therefore not certain. They are both species adapted to open landscapes and would not have lived here in the Older Dunes. *Candidula intersecta* (Poiret, 1801) occurs alive in this valley. *Vertigo moulinsiana* (Dupuy, 1849) and *Balea heydeni* von Maltzan, 1881 are land snails that most likely lived in the Older Dunes, they were however not recovered from *in situ* samples. Thus, the material concentrated by the wind is only partially a reflection of the mollusc fauna in the soil of the top of the Older Dunes of VLS and it cannot be used to reconstruct the environment during the formation of the Older Dunes.

• Surface valley floor

The presence of many loose shells on the bare surface gave an indication that material was to be expected in the soil. The light coloured larger shells *Arianta arbustorum* (Linnaeus, 1758), *Cepaea nemoralis* (Linnaeus, 1758),

origin:	concentrated by the wind	on surface	in soil (in situ)
samples N:	9	6	83
soil:		sand	sand
colour:		l.brown	l.brown
litres:	17	13	207
Carychium minimum O.F. Müller, 1774	xxx	xx	xxxx
Carychium tridentatum (Risso, 1826)	xxx	xx	xxxx
Succinella oblonga (Draparnaud, 1801)	xxx	xx	xx
Oxyloma cf *elegans* (Risso, 1826)	xx	xxx	xx
Cochlicopa lubrica (O.F. Müller, 1774)	xx	xxx	xxx
Cochlicopa lubricella (Porro, 1838)	xxx	xxx	xxx
Vallonia costata (O.F. Müller, 1774)	xxx	xx	xxx
Vallonia pulchella (O.F. Müller, 1774)	xx	-	-
Vallonia excentrica Sterki, 1893/*V. pulchella*	xxx	-	-
Acanthinula aculeata (O.F. Müller, 1774)	xxx	xx	xxx
Spermodea lamellata (Jeffreys, 1830)	xx	xx	xxx
Pupilla muscorum (Linnaeus, 1758)	xxx	x	xx
Columella edentula (Draparnaud, 1805)	xx	xx	xx
Columella aspera Waldén, 1966	xx	?	x
Truncatellina cylindrica (A. Férussac, 1807)	1	-	-
Vertigo antivertigo (Draparnaud, 1801)	xx	xx	xx
Vertigo pusilla O.F. Müller, 1774	xx	x	xxx
Vertigo substriata (Jeffreys, 1833)	xx	xx	xxx
Vertigo pygmaea (Draparnaud, 1801)	xx	x	xx
Vertigo angustior Jeffreys, 1830	x	1	-
Vertigo moulinsiana (Dupuy, 1849)	2	-	-
Merdigera obscura (O.F. Müller, 1774)	-	-	1
Cochlodina laminata (Montagu, 1803)	2	17	5
Clausilia bidentata (Ström, 1765)	xx	xxx	xxx
Balea heydeni von Maltzan, 1881	7	-	-
Alinda biplicata (Montagu, 1803)	xx	xxx	xx
Punctum pygmaeum (Draparnaud, 1801)	xx	xx	xxx
Discus rotundatus (O.F. Müller, 1774)	xx	xx	xx
Vitrea crystallina (O.F. Müller, 1774)	xx	x	xx
Vitrea contracta (Westerlund, 1871)	-	-	1
Euconulus fulvus (O.F. Müller, 1774)	xx	xx	xx
Aegopinella nitidula (Draparnaud, 1805)	xxx	xxx	xxx
Aegopinella pura (Alder, 1830)	xx	xx	xx
Oxychilus sp.	1	-	2
Nesovitrea hammonis (Ström, 1765)	x	4	xx
Zonitoides nitidus (O.F. Müller, 1774)	-	1	x
Vitrina pellucida (O.F. Müller, 1774)	x	2	12
Limacidae (small)	-	11	xx
Limacidae (large)	-	1	1
Trochulus hispidus (Linnaeus, 1758)	xxx	xxx	xxx
Helicella itala (Linnaeus, 1758)	x	x	-
Candidula intersecta (Poiret, 1801)	x*	-	-
Arianta arbustorum (Linnaeus, 1758)	3	xx	29
Cepaea nemoralis (Linnaeus, 1758)	xx	xxx	xx

Table 1. Terrestrial molluscs from the Van Limburg Stirumvalley outcrop.
x = some, xx = dozens, xxx = hundreds, xxxx = thousands
* = living

Trochulus hispidus (Linnaeus, 1758), *Alinda biplicata* (Montagu, 1803) and *Aegopinella nitidula* in particular were clearly distinguishable on the light brown soil. Comparison of the species composition of this material with the *in situ* material shows that the results are very similar (Tables 1 and 2).

• Collected *in situ*
The soil examined is situated between 3.60 - 4.50 m + NAP. Material was collected from 83 samples that were taken from the brown layer of sand (Tables 1 and 2). In addition, 7 peat/wood samples of approximately the same altitude were analysed. In the peat no shells were present, the sediment lacked calcium carbonate.

The freshwater fauna consists of 15 species. In 43 samples a mollusc fauna was found, ranging from 1 to 9 species per sample. Only one sample contained 9, three samples 7 and the others between 1 and 6 species. The animals (*Bithynia tentaculata* (Linnaeus, 1758), *B. leachii* (Sheppard, 1823), *Bathyomphalus contortus* (Linnaeus, 1758), *Gyraulus crista* (Linnaeus, 1758), *Segmentina nitida* (O.F. Müller, 1774), *Planorbarius corneus* (Linnaeus, 1758))

origin:	concentrated by the wind	on surface	in soil (in situ)
samples N:	9	6	83
soil:		sand	sand
colour:		l.brown	l.brown
litres:	17	13	207
Bithynia tentaculata (Linnaeus, 1758)	5	-	-
Bithynia tentaculata (operculum)	-	9	14
Bithynia leachii (operc.) (Sheppard, 1823)	-	-	1
Valvata piscinalis (O.F. Müller, 1774)	1	-	-
Valvata cristata O.F. Müller, 1774	10	2	11
Lymnaea stagnalis (Linnaeus, 1758)	-	1	-
Galba truncatula (O.F. Müller, 1774)	xxx	xx	xxx
Stagnicola palustris s.l. (O.F. Müller, 1774)	xx	xx	xx
Radix balthica (Linnaeus, 1758)	xx	3	8
Aplexa hypnorum (Linnaeus, 1758)	xx	x	25
Planorbarius corneus (Linnaeus, 1758)	2	2	1
Anisus leucostoma (Millet, 1813)	xx	xx	34
Planorbis planorbis (Linnaeus, 1758)	xx	16	20
Gyraulus albus (O.F. Müller, 1774)	x	-	-
Gyraulus crista (Linnaeus, 1758)	2	-	5
Bathyomphalus contortus (Linnaeus, 1758)	18	4	26
Segmentina nitida (O.F. Müller, 1774)	xx	17	104
Pisidium obtusale (Lamarck, 1818)	-	-	18
Pisidium sp.	13	-	51

Table 2. Freshwater molluscs from the Van Limburg Stirumvalley outcrop.
x = some, xx = dozens, xxx = hundreds

that cannot withstand dry periods and live mostly at least in some dm deep water are rare. *Galba truncatula* (O.F. Müller, 1774) has the highest presence, in 27 of the 83 samples. *Galba truncatula, Aplexa hypnorum* (Linnaeus, 1758) (Pl. 2, fig. 4) and *Anisus leucostoma* (Millet, 1813) indicate periodically dry periods in the habitat. Together with the other species they lived in well-vegetated, shallow dune pools and marsh in the Older Dunes landscape.

