Predictive Modelling of Younger Dryas Archaeological Remains in Southern Flevoland (Central Netherlands)

D.F.A.M. van den Biggelaar [corresponding author]
Vrije Universiteit Amsterdam, Institute for Geo- and Bioarchaeology, Faculty of Earth and Life Sciences, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands.
e-mail: don.vanden.biggelaar@vu.nl

S.J. Kluiving
Vrije Universiteit Amsterdam, Institute for Geo- and Bioarchaeology, Faculty of Earth and Life Sciences; Department of Archaeology, Ancient History of Mediterranean Studies and Near Eastern Studies, Faculty of Arts; Research Institute for the heritage and history of the Cultural Landscape and Urban; Environment (CLUE), Faculty of Arts, De Boelelaan 1105, 1081 HV Amsterdam, The Netherlands.
e-mail: s.j.kluiving@vu.nl

J. Kolen
Universiteit Leiden, Faculty of Archaeology; Centre for Global Heritage and Development, Einsteinweg 2, 2333 CC Leiden, The Netherlands.
e-mail: j.c.a.kolen@arch.leidenuniv.nl

C. Kasse
Vrije Universiteit Amsterdam, Cluster Earth and Climate, Faculty of Earth and Life Sciences, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands.
e-mail: c.kasse@vu.nl

Abstract
In this research locations are selected in Southern Flevoland (Central Netherlands) which are most likely to contain archaeological remains dating to the Younger Dryas (YD) [12,900-11,700 cal BP]. To map and determine these locations two steps are performed:

1) The Pleistocene surface of Southern Flevoland is classified into landforms using a GIS application based on Topographic Position Index.
2) Data on the geomorphological setting and the distance to the nearest freshwater source of well-dated YD archaeological sites in the Northwest European Plain are extrapolated to the study area.

The inductive predictive model indicates that elevated areas in close proximity to a freshwater source have the highest probability to contain YD archaeological remains. For potential Federmesser remains a maximum distance of 1500 m from the Eem fluvial system is estimated and for potential Ahrensburgian remains a maximum distance of 2500 metres. The areas with potential YD archaeological remains constitute less than 10% of the total study area. The detailed and well-preserved Pleistocene surface in the study area, combined with potentially well-preserved YD remains due to the Holocene sediment cover, is of major importance for future studies on landscape exploitation by prehistoric hunter – fisher – gatherers. Reconstructing landscape exploitation opens up new avenues to study subsistence economy, settlement patterns and spatial organisation of past societies.

Keywords: Hunter – Fisher – Gatherer Landscape Exploitation, Pleistocene Surface Mapping, Predictive Modelling, Southern Flevoland, Younger Dryas
Introduction

Northwest European archaeological remains dating to the Younger Dryas (YD) (12,900–11,700 cal BP) have been studied intensively (fig. 1, see figure caption for references) (YD age cf. Steffensen et al, 2008). Despite the large number of YD archaeological remains in North-Western Europe, little is known about YD landscape exploitation by Final Palaeolithic groups, who produced the so-called “Federmesser” and “Ahrensburg” lithic industries. The limited knowledge of landscape exploitation during this period is the result of a scarcity of faunal remains and limited data...
Fig. 2. The Netherlands [A] and Southern Flevoland [B – D]. A: Thickness of Holocene deposits (www.dinoloket.nl) and well-dated Younger Dryas archaeological sites in the Netherlands. Location of the sites is compiled from the Radiocarbon Palaeolithic Europe Database v17 (Vermeersch, 2014). Location of Southern Flevoland within the Netherlands is shown (black polygon). B: Pleistocene surface elevations, the Eem fluvial system (after Peeters, 2007),
on archaeological material associated with the subsistence economy [e.g. lithic artefacts with use-wear]. The limited data on such archaeological remains is most likely the result of taphonomic processes [i.e. erosion of and sedimentation on the YD surface].

In the Netherlands, in situ YD archaeological remains have predominantly been found in areas where there are no Holocene deposits (fig. 2A). However, faunal remains and artefacts associated with the subsistence economy are very scarce in those areas, confining research on landscape exploitation. It is most likely that the Western Netherlands also contain in situ YD remains but they have, so far, not been found due to the thick Holocene sediment cover. Due to this Holocene cover, YD archaeological remains are likely to be well-preserved, indicating the potential of this area to study YD landscape exploitation. Also, the Pleistocene surface in the North Sea area has a high potential for future studies on landscape exploitation (see Peeters & Momber, 2014).

One of the “high potential” areas in the Western Netherlands where well-dated YD archaeological remains have not yet been found is Southern Flevoland (Central Netherlands). Previous research indicated the presence of Late Glacial (~14.7-11.7 ka cal BP) deposits in the area [e.g. De Moor, Maurer & Devriendt 2013; De Moor et al, 2013; Makaske et al, 2002; Van Smeerdijk, 2002], indicating the potential for preserved YD archaeological remains. This potential is highest in the vicinity of the Eem fluvial system (fig. 2B) because multiple authors have indicated that YD habitation was generally located near a freshwater source [e.g. Bokelmann, 1991; Crombé et al, 2014; Deeben et al, 2006; Vermeersch, 2008]. In addition, YD hunter – fisher – gatherers selectively used the higher elevated parts of the landscape [e.g. Crombé et al, 2014; Deeben, 1988; Deeben et al, 2006] indicating that a detailed Pleistocene surface geomorphology is of paramount importance to determine areas with high probability of YD archaeological remains.

