UNIVERSITY *of* York

This is a repository copy of *Degradation of the wetland sediment archive at Star Carr:an assessment of current palynological preservation*.

White Rose Research Online URL for this paper:
https://eprints.whiterose.ac.uk/id/eprint/100090/

Version: Accepted Version

Article:

White Rose
university consortium
Universities of Leeds, Sheffield & York

eprints@whiterose.ac.uk
https://eprints.whiterose.ac.uk/

Degradation of the wetland sediment archive at Star Carr: an assessment of current palynological preservation.

Bruce Albert[a], Jim Innes[b*], Jeff Blackford[c], Barry Taylor[d], Chantal Conneller[e], Nicky Milner[f]

[a] *Department of Ecology, Faculty of Environmental Sciences, Czech Life Sciences University, 961/129 Kamýcká, 165 00 Praha-Suchdol, Czech Republic*

[b] *Geography Department, Durham University, Science Labs, South Road, Durham DH1 3LE, UK*

[c] *Department of Geography, Environment and Earth Sciences, University of Hull, Hull HU6 7RZ, UK.*

[d] *Department of History and Archaeology, University of Chester, Parkgate Road, Chester CH1 4BJ, UK*

[e] *Archaeology, SAHC, University of Manchester, Oxford Road, Manchester M13 9PL, UK*

[f] *Department of Archaeology, University of York, The King's Manor, York Y01 7EP, UK*

Abstract

This paper presents the results of an investigation into the preservation status of pollen and other microfossils in the organic sediments at the wetland Mesolithic site of Star Carr. This study assesses the degradation of the pollen record in a profile at the edge of the archaeological site, adjacent to previous pollen work carried out from 1989 to 1991 and using it as a benchmark for comparison. There has been a severe degradation of pollen grains since the earlier work, with the upper peat devoid of pollen and the lower part of the organic profile badly affected. Only the very basal sediments retain well preserved pollen. Comparisons with hydrological and geo-chemical data obtained by other workers during the assessment of the Star Carr site suggest that oxidation caused by drainage and dessication of the organic sediments, perhaps originating in fissures in the drying peat, is a primary cause of the observed severe deterioration of the pollen record. Non-pollen palynomorphs (primarily fungal and algal spores) appear to be better preserved than pollen in the present bio-stratigraphic record, showing little surface degeneration, but are not recorded in the earlier work. The pollen archive in organic sediments at the Star Carr site is now badly damaged. Any further pollen work there should be undertaken urgently but is probably not justifiable.

1. Introduction

It is now six decades since the publication of Grahame Clark's monograph on excavations at the early Mesolithic archaeological site of Star Carr in the eastern Vale of Pickering in North-East England (Clark, 1954). It was the location of the Mesolithic settlement that first drew Clark to the site, as it lay on the edge of an Early Holocene lake (Candy et al., 2015; Palmer et al., 2015), now termed Lake Flixton, and so promised to provide the palaeoenvironmental data that he needed for his research on Mesolithic economy and land use. The iconic status enjoyed by Star Carr since Clark's work, therefore, is due not only to the prolific flint assemblages (Conneller and Schadla-Hall, 2003; Conneller et al., 2009), but also to the remarkable preservation and diversity of organic material associated with the site, which extended into the wetland sediments (Milner et al., 2011a). The organic components of Early Mesolithic material culture, which do not survive on dry sites, were found in abundance and in an excellent state of preservation, stratified within the waterlogged organic deposits that accumulated in the palaeolake margin and in the reedswamp, fen and carr wetland habitats associated with it. This stratification has allowed the use of palaeobotanical analyses, including both macrofossil (Dark, 2004; Taylor, 2011) and pollen (Walker and Godwin, 1954; Cloutman and Smith, 1988; Dark, 1998a,b,c; Cummins, 2000), to reconstruct the vegetation history around the site, providing an environmental context for the settlement at Star Carr (Innes et al., 2011; Milner et al., 2013). This combination of preserved organic cultural remains and multi-disciplinary study has made Star Carr the 'type' site for the British early Mesolithic, and a model for subsequent studies in wetland archaeology (Milner et al., 2011a;). Not only could questions of site function, economy and seasonality of occupation be addressed, but the deeper understanding of the activities carried out at Star Carr allowed the site to be the hub of conceptual models of early Mesolithic land use, territoriality and interactions with the wider landscape (Clark, 1972).