The terrestrial mollusc fauna consists of 36 species. As the 'small' slugs are counted as one species, since their remains cannot be assigned to species level, this is most likely an underestimate of the true diversity. In one sample (nr. 43) a shell (an internal plate) was found of 6,5x4,5x2 mm (Pl. 2, fig. 5). It represents a big species. Most of the shells belongs to 'small' species (*c*. 2,5x1,5x0,5 mm) (Pl. 2, fig. 5).
Likely almost the complete snail fauna of the site is represented. In the 83 samples, 0 to 28 species were present per sample. Some species were sporadically present. In some samples the clausiliums from *Alinda biplicata* and *Cochlodina laminata* were found (Pl. 2, fig. 2). The characteristic species of the soil in the Older Dunes are *Spermodea lamellata* (Pl. 2, fig. 7)*, Acanthinula aculeata* (Pl. 2, fig. 6)*, Vertigo pusilla, V. substriata* (Jeffreys, 1833)*, Clausilia bidentata* (Ström, 1765)*, Alinda biplicata* (Pl. 2, fig. 3)*, Punctum pygmaeum* (Draparnaud, 1801)*, Euconulus fulvus* (O.F. Müller, 1774)*, Aegopinella nitidula, A. pura* (Alder, 1830), *Trochulus hispidus* and *Cepaea nemoralis.* The species in the samples and their ratios correspond well between various samples, which strongly suggests that the soil originates from the same interval. All species lived in the same type of forest.

One of the most interesting finds is *Spermodea lamellata*, a species that is extinct in the Netherlands, which has not been recorded previously from Holocene deposits in The Netherlands. These shells were found in 32 samples, with some samples yielding a few, whereas others contained hundreds. This species lives mainly in old, undisturbed deciduous forests. The soil must be damp or marshy with a good layer of litter and with dead wood. Another unexpected species was *Cochlodina laminata* (Pl. 2, fig. 1). This species lives in forests in the very southern part of the Netherlands and Holocene finds are very rare. The same applies to *Merdigera obscura* (O.F. Müller, 1774). *Acanthinula aculeata*, also a forest species, was present in most of the sampled locations. Together with other forest species they live in the same type of forest as *S. lamellata*. *Vertigo antivertigo* (Draparnaud, 1801) was found in 27 samples, together with *Oxyloma elegans* (Risso, 1826), indicating a very wet environment, such as swamps and swampy banks. Over short distances the area shows differences in humidity. It was a forest-like environment where the vegetation developed undisturbed for hundreds of years, with swampy areas and shallow stagnant water.

There was a low rate of damage caused by beetle predation (see "Miscellaneous"). Damage was observed on shells of *Vallonia costata* (O.F. Müller, 1774)*, Acanthinula aculeata, Spermodea lamellata, Discus rotundatus* (O.F. Müller, 1774)*, Trochulus hispidus, Aegopinella nitidula* and *A. pura*.

Mammals (Mammalia)
Skeletal remains of mammals were found in the samples and as stray finds (Table 3). Six species could be identified:
- **Wood mouse** (*Apodemus sylvaticus* (Linnaeus, 1758)). Four samples yielded bones and molars of wood mice.
- **Mole** (*Talpa europaea* Linnaeus, 1758). Three molars and several dozens of small bone fragments of moles were found in one sample (Pl. 3, fig. 7).
- **Roe deer** (*Capreolus capreolus* (Linnaeus, 1758)). Some roe deer bones, molars, and an antler rod (Pl. 3, figs 1 and 2) were found in the middle of the valley, while the southern part revealed the remains of a left-hind leg (including the terminal phalanges), a shoulderblade, a left lower jaw, a right and left upper jaw and two antlers rods (together).
- **Red deer** (*Cervus elaphus* Linnaeus, 1758). On three locations on the surface of the Older Dunes remains of red deer were found: two molars (Pl. 3, fig. 6), an antler of a young male, seven ribs and a phalanx I.
- **Wild boar** (*Sus scrofa* Linnaeus, 1758). Several bones of wild boar were found in four samples: a lower jaw (Pl. 3, fig. 5), two molar fragments, a front tooth, a fragment of a pelvic bone and two ribs, and in one sample a humerus, radius and ulna (fragment). On the pelvic bone some gnaw marks, possibly of a fox, were present.
- **Brown bear** (*Ursus arctos* Linnaeus, 1758). Several brown bear bones (Pl. 3, fig. 4) were found at one location. After the initial publication (Kuijper *et al*., 2016), additionally three phalanx III (Pl. 3, fig. 3) and three sesamoid bones were collected at the site. That means there were more remains than those of one leg. The other parts of the skeleton may have ended up in the filling of the Van Limburg Stirum canal during the landscape restoration works that exposed the sediments. The sediment around the bear remains, yielded many shells (Pl. 1, fig. 6). They point to a humid old forest.
The brown bear was present in the Netherlands during most of the Holocene. The oldest finds are from the Mesolithic, the youngest from the Early Middle Ages. This indicates the presence of many forested areas in this part of Europe (Kuijper *et al*., 2016). The situation in Belgium and Luxembourg was more or less the same. There, bears were possibly present until the 12th century in the southern and eastern areas (Ervynck, 1993).
The finds of the brown bear in Holocene deposits concur with the historical data about the disappearance (around 1000 AD) of the species in the Netherlands. This implies that the remains found in Noordwijk belong to one of the last wild brown bears in the Netherlands.
Brown bears have a preference for mixed forests and woody areas. To find shelter for their hibernation, the deciduous forest in the temperate climate of the Netherlands offered enough possibilities. Nowadays, the species lives mainly in mountainous areas where only few

	samples N:	83
	soil:	sand
	colour:	l.brown
	litres:	207
mammals		
Talpa europaea Linnaeus, 1758	mole	1
Apodemus sylvaticus (Linnaeus, 1758)	wood mouse	x
Ursus arctos Linnaeus, 1758	brown bear	1
Cervidae	deer	x
Cervus elaphus Linnaeus, 1758	red deer	2
Capreolus capreolus (Linnaeus, 1758)	roe deer	x
Sus scrofa Linnaeus, 1758	wild boar	x
mammalia	mammal	x
birds		
Bubo bubo (Linnaeus, 1758)	eagle owl	1
Anas platyrhynchos Linnaeus, 1758	mallard	1
Turdus cf. *merula* Linnaeus, 1758	blackbird	1
reptiles		
Anguis fragilis Linnaeus, 1758	slow worm	1
Lacerta sp./*Zootoca* sp.	lizard	1
amphibians		
Rana sp./*Bufo* sp.	frog/toad	x
Rana sp.	frog	x
other remains		
bones (small - large)	unidentified	xx
Pisces	fish	1
Lumbricidae	worms (granules)	xxxx
Lumbricidae	worms (egg cocoons)	xxxx