The aim of this research is to use an objective methodology to determine locations in Southern Flevoland with the highest probability of YD archaeological remains. The scarcity of YD finds due to the Holocene cover urges us to detect key areas to study YD landscape exploitation in order to facilitate the next step in unravelling the cultural history of this specific region. For this research Southern Flevoland is selected because the area 1) contains a freshwater source (fig. 2B), 2) has a relatively high-resolution Pleistocene surface elevation map (this study, fig. 2C, D) and 3) is well-preserved underneath Holocene sediments of up to 8 m thickness (see Van den Biggelaar et al, 2015 for the good preservation of the Pleistocene surface in the vicinity of the Eem fluvial system).
To attain the aim of this research we used a GIS application for landform classification of the Pleistocene surface of Southern Flevoland based on the Topographic Position Index (see Weiss, 2001) and applied an inductive predictive modelling approach (cf. Kamermans & Wansleeben, 1999). In such an approach, data of known archaeological sites (e.g. geomorphological setting) is extrapolated to areas where archaeological remains have not yet been found (e.g. Warren, 1990). For this research the geomorphological setting and distance to a freshwater source of well-dated YD archaeological sites from the Northwest European Plain are used to determine areas that have the highest probability of containing YD archaeological remains within Southern Flevoland.

Geological and Cultural Setting

Climate amelioration and permafrost degradation since the start of the Late Glacial coincided with the return of hunter – fisher – gatherer groups to the Northwest European Plain (e.g. Grimm & Weber, 2008; Terberger, Barton & Street, 2009). After the cool and arid climatic conditions at the end of the Late Pleniglacial, climatic circumstances improved at the onset of the relatively warm Bølling-Allerød interstadial (~14.7-12.9 ka cal BP). The Allerød period was especially characterised by landscape stability and soil development (e.g. Hoek, 1997; Walker et al, 1994). During the Allerød, the Northwest European Plain was inhabited by Federmesser hunter – fisher – gatherer. The widespread Federmesser sites have been found on dunes in close proximity to a freshwater source (e.g. lakes, fens and river terraces) (e.g. Arts, 1988; Crombé et al, 2013; Crombé et al, 2011; Deeben, 1988). Very little is known about Federmesser landscape exploitation except that during the Allerød they exploited mammals and fish (e.g. Lauwerier & Deeben, 2011). As argued by Baales (2004), they had a high residential mobility (cf. Binford, 1980) procuring lithic material and subsistence resources within a large area (e.g. ~20,000 km² for the Eiffel region).

Federmesser groups inhabited the Northwest European Plain up to the early part of the cool and arid Younger Dryas (see Deeben et al, 2006) coinciding with the Ahrensburgian hunter – fisher – gatherers. The less expansive Ahrensburgian sites are frequently located along ridges, terrace edges and dunes in close proximity to freshwater sources (e.g. Crombé et al, 2014; Deeben, 1988; Taute, 1968; Vermeersch, 2008). Seasonal movement of the Ahrensburg hunters – fisher – gatherers appears to be related to the movement of reindeer (Baales, 1996; 1999). Based on the faunal remains of reindeer from YD sites, Baales (1996; 1999) argued that the Ahrensburger people lived in the Northwest European Plain during autumn and winter, while during spring and summer the uplands were inhabited (e.g. Eifel and Ardennes, located around Luxembourg) (fig. 1). Intercept strategy is an important hunting technique for hunting reindeer (cf. Burch, 1972). Elevated areas with higher visibility have a higher potential for reindeer hunting than the lower parts (Binford, 1980). Freshwater plays a key role in the functioning of terrestrial ecosystems. This functioning determines the well-being of hominins, which in turn provide them with the capacity to develop and to deal with change (see Rockström et al, 2014). Therefore, areas in close proximity to a freshwater source have a higher habitation potential than areas more distant. Furthermore, the presence of a freshwater source provides possibilities for fishing. Evidence for fishing in the Northwest European Plain dates back to ~19 ka cal BP (Gramsch et al, 2013).

In Southern Flevoland the Pleistocene surface consists of Late Weichselian aeolian deposits (e.g. Menke, Van de Laar & Lenselink, 1998; Spek, Bisdom & Van Smeerdijk, 1997). These deposits were formed regionally during the cool and arid conditions of the Late Pleniglacial (29-14.7 ka cal BP) and more locally during the Late Glacial (14.7-11.7 ka cal BP) (Kasse, 2002). Some erosion of these deposits occurred by the Eem fluvial system, which was present in the study area during the Late Glacial (Menke, Van de Laar & Lenselink, 1998).
### Youger Dryas archaeological sites Northwest European Plain

<table>
<thead>
<tr>
<th>Site No. (see Fig. 1)</th>
<th>Archaeological site/country (1)</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Archaeological unit (2)</th>
<th>Geo- morphological setting (3)</th>
<th>Distance to freshwater in meters (4)</th>
<th>Labora- tory no. (5)</th>
<th>Dated material (6)</th>
<th>14C Age (BP) (7)</th>
<th>Cal BP (2 sigma)</th>
<th>Remarks</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Netherlands</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Duurswoude I (Oud Leger)</td>
<td>6.24</td>
<td>53.06</td>
<td>Feder-messer</td>
<td>Elevated area</td>
<td>?</td>
<td>?</td>
<td>GrN-4871</td>
<td>11150 ± 190</td>
<td>13360-12700</td>
<td>Distance to freshwater unknown</td>
<td>Bohmers &amp; Hout- sma, 1961 [1-3], Lanting &amp; Van der Plicht 1995/1996 (5-7)</td>
</tr>
<tr>
<td>2</td>
<td>Wierden-Enterse Akkers HS</td>
<td>6.57</td>
<td>52.30</td>
<td>Feder-messer</td>
<td>Cover sand ridge</td>
<td>~100</td>
<td>?</td>
<td>GrA-23973</td>
<td>10720 ± 60</td>
<td>12740-12570</td>
<td></td>
<td>Deeben et al., 2006 [1-3, 5-7], Deeben et al., 2006; Van Beek, 2009 (4)</td>
</tr>
<tr>
<td>2</td>
<td>Wierden-Enterse Akkers HS</td>
<td>6.57</td>
<td>52.30</td>
<td>Feder-messer</td>
<td>Cover sand ridge</td>
<td>~100</td>
<td>?</td>
<td>GrA-24847</td>
<td>10690 ± 50</td>
<td>12720-12560</td>
<td></td>
<td>Deeben et al., 2006 [1-3, 5-7], Deeben et al., 2006; Van Beek, 2009 (4)</td>
</tr>
<tr>
<td>2</td>
<td>Wierden-Enterse Akkers HS</td>
<td>6.57</td>
<td>52.30</td>
<td>Feder-messer</td>
<td>Cover sand ridge</td>
<td>~100</td>
<td>?</td>
<td>GrA-24580</td>
<td>10610 ± 60</td>
<td>12710-12510</td>
<td>12500-12420</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Doetinchem-Dichteren 8</td>
<td>6.28</td>
<td>51.95</td>
<td>Feder-messer</td>
<td>Aeolian ridge</td>
<td>&lt; 1500</td>
<td>?</td>
<td>GrA-13388</td>
<td>10930 ± 50</td>
<td>12940-12700</td>
<td></td>
<td>Niekus et al., 1998 [1-3], Cohen et al., 2012 [4], Aerts-Bijma et al., 1999 [5, 7], Johansen et al., 2000 (6)</td>
</tr>
<tr>
<td>3</td>
<td>Doetinchem-Dichteren 8</td>
<td>6.28</td>
<td>51.95</td>
<td>Feder-messer</td>
<td>Aeolian ridge</td>
<td>&lt; 1500</td>
<td>?</td>
<td>GrA-13387</td>
<td>10880 ± 50</td>
<td>12840-12690</td>
<td></td>
<td>Niekus et al., 1998 [1-3], Cohen et al., 2012 [4], Aerts-Bijma et al., 1999 [5, 7], Johansen et al., 2000 (6)</td>
</tr>
<tr>
<td>3</td>
<td>Doetinchem-Dichteren 8</td>
<td>6.28</td>
<td>51.95</td>
<td>Feder-messer</td>
<td>Aeolian ridge</td>
<td>&lt; 1500</td>
<td>?</td>
<td>GrA-13686</td>
<td>10870 ± 50</td>
<td>12830-12680</td>
<td></td>
<td>Niekus et al., 1998 [1-3], Cohen et al., 2012 [4], Aerts-Bijma et al., 1999 [5, 7], Johansen et al., 2000 (6)</td>
</tr>
<tr>
<td>5</td>
<td>Geldrop, Mie Peels</td>
<td>5.53</td>
<td>51.37</td>
<td>Ahrens- burgian</td>
<td>Cover sand ridge</td>
<td>~2500</td>
<td>OxA-2563</td>
<td>Charcoal</td>
<td>10610 ± 100</td>
<td>12730-12370</td>
<td>12350-12230</td>
<td>12210-12170</td>
</tr>
</tbody>
</table>
Youger Dryas archaeological sites Northwest European Plain

<table>
<thead>
<tr>
<th>Site No. (see Fig. 1)</th>
<th>Archaeological site/country (1)</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Archaeological unit (2)</th>
<th>Geomorphological setting (3)</th>
<th>Distance to freshwater in meters (4)</th>
<th>Laboratory no. (5)</th>
<th>Dated material (6)</th>
<th>(^{14} \text{C} ) Age (BP) (7)</th>
<th>Cal BP (2 sigmas) (7)</th>
<th>Remarks</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Ruien</td>
<td>3,48</td>
<td>50,77</td>
<td>Ahrensburgian Ridge</td>
<td>Ash layer</td>
<td>1000</td>
<td>RICH-20142</td>
<td>Ash layer</td>
<td>10843 ± 50 BP</td>
<td>12810-12680</td>
<td></td>
<td>Crombé et al., 2014 [1-7]</td>
</tr>
<tr>
<td>8</td>
<td>Ruien</td>
<td>3,48</td>
<td>50,77</td>
<td>Ahrensburgian Ridge</td>
<td>Ash layer</td>
<td>1000</td>
<td>RICH-20143</td>
<td>Ash layer</td>
<td>10962 ± 48 BP</td>
<td>12980-12710</td>
<td></td>
<td>Crombé et al., 2014 [1-7]</td>
</tr>
<tr>
<td>9</td>
<td>Zonhoven Molenhheide</td>
<td>5,42</td>
<td>51,00</td>
<td>Ahrensburgian</td>
<td>At the edge of a terrace</td>
<td>1000</td>
<td>UIC-3720</td>
<td>Dispersed charcoal fragment</td>
<td>10760 ± 70</td>
<td>12760-12560</td>
<td></td>
<td>Peleman et al., 1994; Vermeersch &amp; Creemers, 1994; Vermeers, 2008 [1-3], Vermeersch, 2008 [4-7]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Bedburg-Königshoven</td>
<td>6,51</td>
<td>51,03</td>
<td>Ahrensburgian Foot of a hill adjacent to a Late Glacial lake</td>
<td>KN-4138 Bone Bos primigenius</td>
<td>100</td>
<td>KN-4137</td>
<td>Bone Bos primigenius</td>
<td>10290 ± 100</td>
<td>12530-12470 12430-11700 11670-11640</td>
<td>Street, 1991 [1-4], Street, 1993 [5-7]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Bedburg-Königshoven</td>
<td>6,51</td>
<td>51,03</td>
<td>Ahrensburgian Foot of a hill adjacent to a Late Glacial lake</td>
<td>KN-4137</td>
<td>100</td>
<td>KN-3195</td>
<td>wood</td>
<td>10270 ± 90</td>
<td>12420-11790 11670-11640</td>
<td>Street, 1991 [1-7]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Bedburg-Königshoven</td>
<td>6,51</td>
<td>51,03</td>
<td>Ahrensburgian Foot of a hill adjacent to a Late Glacial lake</td>
<td>KN-4139</td>
<td>100</td>
<td>KN-4139</td>
<td>Bone Bos primigenius</td>
<td>10140 ± 100</td>
<td>12130-11310</td>
<td>Street, 1991 [1-4], Street, 1993 [5-7]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Lemförde am Dümmer</td>
<td>8,38</td>
<td>52,47</td>
<td>Final Palaeolithic</td>
<td>?</td>
<td>100</td>
<td>Hv-14972</td>
<td>antler, point</td>
<td>10955 ± 315</td>
<td>13480-12060</td>
<td>Veil et al., 1991 [1-7]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Alt Duvenstedt LA 121</td>
<td>9,59</td>
<td>54,35</td>
<td>Ahrensburgian Trasition between elevated area and a plain</td>
<td>AAR-2245 Charcoal</td>
<td>100</td>
<td>AAR-2245.2</td>
<td>Charcoal</td>
<td>10770 ± 60</td>
<td>12760-12590</td>
<td>Clausen, 1995 [1-2], Kaiser &amp; Clausen, 2005 [3-7]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Alt Duvenstedt LA 121</td>
<td>9,59</td>
<td>54,35</td>
<td>Ahrensburgian Trasition between elevated area and a plain</td>
<td>AAR-2245 Charcoal</td>
<td>100</td>
<td>AAR-2245.2</td>
<td>Charcoal</td>
<td>10770 ± 60</td>
<td>12760-12590</td>
<td>Clausen, 1995 [1-2], Kaiser &amp; Clausen, 2005 [3-7]</td>
<td></td>
</tr>
</tbody>
</table>
### Youger Dryas archaeological sites Northwest European Plain