Table 3. Animal remains (minimum number, other than molluscs) from the Van Limburg Stirumvalley outcrop. x = some, xx = dozens, xxxx = thousands

humans venture. Bears lead solitary lives, except when the females have young. The animals have a varied omnivorous diet consisting of fruits, nuts, plants, roots, large insects, fish, bait, small mammals, and sometimes larger mammals. In addition to the ^{14}C measurement on a bone of the bear, the stable isotopes ^{13}C and ^{15}N were also measured: $\delta\ ^{13}C$ = -21.60 ‰, and $\delta\ ^{15}N$ = 5.08 ‰. These are within the normal range for herbivore mammals (Kuijper *et al.*, 2016).

The species indicate an area at and around the site with many habitats: woods with undergrowth and their fringes, open fields with cover, dunes, and dry and wet areas. The wood mouse and the mole dig tunnels in open country, forest *etc*., with a loose soil. Red deer lives mainly in herds in open woodland, roe deer occurs in all types of habitat. Wild boar prefers areas with wet places (small lakes, marsh). From archeological excavations of Early Middle Age settlements we know that both red deer and roe deer lived in the Older Dunes of Holland, as well as fox *Vulpes vulpes* (Linnaeus 1758), and elk *Alces alces* (Linnaeus, 1758) (de Vries, 2015).

Birds (Aves)

Three bird species could be identified (Table 3), including the Eurasian eagle owl (*Bubo bubo* (Linnaeus, 1758)) (Pl. 3, figs 8 and 9) (Vader, 2019), which is rarely found in excavations (*e.g.* Zeiler, 1997). The bones comprise wing, shoulder, and leg bones, as well as parts of the sternum. We assume that they belong to one individual. Eurasian eagle owls (Fig. 4) are at the top of the food chain. They are carnivores and hunt small mammals (voles, mice, rats, hares, juveniles of bigger species), big insects and birds. When there is enough food they live in many different wooded areas, deserts, mountains, dunes, grassland. The other bird species are mallard (*Anas platyrhynchos* Linnaeus, 1758) and blackbird (*Turdus* cf. *merula* Linnaeus, 1758). Of the latter, a wing bone (humerus) was found. Near the same location wing and shoulder bones as well as a number of sternum fragments of a mallard, most probably deriving from one individual, were found. Both are common species: mallard prefers wet areas and blackbirds live in forest and forested areas.

Figure 4. Eurasian eagle owl (*Bubo bubo* (Linnaeus, 1758)), Zuid Limburg, The Netherlands (Photo Cees Timmermans).

Amphibians (Amphibia)

One of the samples yielded the remains (2 humerus left, 2 humerus right, 1 ilium left, 1 ilium right) of several individuals of a frog (*Rana* sp.). In the same sample dozens of undiagnostic skeletal elements and fragments of frog or toad were present. In two other samples a bone of a frog or toad was found. The most likely species is the com-

mon frog (*Rana temporaria* Linnaeus, 1758). This animal is well suited to life in the wet to moist environment as indicated by the other finds.

Reptiles (Reptilia)

An unexpected find was that of the small characteristic osteoderms of a slow worm (*Anguis fragilis* Linnaeus, 1758) (Pl. 2, fig. 8). Osteoderms are plates/scales of bony material that are located under the skin of crocodiles, turtles, and some lizards. Zylberberg & Castanet (1985) deal with the anatomy of *Anguis fragilis* and mention that osteoderms are mineralised oval plates of 100-150 µm thick; their greatest diameter (1.8-5 mm) is transverse to the body axis. In SEM, the anterior part of the osteoderm appears as a woven smooth surface, whereas the posterior is furrowed with grooves that fan out in every direction. The underside of the osteoderm is flat.

In one sample ten pieces were found, the largest specimen was 1.9 x 1.15 mm (Pl. 2, fig. 9), some were damaged. Knobs and ribs are present, there is a smooth zone running lenghtwise along the edge covering about a third of the surface. The other side is smooth, with some perforations. The small osteoderms were identified as slow worm. There are several species living in Europe (*Anguis fragilis, A. cephallonica* Werner, 1894*, A. colchica* (Nordmann, 1840)*, A. graeca* Bedriaga, 1881 *and A. veronensis* Pollini, 1818) (Gvoždík *et al*., 2013). Of these, only *A. fragilis* lives in North-West Europe, so we accept this must be the species we found.

Anguis fragilis is a legless lizard found almost everywhere on the European continent, including the southern Iberian Peninsula and northern regions. The animal prefers moist habitats with lots of vegetation, particularly in forests, forest fringes and heathlands. It is a soil dweller that likes to hide under leaves, wood and stones. In the Netherlands, the oldest fossil find of the slow worm comes from the quarries at Tegelen and dates back to the Tiglian (early Pleistocene). Another site where the species was found is Maastricht (Belvédère 4), which has an age of Saalian (late middle Pleistocene) (Schouten, 2016). The current find is the first from the Dutch Holocene. The current presence of the slow worm in the coastal dunes is most probably due to introduction (Creemers & Van Delft, 2009).

Another surprising find was that of the remains of a lizard (*Lacerta* sp.). In a sample, between small bones, parts of the jaws were present: a lower maxilla left and right, and a premaxilla (Pl. 2, fig. 10). Nowadays, only the sand lizard (*Lacerta agilis* Linnaeus, 1758), lives in the study area, in a dry and open landscape with shrubs. It is a species of the higher sandy soils in the Netherlands. The other well-known lizard is the common lizard (*Zootoca vivipara* (Jaquin, 1787), syn. *Lacerta vivipara*). The animal is a more moist-loving species and lives in wet and dry areas, sometimes coastal dunes. Both species can be found in a large part of Europe (Creemers & Van Delft, 2009). Like in the case of the slow worm, the find of a lizard is the first from the Dutch Holocene.