<table>
<thead>
<tr>
<th>Site No. (see Fig. 1)</th>
<th>Archaeological site/country (1)</th>
<th>Longi- tude</th>
<th>Lat- itude</th>
<th>Archaeo- logical unit (2)</th>
<th>Geo- morpho- logical setting (3)</th>
<th>Dis- tance to fresh- water in meters (4)</th>
<th>Laboratory no. (5)</th>
<th>Dated material (6)</th>
<th>14C Age (BP) (7)</th>
<th>Cal BP (2 sig- ma)</th>
<th>Remarks</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>Nahe LA 11</td>
<td>10,14</td>
<td>53,77</td>
<td>Ahrens- burgian</td>
<td>Foot of a hill adjacent to a Late Glacial lake</td>
<td>?</td>
<td>KIA- 23370</td>
<td>Antler/ bone</td>
<td>10172 ± 45</td>
<td>12600- 11670 11680- 11630</td>
<td>Distance to freshwater unknown</td>
<td>Weber et al., 2011 (1-3, 5-7)</td>
</tr>
<tr>
<td>16</td>
<td>Stellmoor</td>
<td>9,37</td>
<td>53,15</td>
<td>Ahrens- burgian</td>
<td>Foot of a hill adjacent to a Late Glacial lake</td>
<td>~100</td>
<td>KN- 2222 Bulk bone sample</td>
<td>10160 ± 90</td>
<td>12150- 11330 11380- 11350</td>
<td></td>
<td>Rust, 1943; Taute, 1968 (1-3), Tromnau, 1975, Bokelmann, 1991 (4), Weber et al., 2011 (5-7)</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Stellmoor</td>
<td>9,37</td>
<td>53,15</td>
<td>Ahrens- burgian</td>
<td>Foot of a hill adjacent to a Late Glacial lake</td>
<td>~100</td>
<td>K- 4326 Bone collagen Rangifer tarsanus</td>
<td>10140 ± 105</td>
<td>12150- 11290</td>
<td></td>
<td>Rust, 1943; Taute, 1968 (1-3), Tromnau, 1975, Bokelmann, 1991 (4), Fischer &amp; Tauber, 1986 (5-7)</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Stellmoor</td>
<td>9,37</td>
<td>53,15</td>
<td>Ahrens- burgian</td>
<td>Foot of a hill adjacent to a Late Glacial lake</td>
<td>~100</td>
<td>K- 4578 Bone Rangifer tarsanus</td>
<td>10100 ± 100</td>
<td>12070- 11310 11300- 11290</td>
<td></td>
<td>Rust, 1943; Taute, 1968 (1-3), Tromnau, 1975, Bokelmann, 1991 (4), Fischer &amp; Tauber, 1986 (5-7)</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Melbeck-Friedhof 3_3A</td>
<td>10,40</td>
<td>53,18</td>
<td>Ahrens- burgian</td>
<td>Cover- sand dune</td>
<td>~100</td>
<td>Hv- 17306 Char- coal</td>
<td>10515 ± 95</td>
<td>12680- 12110</td>
<td></td>
<td>Richter, 1992 (1-7)</td>
<td></td>
</tr>
</tbody>
</table>
### Youger Dryas archaeological sites Northwest European Plain

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Archaeological site/country (1)</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Archaeological unit (2)</th>
<th>Geo-morphological setting (3)</th>
<th>Distance to freshwater in meters (4)</th>
<th>Laboratory no. (5)</th>
<th>Dated material (6)</th>
<th>14C Age (BP) (7)</th>
<th>Cal BP (2 sig-ma)</th>
<th>Remarks References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Gross Lieskow</td>
<td>14.45</td>
<td>51.78</td>
<td>Federmesser</td>
<td>Aeolian dune</td>
<td>&lt; 1000</td>
<td>LZ-1351</td>
<td>Big pieces of charcoal mixed with sand</td>
<td>10520 ± 100</td>
<td>12690-12110</td>
<td>Bittmann &amp; Pasda, 1999 [1, 3, 5-7], Pasda, 2002 [2], Kühner et al., 1999; Horn et al., 2005 [4]</td>
</tr>
</tbody>
</table>

Tab. 1. Geomorphological setting, distance to a freshwater source and 14C/AMS dates of Younger Dryas archaeological sites from the Northwest European Plain. The coordinates of the well-dated archaeological sites have been obtained from the Radiocarbon Palaeolithic Europe Database v17 (Vermeersch, 2014). The radiocarbon dates have been calibrated with the IntCal13 atmospheric curve (Reimer et al, 2013), using OxCal v4.2.4 (Bronk Ramsey, 2009). The resulting ages are given in cal BP in the 95.4% confidence interval.

In the study area, Allerød soils and peat deposits have rarely been found (e.g. De Moor, Maurer & Devriendt, 2013; De Moor et al., 2013; Van Smeerdijk, 2002). Allerød soils and peat deposits can only be distinguished from soils in the uppermost Pleistocene surface when sedimentation has occurred during the YD. In areas without sedimentation or erosion the Allerød soil was overprinted by Holocene soil formation (Kasse, 1999). In the study area, localised aeolian sedimentation took place during the YD along the banks of the Eem fluvial system where source-bordering aeolian dunes formed (e.g. Menke, Van de Laar & Lenselink, 1998). Another region of YD aeolian deposition is associated with the higher well-drained coversand areas which had formed during the preceding periods (Late Pleniglacial and the early part of the Late Glacial). The increased aridity during the YD stadial caused a decrease in vegetation cover, resulting in aeolian reworking of the higher dry parts of the landscape. Despite local aeolian deposition and changes in morphology during the YD, the Pleistocene surface in the study area can generally be associated with YD hunter – fisher – gatherers. This surface is predominantly well-preserved in the surrounding of the Eem fluvial system (see Van den Biggelaar et al, 2015).

The elevation of the southeast to northwest-sloping Pleistocene surface ranges from -2 m Dutch Ordnance Datum (O.D., ~ mean sea level) in the southeast to -12 m in the northwest (fig. 2B). The undulating topography of this surface is the result of incision by the Eem fluvial system and the formation of aeolian dunes and ridges (Menke, Van de Laar & Lenselink, 1998; Peeters, 2007). The top of these dunes and ridges can be up to 1-2 m above the general Pleistocene surface (Menke, Van de Laar & Lenselink, 1998).

Since the onset of the Holocene (~11.7 ka cal BP), climate amelioration and sea-level rise resulted in the deposition of peat, clay, sand and organic sediments in Southern Flevoland. These Holocene deposits can reach a thickness of up to ~8 m (Menke, Van de Laar & Lenselink, 1998).
Methods

The research is divided into two parts:
1) a literature study to determine the geomorphological setting and the distance to the nearest freshwater source of well-dated YD archaeological remains in the Northwest European Plain and,
2) the mapping of the Pleistocene surface of Southern Flevoland. The study area contains a large freshwater source and has a relatively high coring density to provide for a detailed Pleistocene surface elevation map. The detailed Pleistocene surface elevation map is used to classify landforms.

Geomorphological Setting of Well-Dated YD Archaeological Sites in the Northwest European Plain

Sites that have been \(^{14}\text{C}-\) or AMS-dated to the Younger Dryas (12,900-11,700 cal BP) and are located in the Northwest European Plain have been taken into account (fig. 1; tab. 1), because during the YD the study area was also located in a lowland area. The coordinates of the well-dated archaeological sites have been obtained from the Radiocarbon Palaeolithic Europe Database v17 (Vermeersch, 2014). The radiocarbon dates have been calibrated with the IntCal13 atmospheric curve (Reimer et al, 2013), using OxCal v4.2.4 (Bronk Ramsey, 2009). The resulting ages are given in cal BP in the 95.4% confidence interval. For each of the selected sites the following parameters are taken into account:
1) distance to a freshwater source, and
2) geomorphological setting.

These parameters provide insight in the most preferable location of habitation during the YD in the Northwest European Plain.

Pleistocene Surface Southern Flevoland

To map the YD palaeotopography of Southern Flevoland a 50 m resolution palaeotopographical map was constructed with the use of approximately 26,000 core logs (fig. 2C). These core logs were obtained from the TNO geological survey database (DINO and RIJP-corings; www.dinoloket.nl) and from archaeological survey projects (see caption fig. 2C for references). For details on the distribution, advantages and disadvantages of each core data set, see Van den Biggelaar et al (2015). Prior to creating the Pleistocene surface map, outliers (high and low) were removed from the core data set with the use of a Cluster and Outlier Analysis (Anselin Local Morans I) in ArcGIS 10.3. In all, 253 corings were removed from the core data set.

The newly constructed 50 m palaeotopographical map (~58 cores/ km\(^2\)) allows for a more detailed reconstruction of the Pleistocene surface geomorphology of Southern Flevoland than has been published before (e.g. Peeters, 2007). The palaeotopographical map was created with the Kriging Interpolation method. This method has an added value relative to other interpolation methods when applied on datasets with an irregular distribution of data points (see Burrough & McDonnell, 1998).