Miscellaneous

Besides the mollusc, mammal, bird, amphibian and reptile remains, also remains of fish, earthworms and insects were found. In one sample a fragment of a fish vertebra was found. This would have been a (small) species that could live in shallow water. Earthworms (Lumbricidae) are represented by numerous calcite granules (Pl. 2, fig. 11). The species is possibly *Lumbricus terrestris* Linnaeus, 1758; these worms produce many granules. In the Older Dunes soil they are present by the hundreds per litre, but are absent in the shell-free sand and peat/wood samples. The egg cocoons of these animals were also found. Insect remains (terrestrial beetles) are present as a single fragment in various samples. Indirectly, the activities of beetles were also observed. Some shells of terrestrial snails show the characteristic damage by carabid beetles. The beetle starts the attack at the shell aperture and then bites the upper side of the spirals towards the apex. This damage is Type 1 of Millar & Waite (2004).

Apart from molluscs, the fish vertebra and frog, no remnants of the freshwater macrofauna were found. No doubt many species would have lived here. In addition to our analysis, information is available from corings and sections near our site. In corresponding sediments from the same period we found: freshwater sponge (*Ephydatia fluviatilis* Linnaeus, 1759), crystal moss animal (*Lophopus crystallinus* (Pallas, 1768)), water fleas (Cladocera), ostracods (Ostracoda), fresh water leeches (Hirudinea), caddis flies (Trichoptera) and moss mites (Oribatida) (Kuijper, 1993).

Wood

The most striking features were 20 tree stumps in the southern part of the VLS (Fig. 1). Some horizontal root systems were still partially visible (Pl. 4, fig. 3). In general, these were very strongly eroded, and mainly visible due to their black colour. Some stumps were identified: four are birch (*Betula* sp.) (Pl. 4, fig. 2) and one is alder (*Alnus* sp.) (Pl. 4, fig.1). The trunk diameters measure between 25 and 50 cm. In some other places, spots of black and very humic sand were observed. It is likely that also these are remains of trees. In the samples, regularly pieces of wood from trunks, branches, bark or roots were found. These were difficult to identify due to flattening, small size, and degradation. One piece of wood was found with the characteristic bark of birch. The identified tree remains evoke a forest with old-age birch and alder on the wet to moist parts of the Older Dunes. Earlier finds of birch and alder in this area concerned the species *Betula pubescens* and *Alnus glutinosa* (Kuijper, 1993). In the centre of the VLS, a piece of wood was identified as juniper (*Juniperus*). Nowadays juniper is absent in the dunes, but it did grow in the Older Dunes (Zagwijn, 1997).

Soil fungus

Common finds in many samples were the black, round, solid remains (Pl. 4, fig. 5), up to ca. 2 mm in diameter, of a soil fungus: *Cenococcum geophilum* Fries, 1829. In the Older Dunes soil these sclerotia were sometimes found

by the thousands per litre. *Cenococcum geophilum* occurs in many habitats, it is a well-known ectomycorrhizal ascomycete species, that lives on tree roots in forests.

Seeds

Many samples of the Older Dunes soil contained seeds (and seed fragments) (Table 4). The strong corrosion of plant material caused a selection to be preserved in the sandy sediment. Hemp agrimony (*Eupatorium cannabinum*) (Pl. 4, fig. 6) was found in large numbers, up to several hundreds per litre. Aside from this species, single seeds of *Mentha aquatica* (or *M. arvensis*), *Moehringia trinervia,* some *Carex* species, *Sambucus* sp., *Rubus* sp., *Typha* sp. and *Viola* sp., were preserved. These species all have seeds with a seed wall, that can withstand degradation for a long time. Especially the seeds of *E. cannabinum* are known for their long preservation in oxygen-rich sediments such as those studied here (*e.g.,* Preece & Bridgland, 1999: 1107). No doubt more species have grown here, but their seeds have not been preserved; either way *E. cannabinum* was a common species. Its seeds were present in 66 of the 83 samples. It prefers a wide range of damp and wet habitats, like marsh, banks, dune valleys, and wet woodland. The species is characteristic of sites where a lot of organic matter quickly decomposes in moist and/or chalk-based environments. In chalk-rich dunes, *E. cannabinum* occurs between scrub, especially on the edge of humid valleys between *Hippophae rhamnoides*, together with, among others *Mentha aquatica*. However, on calcareous dune sand they also grow far above groundwater.

origin:	**in soil (*in situ*)**	**deposits (*in situ*)**	**tree stubs (*in situ*)**
samples N:	83	7	20
soil:	sand	peat	sand
colour:	l.brown	black	l.brown
litres:	207	5	
species:	10	12	2
wood/root/bark	xx	xxx	xx
charcoal	x	-	-
Alnus sp.	-	-	1
Betula sp.	1 (wood)	-	4
Juniperus communis L.	1 (wood)	-	
Fagus sylvatica L.	-	1	
Eupatorium cannabinum L.	xxx	-	
Mentha aquatica L./*M. arvensis* L.	x	27	
Moehringia trinervia (L.) Clairv.	x	-	
Ranunculus cf. *repens* L.	-	1	
Ranunculus flammula L.	-	1	
Carex sp., 2-sided	x	-	
Carex sp., 3-sided	x	2	
Viola sp.	4	5	
Rubus sp.	1	3	
Sambucus sp.	1	-	
Solanum dulcamara L.	-	1	
Sparganium erectum L.	-	1	
Glyceria sp.	-	1	
Typha sp.	1	-	
Iris pseudacorus L.	-	1	
Chara sp. dif.	-	xx	
Cenococcum geophilum Fries, 1829	xxxx	xxx	

Table 4. Plant remains from the Van Limburg Stirumvalley outcrop.
x = some, xx = dozens, xxx = hundreds, xxxx = thousands

Water mint, *Mentha aquatica* was found in 13 of the 83 soil samples. Usually, it grows in places where the water level is at or above surface level year round, on sunny to slightly shaded places with a humus-rich to peaty soil, such as in wet dune valleys, along scrub on the edge of wet valleys, but sometimes also on less wet north slopes. In 18 of the 83 samples *Moehringia trinervia* was found, a plant that prefers semi-shaded areas and it is sensitive to drought. It generally grows in woodland on humus-rich, not too dry but also not too wet sandy soil, especially in places where a lot of plant material decays quickly. This is particularly the case where the water level fluctuates strongly, or where the soil contains chalk or is suddenly exposed to the light. The species can also be commonly found under, among others, dune scrub.