The location of the Eem fluvial system was obtained from Menke, Van de Laar & Lenselink (1998), Peeters (2007) and Van den Biggelaar et al (2015) and modified on the basis of the topography of the newly created Pleistocene surface map. Following Guisan, Weiss & Weiss, (1999), Weiss (2001) introduced the concept of Topographic Position Index (TPI) to classify the landscape into different geomorphological features (e.g. valley, hillslope, etc.). The TPI indicates for each cell whether the elevation is higher (positive value) or lower (negative value) than the average elevation of surrounding cells (cf. Gallant & Wilson, 2000). For this research, a 3-category Slope Classification raster is created with the use of the TPI:
1) Valleys/other depressions (TPI \(\leq\) -0.25 m),
2) Plain \(-0.25 \text{m} < \text{TPI} \leq 0.5 \text{m}\) and
Fig. 3. Landform classification of the Pleistocene surface of Southern Flevoland, based on TPI. For this research, TPI neighbourhood sizes include: (A) 500 m, (B) 1000 m, (C) 1500 m, (D) 2000 m, (E) 2500 m and (F) 3000 m. These maps show the distribution of the different landforms in the study area using a “Rijksdriehoekstelsel” coordinate system.
3) Hills/ridges (TPI > 0.5 m).

The boundaries of these classes are based on the Geomorphological map scale 1:50000 (Ten Cate & Maarleveld, 1977). Valleys and other depressions deeper than 5 m do not exist in the study area, therefore all cells with a TPI below -0.25 m are characterised as a valley. Also, hills/ridges 5 m higher than their surrounding do not exist either (see Menke, Van de Laar & Lenselink, 1998), therefore all cells with a TPI above 0.5 m are characterised as a hill/ridge.

To classify the geomorphology of the study area the selected size and shape of the area that is taken into account surrounding any given cell (neighbourhood) is of paramount importance to the analysis. A circular neighbourhood was chosen to take into account the value of all neighbouring cells. Choosing the most insightful neighbourhood size for the TPI is based on an iterative process in which several options are tried. For this research, TPI grids are generated from neighbourhood sizes of 500 (i.e. 500 x 500 m), 1000, 1500, 2000, 2500 and 3000 m (fig. 3).

---

**Results**

**Geomorphological Setting of Well-Dated YD Archaeological Sites in the Northwest European Plain**

A total of 20 well-dated (\(^{14}\)C- or AMS-dated) YD archaeological sites in the Northwest European Plain have been obtained from the Radiocarbon Palaeolithic Europe Database v17 (Vermeersch, 2014) (fig. 1; tab. 1). Six of these sites are characterised as Federmesser and nine as Ahrensburgian on the basis of their artefact assemblage (see Bohmers & Houtsma, 1961; Bohmers & Wouters, 1962; Clausen, 1995; Crombé et al, 2014; Deeben, 1990; Deeben et al, 2006; Niekus, Stapert & Johansen, 1998; Pasda, 2002; Peleman, Vermeersch & Luypaert, 1994; Richter, 1992; Rozoy, 1978; Rust, 1943; Schwabedissen, 1954; Street, 1991; Taute, 1968; Van Noort & Wouters, 1987; Vermeersch, 2008; Vermeersch & Creemers, 1994; Weber, Grimm & Baales, 2011). Five sites are indicated as Final Palaeolithic because their artefact assemblages could not be specified to one Late Glacial culture (see Cziesla & Pettitt, 2003; Erdbrink, Meiklejohn & Tacoma, 1980; Gowlett et al, 1987; Gramsch & Beran, 2010; Stampfuss & Schütrumpf, 1970; Veil et al, 1991) (Table 1).
All of the Federmesser sites are located at elevated areas (N=5). The majority of the Ahrensburgian sites (N=5) are located at elevated areas (e.g. dunes, ridges, hills). Four Ahrensburgian sites are located at the transition from an elevated area to a plain (e.g. foot of a hill). For the five Final Palaeolithic sites the geomorphological context is unknown (fig. 4A).

For the Federmesser sites in NW Europe, the maximum distance to a freshwater source is ~ 1500 m, while for the Ahrensburg sites the maximum distance is ~ 2500 metres. For the five Final Palaeolithic sites the geomorphological context of the Pleistocene surface is based on the TPI grid of 1500 m neighbourhood size using a “Rijksdriehoekstelsel” coordinate system.

Based on geomorphological setting and the distance to a freshwater source for YD sites in the Northwest European Plain, potential Federmesser and Ahrensburgian sites in Flevoland are most likely to be expected at elevated areas in close proximity to the Eem fluvial system. For potential Federmesser sites this proximity is estimated at a maximum distance of 1500 m. For the potential Ahrensburgian sites the maximum distance from the Eem fluvial system might be 2500 m (fig. 4B).

Pleistocene surface Southern Flevoland

After removal of the outliers in the core dataset, the palaeotopographical map of Southern Flevoland has high accuracy because the mean prediction error is close to zero (0,001), the root-mean-square standardised prediction error is close to 1 (1,075) and the value of the root-mean-square prediction error (0,536) is almost similar to that of the average standard error (0,495). The Pleistocene surface elevation of Southern Flevoland varies from -15 m to -1 m relative to Dutch O.D. This surface gradually slopes to the northwest (fig. 2D).

The six TPI maps show that the geomorphology of the Pleistocene surface has an undulating character with a patchy distribution of features (e.g. elevated areas and valleys) (fig. 3). The size of these features increases when the neighbourhood size increases. The 2000, 2500 and 3000 m neighbourhood maps have a TPI that extend above 5 m (fig. 3D, E, F). Elevated areas more than 5 m above their surrounding (high hills, cf. Ten Cate & Maarleveld, 1977) do not exist in the study area.
and therefore these maps are not considered in this research.

In the three remaining TPI maps (fig. 3A, B, C) plains dominate, followed by valleys/other depressions and hills/ridges (tab. 2). To determine which TPI map generates the most accurate landform classification, the output of the 500, 1000 and 1500 m neighbourhood maps was compared to the location of known topographic features (Eem fluvial system and elevated areas). The 1500 m neighbourhood map provides the most accurate prediction of the location of known elevated areas (36%) and the Eem fluvial system (67%) (tab. 2) indicating that this is the best map for this research.

On the 1500 m neighbourhood map, areas are selected that have the highest probability of Younger Dryas archaeological remains. For Federmesser remains elevated areas within 1500 m from the Eem fluvial system are highlighted (fig. 5A), while for Ahrensburgian remains the elevated parts within 2500 m from the river are selected (fig. 5B).

Discussion and Conclusions

Data on the geomorphological setting of well-dated YD sites from the Northwest European

Plain are used to predict the locations in Southern Flevoland that are most likely to contain YD archaeological remains. Based on this data, the elevated areas in close proximity to the Eem fluvial system have the highest probability of containing YD archaeological remains within the study region (fig. 5A, B). The elevated areas in the study region comprise only 10% of the surface area (see tab. 2). When also taking into account the distance to the Eem fluvial system, the specific locations with the highest chance of Ahrensburgian or Federmesser remains constitute a surface area of less than 10% of the study region (compare tab. 2 and fig. 5A, B). This surface area is the maximum area that most likely contains YD archaeological remains because the data on the distance to a freshwater source for Federmesser and Ahrensburgian sites indicates the maximum distance. There might have been sources closer by that do not exist anymore. Although the inductive predictive model indicates that the remainder of the study area has a lower probability to contain YD remains, these locations should not automatically be disregarded. This is because an inductive model is based on the archaeological sample that has been discovered and is therefore rarely representative for the remains that have been distributed originally (see Kamermans, 2000; Verhagen & Whitley, 2012 for further discussion on the advantages and disadvantages of inductive modelling). Therefore, locations with a lower potential may also hold such remains. Additional fieldwork could reveal the accuracy of the model.

Although we focus on the geomorphological setting and distance to freshwater of Younger Dryas archaeological sites, we do not deny the role of other factors in settlement location choice (e.g. social, symbolic and distance to resources

<table>
<thead>
<tr>
<th>Neighbourhood size</th>
<th>Landform classification (% of total)</th>
<th>Overlap with known features (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Valleys/other depressions</td>
<td>Plain</td>
</tr>
<tr>
<td>500 m</td>
<td>9</td>
<td>89</td>
</tr>
<tr>
<td>1000 m</td>
<td>18</td>
<td>76</td>
</tr>
<tr>
<td>1500 m</td>
<td>23</td>
<td>67</td>
</tr>
</tbody>
</table>

Tab. 2. Percentage of valleys/other depressions, plain and hills/ridges of the Pleistocene surface of Southern Flevoland, based on the TPI of neighbourhood sizes 500, 1000 and 1500 m. Also, percentage of overlap is shown between the classified landforms and known landforms (elevated areas and Eem fluvial system) for each of the three TPI maps.
such as wood (fuel) or lithic raw materials. However, for comparison purposes between the known archaeological sites in lowland Northwest Europe and the reconstructed Younger Dryas palaeogeography in Southern Flevoland, only variables were used for which data is available in both areas (geomorphology and distance to freshwater). Apart from the available data on archaeological remains, the accuracy of the predictive model generated in this study is also dependent on the quality of the Pleistocene surface elevation map of the study area. The quality of the reconstructed Pleistocene surface depends on the quality of the core data and the core density. Although the quality of core data varies (see Table 1 in Van den Biggelaar et al, 2015), the core data has a high statistical significance. Furthermore, the large number of the cores limits the errors resulting from poor-quality core-data. Despite the high core density (~58 cores/km²), geomorphological features smaller than one hectare could have been missed. Nevertheless, the Pleistocene surface map reconstructed in this study is the most detailed to date for the regional perspective of the research.

Due to the detailed Pleistocene surface elevation map of Southern Flevoland, the concept of TPI provides a powerful tool to classify landforms (e.g. Tagil & Jenness, 2008; Weiss, 2001). The location of valleys/other depressions on the 1500 m neighbourhood TPI map corresponds well to the location of the Eem fluvial system (67%). The elevated areas are less well-predicted (36%) but could be related to the lower percentage of cells classified as hills/ridges compared to valleys/other depressions (see tab. 2). The dominance of valleys/other depressions over hills/ridges suggests that the Pleistocene surface morphology of the region has an undulating topography with broad valleys. Determining the accuracy of the TPI-generated landscape classification is highly dependent on the availability of known landforms. Therefore, future research is needed to test the accuracy of the landform classification of this study. For the current research, the generated Pleistocene surface topography provides sufficient accuracy due to the regional perspective of this study.

For several reasons the results of this study are considered relevant for future research on landscape exploitation by YD Palaeolithic groups. The Pleistocene surface topography that is reconstructed for Southern Flevoland is one of the most detailed within the Western Netherlands, an area where Holocene deposits cover the Pleistocene surface (see fig. 2A). Due to the Holocene cover, potential YD remains in the study area are likely to be well-preserved. The high detail of the Pleistocene surface, combined with the good preservation of this surface (see Van den Biggelaar et al, 2015) provide for an excellent opportunity for further research on YD landscape exploitation. Furthermore, outside the Western Netherlands very few YD remains have been discovered that are associated with the subsistence economy of YD cultural groups (e.g. Baales, 1996; 1999 for model on reindeer hunting). Therefore, knowledge on YD landscape exploitation in Northwest Europe is very limited. The potential of well-preserved YD remains in the study region to improve our understanding of YD landscape exploitation is therefore large.