Although the seed flora is inevitably incomplete, it still provides clear indications of the type of local environment. The three common species found (*E. cannabinum, M. aquatica, M. trinervia*) indicate, together with the few other species, a wet to humid valley. The soil was calcareous and rich in humus, the groundwater level fluctuated around soil surface level. The plant material on the soil surface decayed quickly under the influence of oxygen and chalk. This swampy vegetation was lightly shaded by trees and scrub. The trees may have been birch and alder in the wetter parts, and oak and beech on the higher, drier slopes. One of the samples provides an indication of this: in a compact peat sample some seeds were found, including a fruit of a beech (*Fagus sylvatica*). In three samples of this peat from the middle of the VLS no seeds were present. The seeds in some of the peat samples in the northwestern part of the VLS gave an indication of the vegetation in the marsh in the lower parts. Specifically, *Mentha aquatica, Ranunculus* cf *repens, Ranunculus flammula, Carex* sp*., Viola* sp*., Rubus* sp*., Solanum dulcamara, Sparganium erectum, Glyceria* sp*., Iris pseudacorus* (Pl. 4, fig. 4) and *Chara* species (oogonia) point to a low vegetation on a wet soil, with water in the low parts. Tree species are absent, the fruit of a beech may be from a tree that grew a short distance away on a slightly higher slope.

Lower part Younger Dunes

22 Samples were taken at a slightly higher level than the Older Dunes surface that we discussed above: between 5.00 and 5.60 m + NAP. Here we only mention some characteristics and do not treat these sediments extensively. The freshwater mollusc fauna consists of large numbers of *Galba truncatula* and *Stagnicola palustris*. The ter-

restrial mollusc fauna consists mainly of *Carychium minimum, Succinella oblonga, Oxyloma elegans, Vallonia pulchella* (O.F. Müller, 1774), *Vertigo antivertigo* and Limacidae. In one sample, a nearly complete skeleton of a root vole (*Microtus oeconomus* (Pallas, 1776)) was found. Characteristic of the seed flora are: *Chara* sp. (oogonia, different species), *Mentha aquatica/arvensis, Hydrocotyle vulgaris, Eleocharis palustris, Carex* sp. (different species) and *Potentilla anserina.* Molluscs and plants indicate shallow dune pools with clear, calcium-carbonate rich, oligo-mesotrophic water with a pioneer vegetation dominated by *Chara* species. These pools potentially dried out in summer. The open vegetation in the wet margins and marshy locations was low. They indicate a plant community within the class of small sedges (Schaminée, 2019). Flora and fauna were markedly different compared to that of the underlying Older Dunes.

Information from the surroundings

At the beginning of the 21st century, when the Van Limburg Stirumcanal was being filled in as part of the landscape restoration, a couple of sections in some of the high banks were documented for geological and archaeological research (Vossen, 2007; Bosman, 2009). The information obtained from that research is a valuable complementary data set for the current study. In the east bank of the northern point of the former canal a solid peat layer of 1.90–2.14 m + NAP was present (Fig. 5). Based on other research in the AWD, its occurrence at this level, indicates this peat may date from between 0 and 1000 AD (Bosman, 2009), which means that it represents the wet facies of the soil horizon in the top of the Older Dunes. This locality (Section Pw in Fig. 1) is 120 m southeast of the centre of the VLS. The base of this peat layer contains shells, mainly *Segmentina nitida* and small quantities of 11 other freshwater species (Table 5). These shells indicate a body of water with lots of vegetation, rich in chalk, shallow but not dry in summer. Dozens of ostracods are present. The plant remains (Table 6) in this peat are mainly from *Eleocharis palustris* and *Schoenoplectus tabernaemontani*, and the aquatic plant species *Chara* sp. (thousands of oogonia) and *Nymphaea alba.* Seeds of *Betula* sp. and *Alnus glutinosa* were blown into the water from a nearby bank. Pieces of wood are identified as *Salix* sp. (Kuijper, 2007).

Four sections were taken along the north-west bank of the northernmost point of the canal (Vossen, 2007; Van Smeerdijk, 2007; Fig. 1). One section (P2), 100 m east-southeast of the centre of the VLS, contained a soil at about 3.10 m + NAP. The few pollen identified in a peat sample (3.14 m + NAP) indicate a forest environment. *Pinus*, *Betula,* and *Corylus* are present in low quantities, whereas *Quercus, Fagus* and *Alnus* are more dominant. Lastly Poaceae, *Asteracea liguliflorae* and *Dryopteris* type are notable. The peat of section P1 (120 m east of the center of VLS) was analysed at several points for pollen and macro remains (Table 6). In the layers under the peat (1.89 m + NAP), pollen of *Hippophae* dominated, along with *Juniperus*, *Salix* and small amounts of *Quercus* and *Pinus*. The peat was composed mainly of Cyperaceae and Poaceae. Consequently the landscape was not very wooded. In a subsequent sample (1.87-1.89 m + NAP) seeds

Figure 5. Van Limburg Stirumkanaal, section of the former east bank, at the northern point (from Bosman, 2009) with a solid black peat layer. See Fig. 1 for location (Pw). (Photo Wim Bosman).

	section Pw 120 m s.e.	excavated 0,5 - 1 km s.w.	some corings
freshwater species			
Valvata cristata O.F. Müller, 1774	-	xx	x
Bithynia tentaculata (Linnaeus, 1758)	x	xx	x
Bithynia leachii (Sheppard, 1823)	x	x	x
Radix balthica (Linnaeus, 1758)	1	1	-
Lymnaea stagnalis (Linnaeus, 1758)	1	x	-
Stagnicola palustris s.l. (O.F. Müller, 1774)	x	xx	1
Planorbarius corneus (Linnaeus, 1758)	x	x	-
Planorbis planorbis (Linnaeus, 1758)	x	xx	-
Anisus vortex (Linnaeus, 1758)	1	-	-
Anisus vorticulus (Troschel, 1834)	-	xx	-
Bathyomphalus contortus (Linnaeus, 1758)	-	x	-
Gyraulus crista (Linnaeus, 1758)	x	xxx	-
Segmentina nitida (O.F. Müller, 1774)	xx	xx	1
Acroloxus lacustris (Linnaeus, 1758)	1	x	-
Sphaerium corneum (Linnaeus, 1758)	x	xx	2
Pisidium sp.	-	1	-
land species			
Oxyloma cf. *elegans* (Risso, 1826)	-	x	-
Carychium minimum O.F. Müller, 1774	-	x	-
Limacidae (small)	-	1	1
Cepaea nemoralis (Linnaeus, 1758)	-	1	1
non-molluscs (freshwater)			
Cladocera (ephippium)	-	x	xx
Ostracoda (double valved)	xx	xx	x
Vermes (egg-cocoon)	x	xx	-
Hirunidea (egg-cocoon)	1	-	1
Insecta (fragment)	xx	xx	x
tubes (covered with sand)	-	x	1
Copepoda: *Diaptomus* sp. (egg sac)	-	-	x
Lophopus cristallinus (Pallas, 1768) (statoblast)	-	-	x

Table 5. Mollusc species present in peat in elongated depressions in the Older Dunes in the surroundings of the study area in the Van Limburg Stirumvalley (within a radius of *c.* 2 km).
x = some, xx = dozens, xxx = hundreds

of *Carex* sp., *Eleocharis palustris, Hydrocotyle vulgaris, Schoenoplectus lacustris, Mentha* sp., *Juncus* sp., *Potamogeton* sp., many *Chara, Salix* sp., and wood of *Alnus* were found. The seeds were ^{14}C dated to between 175 - 40 cal BC (UtC-15080).

At a higher point (1.97 m + NAP) in the peat layer of P1, an increase in pollen of *Betula, Quercus, Alnus* and *Salix*, and slightly more *Corylus*, *Fagus, Fraxinus, Sambucus* were found. Pieces of alder (*Alnus*) wood were found in the layer between 1.92–1.96 m + NAP. Cyperaceae, Poaceae and especially *Dryopteris* type are common. At the top of the peat layer (2.15 m + NAP), there is a decrease in concentration of *Betula, Quercus,* and *Salix,* a very strong increase in *Fagus*, and occasionally in *Carpinus*. *Hippophae* and *Juniperus* have disappeared. In the local vegetation, a high proportion of *Nymphaea alba* and *Sparganium erectum* was found. At the top of the sandy peat layer (2.16-2.17 m + NAP) many seeds originate of *Schoenoplectus lacustris,* alongside some *Carex* and *Eleocharis palustris*. From the sediment directly above this layer (2.17-2.18 m + NAP), remains of *Schoenoplectus lacustris* and *Chara* were identified. Of these, ^{14}C dating ranges between 772 - 887 cal AD (UtC-15081).

The (lower) peat layer in the four sections along the west side of the Van Limburg Stirumcanal originated from depressions in the Older Dunes surface. This layer is situated higher up in section P2 and developed there as a soil. The level is around 3.14 m + NAP and correlates well with the Older Dunes palaeosoil analysed in the current paper. Unfortunately, no shell analysis has been carried out in these

sections. However, the soil recovered in the sections (3.12–3.15 m + NAP) contains many *Cenococcum* and egg cocoons of earthworms, just like the Older Dunes soil in the valley. The pollen spectrum at the altitude of about 3.14 m + NAP indicates a mixed forest, both on wet and dry soil, including the shade tolerant *Fagus* (Van Smeerdijk, 2007). It is likely that the results from the sections mentioned originate from the same period as the deposits examined in the current research from the adjacent VLS. They can be dated to the same era, with an end date at ca. 1100 AD.

	Section Pw 120 m s.e.	**section P1 120 m e.**	**excavated 0,5 - 1 km s.w.**	**some corings**
trees and scrubs				
Quercus sp.	1	-	-	x
Betula sp.	x	-	-	xx
Alnus glutinosa (L.) Gaertn.	x	x	1 cone	x
Populus sp.	-	-	-	1
Salix sp.	x	x	-	x
Cenococcum geophyllum Fries, 1829	-	-	1	x
humic - wet soil				
Rubus fruticosus L. *s.l.*	-	-	-	x
Ranunculus cf *repens* L.	-	-	-	x
Urtica dioica L.	-	-	-	x
Moehringia trinervis (L.) Clairv.	-	-	-	2
Potentilla erecta (L.) Raeusch. - type	-	-	-	x
Mentha aquatica L./*M. arvensis* L.	-	x	-	x
Hydrocotyle vulgaris L.	-	x	-	-
Ajuga reptans L.	-	-	-	1
Viola sp.	-	-	-	1
Lychnis flos-cuculi (L.) Greuter & Burdet	-	-	-	1
Juncus sp.	-	x	-	x
Juncus articulatus L.	-	-	-	x
marsh and along banks				
Calliergon cf *giganteum* (Schimp.) Kindb.	-	-	-	x
Eleocharis palustris (L.) Roem. & Schult.	xx	x	x	xx
Apiaceae	-	-	x	x
Oenanthe aquatica (L.) Poir.	-	-	x	x
Carex pseudocyperus L.	-	-	x	x
Carex sp. dif.	x	x	x	x
Lythrum salicaria L.	-	-	-	2
Lycopus europaeus L.	-	-	-	1
Galium palustre L.	-	-	1	-
Rumex hydrolapathum Huds.	-	-	x	x
Menyanthes trifoliata L.	-	-	-	xx
Solanum dulcamara L.	-	-	-	1
Schoenoplectus tabernaemontani (C.C.Gmel.) Palla	xx	-	xxx	xx
Schoenoplectus lacustris (L.) Palla	-	xx	-	-
Cladium mariscus (L.) Pohl	-	-	x	-
Sparganium emersum Rehmann/*S. natans* L.	-	-	-	x
Typha sp.	1	-	-	-
water				
Chara sp. dif.	xxxx	xx	xxxx	xxx
Ranunculus circinatus Sibth. - type	-	-	-	x
Potamogeton sp.	-	x	-	2
Nymphaea alba L.	x	-	x	2

Table 6. Plant species (seeds, wood, etc.) present in peat in elongated depressions in the surroundings of the study area in the Van Limburg Stirumvalley (within a radius of *c*. 2 km).
x = some, xx = dozens, xxx = hundreds, xxxx = thousands

In addition to the soil sections, information is available from corings in the AWD. A study of the macro remains of several dozen small peat samples from these corings gives a better picture of the aquatic environment, the water margins and the marsh vegetation (Kuijper, 1993). Another relevant study concerns large pieces of peat along the western side of the former Van Limburg Stirumcanal about 0.5 km southwest of the VLS outcrop. The peat was deposited there during the construction of the canal; its exact origin is unknown. In the subsoil, however, there is one peat layer that originated from the westernmost beach plain in the Older Dunes. This peat layer of some dm thick is situated between 1.40 and 2.10 m + NAP. In Table 5 and 6, the molluscs and seeds found therein are listed.

Discussion and conclusion

Landscape

The sediments analysed from the VLS, together with the information from sections in the immediate vicinity, give an impression of the natural environment at the end of the formation period of the Older Dunes. This interval coincides with the Early Middle Ages (ca 450 – 1050 AD). It was a dune landscape with elevation differences of some metres. The site was located on a northeast–southwest orientated dune ridge, with kilometres long marshlands running parallel west and east of it in the beach plains. This situation lasted from Roman times to about the year 1100. It was a period during which there was little displacement of sand by the wind at this location. This allowed marshes and pools, up to about 1 metre deep, to develop in the low parts. In the higher areas, undisturbed forest developed, with marshy conditions. The resulting substrate was peat, with forest soils on the higher parts. The groundwater level was high, the water and soil were rich in calciumcarbonate. Remarkable at VLS is the richness in calcareous material at various locations. This is probably caused by calciumcarbonate-rich seepage. In general, over centuries, the top of the Older Dunes decalcified.