In summary, for this research we used an inductive predictive modelling approach to determine locations in Southern Flevoland with the highest probability of YD archaeological remains. The results of this study indicate specific locations with high potential for Ahrensburgian and Federmesser remains (elevated areas and nearby water) that constitute less than 10% of the total study area. For potential Federmesser remains a maximum distance of 1500 m from the Eem fluvial system is estimated and for potential Ahrensburgian remains a maximum distance of 2500 m. These results have a heuristic value that can be used for future research and testing. The detailed and well-preserved Pleistocene surface in the study area, combined with potential well-preserved YD remains due to the Holocene cover, are of major importance for future studies on landscape exploitation. Reconstructing landscape exploitation enables us to advance hypotheses on
subsistence economy, settlement patterns and spatial organisation of past societies.

Acknowledgements

This article is part of the PhD research of Don F.A.M. van den Biggelaar at the VU University Amsterdam (VU). This research is part of the multidisciplinary Biography of the New Land research program of CLUE (VU), in collaboration with the Nieuw Land Heritage Centre (Lelystad, The Netherlands). This program is jointly funded by the research institute CLUE (VU) and the Nieuw Land Heritage Centre (Lelystad, The Netherlands).

We thank the Ministry of Infrastructure and the Environment for providing the digital elevation model of the surface elevation of Southern Flevoland (Actueel Hoogtebestand Nederland). In addition, we would like to thank Dr. Philip Verhagen (VU) for discussing this topic with us. His comments greatly improved the quality of this research. Finally, we thank two anonymous reviewers for their recommendations for improvement of this paper.

References


Babarens GW, ES Deevey & LJ Gralenski 1957: Yale Natural Radiocarbon Measurements III. Science 126, 909-19


Bohmers A & A Wouters 1962: Belangrijke vondsten van de Ahrensburgcultuur in de gemeente Geldrop, Brabants Heem, 14, 3-20


Bongers JMG, 2009b: Almere, Olympiakwartier West “De Key” (Gemeente Almere, Flevoland). Een Inventariserend Archeologisch Veldonderzoek, Steekproefrapport 2009-05/04, De Steekproef,
Zuidhorn.


Cziesla E & PB Pettitt 2003: AMS-14C-datierungen von spätpaläolithischen und mesolithischen funden aus dem büttzsee (Brandenburg), Archäologisches Korrespondenzblatt, 33, 21-38.


Deeben J, 1994: De laatpaleolithische en mesolithische sites bij Geldrop (N.Br.). Deel 1, Archeologie, 5, 3-57.
Deeben J, 1995: De laatpaleolithische en mesolithische sites bij Geldrop (N.Br.). Deel 2, Archeologie, 6, 3-52.

Erdbrink D, C Meiklejohn & J Tacoma 1980: River Valley People: fossil human remains from river deposits in the IJssel valley in the Dutch provinces of Gelderland and Overijssel (postcranial specimens and some recently found additions). Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen, Series C: Biological and Medical Sciences, 83, 363-86.


Huisman JJ & HCJ Visscher 2005: Basisrapportage vooronderzoek waardestelling, selectieadvies tekst bestemmingsplan Plangebied 328 NBC Oostvaardersplassen, Archeologische rapporten

Huisman JJ & P Visscher 2006b: Eindrapportage vooronderzoek waardestelling, selectieadvies tekst bestemmingsplan 1R12 Stichtse Kant Oost, Archeologische Rapporten Almere 17, Gemeente Almere, Almere.


Lanting JN & WG Mook 1977: The pre-and protohistory of the Netherlands in terms of radiocarbon dates, Groningen.


Kühner R, A Hiller & FW Junge 1999: Die späteiszeitlichen Ablagerungen der Spree im Tagebau Cottbus-Nord und ihre zeitliche Einordnung unter besonderer Berücksichtigung von ersten 14C-Daten an Hölzern, Quartär, 49(50), 7-20


Lauwerier R & J Deeben 2011: Burnt animal remains from Federmesser sites in the Netherlands, Archäologisches Korrespondenzblatt, 41, 1-20


Pasda C, 2002: A short note on man in the Allerød/Younger Dryas environment of lower Lusatia [Brandenburg, Germany], in Eriksen BV & Bratlund B

Peeters JHM, 2007: Hoge Vaart-A27 in context: towards a model of Mesolithic-Neolithic land use dynamics as a framework for archaeological heritage management, University of Amsterdam, Amsterdam.


Smith W, 2010: Basisrapportage bureauonderzoek Plangebied de Laten (1M2 en 1M1), Archeologische rapporten Almere 68, Gemeente Almere, Almere.


Stuart CDR, JJ Huisman, HCJ Visscher & SADS Post 2006d: Basisrapportage vooronderzoek waardestelling, selectieadvies, tekst bestemmingsplan: Plangebied 5B3, Vogelhorst.
Archeologische rapporten Almere 3, Gemeente Almere, Almere.


Visscher HCJ, 2006a: Basisrapportage vooronderzoek tekst bestemmingsplan, Archeologische Rapporten Almere 20, Gemeente Almere, Almere.

Visscher HCJ, 2006b: Basisrapportage vooronderzoek tekst bestemmingsplan Plangebied 5ZW1, Verlengde
Tussenring Hout Noord, Archeologische rapporten Almere 19, Gemeente Almere, Almere.

Visscher HCJ, 2006c: Basisrapportage vooronderzoek waardestelling, selectieadvies, tekst bestemmingsplan Plangebied 3KNS Spoorzone, Archeologische rapporten Almere 8, Gemeente Almere, Almere.


Wouters A, 1957: Een nieuwe vindplaats van de Ahrensburgcultuur onder de gemeente Geldrop, Brabants Heem, 9, 2-12.