After this period, the Older Dunes landscape was covered over by sand, brought in by the wind, thus forming the Younger Dunes. The result was a completely different environmental context. The landscape was transformed into one of low vegetated dunes with moving sand. In low-lying areas, calciumcarbonate-rich shallow pools developed for short periods of time, only to be covered again by the moving sand.

Plant world

In the Roman period and the beginning of the early Middle Ages, the light-demanding sea buckthorn and juniper grew in the higher, relatively dry spots, alongside other species. At the end of that time they disappeared and the landscape became forested, especially the highest parts of the Older Dunes. It was a deciduous forest on damp soil with oak, birch, ash, poplar, and over the centuries an increasing proportion of beech (Fig. 6). Particularly in the highest areas, oaks and beeches could grow to quite

Figure 6. Image of an environment closely resembling what the study area would have looked like: forest in a humid situation with beech and oak during the end phase of the Older Dunes (Denmark, Moesgard).

Figure 7. Image of an environment closely resembling what the study area would have looked like: forest in wet places with birch, alder and oak during the end phase of the Older Dunes. (Photo Wil Heemskerk, Amsterdamse Waterleidingduinen - Eiland van Rolvers).

large trees. The chalk-rich soils made the organic debris decay well. There was a rich undergrowth, with decomposing herbaceous plants and wood. The type of forest was an oak–beech forest. The shrubs included elder, hazel, blackberry, and blackthorn. In the lower areas, *i.e.* the more moist and wet locations, mainly birch, black alder, and willow grew (Fig. 7).

The herbaceous vegetation in the higher areas, partially under the trees, is difficult to reconstruct. In the humid and wet areas, lots of *Eupatorium cannabinum, Mentha aquatica, Hydrocotyle vulgaris,* and *Juncus* species occur. In addition, there were *Viola* sp., *Moehringia trinervia, Ajuga reptans, Ranunculus repens* type, *Urtica dioica, Solanum dulcamara, Potentilla erecta* type, and several moss species. In the marshy locations and along pools there were Poaceae, *Eleocharis palustris*, Apiaceae, *Oenanthe aquatica, Carex pseudocyperus,* various other *Carex* species, *Ranunculus flammula, Lythrum salicaria, Rumex hydrolapathum, Sparganium erectum, Sparganium emersum/S. minimum, Schoenoplectus tabernaemontani, Schoenoplectus lacustris,* and *Typha* sp. In shallow water different *Chara* species, *Ranunculus circinatus* type, and various species of *Potamogeton* occurred. The plant species identified in the larger marshes of the beach plains near the VLS correspond to those in the marshy low parts of the higher dunes. In the water, a lot of *Chara* species was present, with *Nymphaea alba* growing in the deeper parts. To a large extent, *Schoenoplectus*, *Eleocharis,* and *Carex* species determined the overall appearance of the vegetation.

Animal world

The rich fauna in the dunes, with 36 species of terrestrial snails, including some rare and even currently extinct species in the dunes, is remarkable. The characteristic species of the Older Dunes are *Spermodea lamellata, Acanthinula aculeata, Vertigo pusilla, Vertigo substriata, Clausilia bidentata, Cochlodina laminata, Merdigera obscura,* and *Alinda biplicata.* These species also occur as part of a forest fauna. The plaited snail (*Spermodea lamellata*) in particular, a species nowadays extinct in the Netherlands, is a species indicative of old, undisturbed deciduous woods. The soil was damp or marshy, covered with a layer of litter and dead wood. Several land snail species lived exclusively in very wet places (swamp), and at the margins of pools. These shallow pools and swampy areas showed a fluctuating water level with banks that periodically fell dry; the water snails *Galba truncatula, Aplexa hypnorum,* and *Anisus leucostoma* lived there. The total aquatic fauna consisted of 15 species, all living in densely vegetated shallow water.

Earthworms lived in the soil, above groundwater level. Large numbers of calcite granules and egg cocoons, most likely belonging to *Lumbricus terrestris*, indicate that the soil of the Older Dunes was a good habitat for this species. Only sporadic remains of insects were found. Carabid beetles predated landsnails. Several birds were found, including the eagle owl. This biggest European owl indicates that the area had a good food supply and a rich avian fauna. The various finds of small and large mammals show that the Older Dunes provided a suitable

habitat for many species. Brown bear, wild boar, red deer, roe deer, mole, and wood mouse were present. From excavations in other areas we know that fox and elk also inhabited the Older Dunes. The area was varied and large enough to serve as a territory for bears. Frogs lived in the area. The slow worm and lizard were unexpected finds, both represent the first Holocene finds in the Netherlands.

From the 11th century AD onwards, the Dutch dunes changed mainly by overblowing with layers of sand and human intervention (chopping wood, creation of fields for farming, hunting, introducing species), and plaited snail, slow worm, eagle owl, brown bear, wild boar, and red deer no longer inhabit the area. In summary, the current study combined with previous datasets provides a glimpse into the natural environment of the last century of the Older Dunes, showing a varied landscape with a high biodiversity. The species found should be considered in dune rewilding and restoration programs (Bakker, 2018). The integrated palaeoecological documentation of key preservation sites is essential to understand natural baseline conditions.

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Plate 1

1. Overview (viewing north) of the Van Limburg Stirumvalley outcrop in the Amsterdamse Waterleidingduinen, surrounded by the Younger Dunes. The dark bands are the edges of palaeosoils and peat layers, 27-10-2019.
2. Surface of the palaeosoil in the top of the Older Dunes in the Van Limburg Stirumvalley outcrop. The 4 black spots are the remains of tree stumps. 19-2-2016.
3. Edge of a peat layer, about 1 dm thick. 10-1-2020.
4. Ribs of red deer (*Cervus elaphus* Linnaeus, 1758) *in situ*, they became visible on the surface after a few cm of the upper part of the soil horizon was blown away by the wind and partly covered again by fresh drift sand. 13-5-2016.
5. Older Dunes palaeosoil of about 5 cm humic sand in the southern part of the valley.
6. Example of a residue (nr. 31) from a soil sample from the top of the Older Dunes. Scale bar 1 cm.

Plate 2

1. *Cochlodina laminata* (Jeffreys, 1830) from the soil in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop. Scale bar 1 mm.
2. *Cochlodina laminata* (Jeffreys, 1830), clausilium, from the soil in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop. Scale bar 1 mm.
3. *Alinda biplicata* (Montagu, 1803) from the soil in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop. Scale bar 5 mm. (Photo Petra Sonius, Naturalis).
4. *Aplexa hypnorum* (Linnaeus, 1758) from the soil in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop. Scale bar 1 mm.
5. Shells (internal plates) of slugs. A large shell, a small shell and (on top) an unknown type in a sample (nr. 43). Scale bar 1 mm.
6. *Acanthinula aculeata* (O.F. Müller, 1774) from the soil in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop. Scale bar 2 mm. (Photo Petra Sonius, Naturalis).
7. *Spermodea lamellata* (Jeffreys, 1830) from the soil in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop. Scale bar 1 mm.
8. Slow worm (*Anguis fragilis* Linnaeus, 1758) osteoderms, from the soil in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop. Scale bar 1 mm.
9. Slow worm (*Anguis fragilis*, Linnaeus, 1758) osteoderm, from the soil in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop. Lateral view of the (broken) largest specimen. Scale bar 1 mm.
10. Lizard (*Lacerta* sp.) from the soil in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop. Two maxillae in medial view and a premaxilla (right below) in internal view. Scale bar 1 mm.
11. Earthworms (Lumbricidae), granules, from the soil in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop. Scale bar 1 cm.

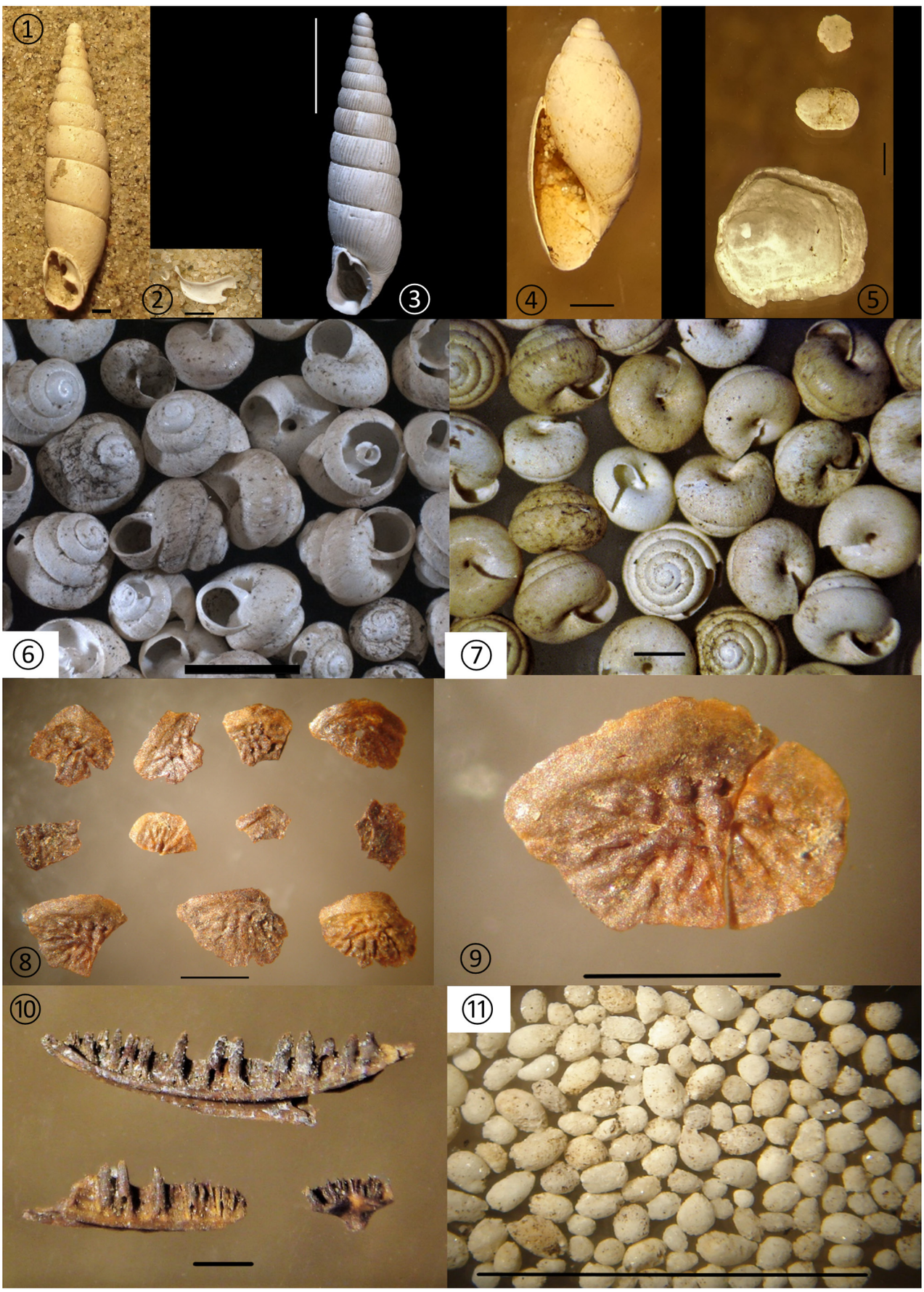

Plate 2

Plate 3

1-2. Roe deer (*Capreolus capreolus* (Linnaeus, 1758)) from the soil in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop; 1. antler, partly visible on the surface after a few cm of the upper part of the soilhorizon was blown away; 2. the complete antler. (Photo Hans Vader).

3. Brown bear (*Ursus arctos* Linnaeus, 1758), a phalanx III from the soil in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop. Scale bar 1 cm.
4. Brown bear (*Ursus arctos* Linnaeus, 1758), bones from the left front leg reconstructed in anatomical context, from the soil in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop. (Photo Ivo Verheijen, Fac. Archaeology-Leiden University). Scale bar 10 cm.
5. Wild boar (*Sus scrofa* Linnaeus, 1758), lower jaw, length 24 cm, from the soil in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop.
6. Red deer (*Cervus elaphus* Linnaeus, 1758), molar (M2) from upper right jaw from the soil in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop. Scale bar 1 cm.
7. Mole (*Talpa europaea* Linnaeus, 1758). Remains in one sample from the soil in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop. Scale bar 1 cm.
8. Eurasian eagle owl (*Bubo bubo* (Linnaeus, 1758)), two coracoids from the soil in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop, with a reference specimen of a modern individual from the collection of the Groningen Institute of Archaeology. Scale bar 1 cm.
9. Eurasian eagle owl (*Bubo bubo* (Linnaeus, 1758)), pelvic bone and femur from the soil in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop. Scale bar 1 cm.

Plate 3

Plate 4

1. Stump of an alder (*Alnus* sp.) in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop. 25-11-2016.
2. Stump of a birch (*Betula* sp.) in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop. Partly covered with fresh drift sand. 25-10-2015.
3. Remains of a root system in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop. 29-4-2017.
4. Yellow iris (*Iris pseudacorus* L.) seed from the peat layer in the middle of the Van Limburg Stirumvalley outcrop. Scale bar 1 mm.
5. Soil fungus (*Cenococcum geophilum* Fries, 1829) sclerotia from the soil in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop. Scale bar 1 cm.
6. Hemp agrimony (*Eupatorium cannabinum* L.) seeds from the soil in the top of the Older Dunes from the Van Limburg Stirumvalley outcrop. Scale bar 1 mm.