1.1 *Condition of the sediments*

The continued existence of the palaeoenvironmental archive at Star Carr, and the potential for further multi-disciplinary analyses there, depends upon the quality of preservation of the waterlogged sediments and organic remains. Excavations in the mid 1980s (Schadla-Hall, 1987; Schadla-Hall and Cloutman, 1985; Mellars and Dark, 1998), however, showed that organic preservation had deteriorated since Clark's work in 1950, and excavations since 2004

67   (Conneller, 2007; Milner et al. 2011b) have shown that the faunal and wood remains are now

68   severely degraded. Drying, shrinkage and weathering of the peat has occurred and it is clear

69   that modern land-use practices, particularly land drainage, have had an adverse effect on the

70   hydrology and chemistry of the site and its environs (Brown et al., 2011), and therefore on

71   the preservation of the organic material (Holden et al., 2006; Milner, 2007; Milner et al.,

72   2011b). Installation of highly effective land drains in the last decade (Brown et al., 2011;

73   Vorenhout, 2011) has accelerated this process, and the level of the peat surface has dropped

74   considerably. Although the water level and the position of the edge of Lake Flixton fluctuated

75   during the Early Mesolithic (Taylor, 2011), the edge remained a narrow zone and it is the

76   deposits that formed in this lake-edge ecotone adjacent to the Mesolithic settlement (Dark,

77   1998a; Mellars, 1998) that today contain the archaeological organic remains. These shallow

78   lake-edge peats are vulnerable to modern hydrological change, however, and are suffering the

79   effects of drainage and falling water-tables. The vulnerability of wetland archaeology to such

80   damage is a problem at a national level, and many such sites and wetland landscapes are at

81   risk (e.g. van de Noort et al. 2002; Brunning, 2013; Davis et al., 2015). At Star Carr, a

82   national flagship site for wetland archaeology, the dessication of the organic sediments, and

83   thus the degradation of the materials and information they contain, appears to have

84   accelerated in the last decade, to the point where the archive of archaeological material is

85   badly damaged (Milner et al., 2011b). Recent research at Star Carr, therefore, has

86   concentrated on assessing the present condition of the organic sediments on and close to the

87   archaeological site itself, to provide a benchmark to inform decisions regarding its future

88   management and study (Emerick, 2011). Brown et al.'s (2011) work on the hydrology of the

89   site and its catchment has shown that recent land drainage has been the cause of the

90   dessication and oxidation of the peat causing chemical changes and promoting extreme

91   sediment acidity. Boreham et al. (2011a, 2011b) performed a series of physical and

92   geochemical analyses at the site that also showed severe acidification of the sediments due to

93   lowered and fluctuating water tables. Oxidation and acidification have caused very serious

94   and rapid decay of the antler, bone and wood remains (Milner et al., 2011a). In theory this

95   very high acidity might not have such a severe effect upon pollen grain preservation, but

96   watertable fluctuation, and associated peat de-watering, could well cause their corrosion

97   (Lowe, 1982), and so the palynological record at Star Carr may be in as much danger as the

98   rest of the organic material there. An assessment of current pollen preservation was therefore

99   urgently required.

100

101   1.2 *Previous palynological work*

102   In this paper we present the results of an assessment of the current palynological status of

103   the peat at Star Carr. We take as our benchmark the palynological analyses closest to the site

104   itself (Day, 1993; Dark, 1998c) in the shallow lake margin peats adjacent to Clark's

105   archaeological excavations (Fig. 1). Cloutman and Smith (1988) had earlier conducted pollen

106   analyses on three profiles from a trench (VP85A) across the peat margin close to the site, and

107   did not report any problems with poor pollen preservation. However, when Dark (1998c)

108   performed more detailed pollen analyses from the same Trench (A), it was clear that the

109   upper peats had been subject to drying and shrinkage. Dark (1998c) also noted a gradual

110   deterioration of pollen and spore preservation with proximity to the surface, with well-

111   preserved pollen being absent above 70 cm from the basal gravel. Dark (1998a) sampled at

112   high resolution (approximately 2 to 4 year intervals) through the Mesolithic occupation

113   phases, and identified phases of vegetation disturbance that coincided with increased

114   microcharcoal percentages and also with the archaeologically-rich levels. Her interpretation

115   that burning and significant disturbance of the local vegetation accompanied the phases of

116   occupation at Star Carr was the first recognition of Early Mesolithic environmental impact

117   there. During recent excavations in 2010 (Conneller et al., 2012) we recovered a peat profile

118   from a new site, 20 metres west of Dark's (1998a) profiles (Boreham et al., 2011b), and have

119   conducted comparable analyses in order to investigate the condition of palynological remains,

120   twenty years after Dark analysed her Star Carr samples.

121

122   **2. Methods**

123   A bulk sample of the basal 75 cm of sediment was recovered in aluminium monolith tins

124   (numbered 321 and 322) from the southern end of excavation trench SC24 (Fig.2), in a

125   location selected to correspond closely to the altitude and position within the lake-edge peats

126   of the Dark (1998a) profile. The surface altitude of the sampled location was 24.36 m OD.

127   The peat between the top of the upper tin 322 and the ground surface was very dry and badly

128   dessicated, and was not sampled. The sampled lower peat was from the edge of the

129   archaeological site and contained occasional flint flakes, animal bone, and wood pieces; as

130   such it was appropriate to sample in order to test the preservation of pollen and spores close

131   to recent and future excavations. Its lithostratigraphy is shown in Table 1. Other monolith tins

132   were collected from adjacent sections in case the first set proved barren of pollen, but these

133   have not had to be used and are archived.

134   Pollen samples were analysed at 5 mm intervals, to provide a detailed assessment of

135   microfossil preservation. Twelve samples are from the basal, minerogenic sediments and the

136   remainder from the organic mud and peat above. Samples were prepared at the Department of

137   Geography, University of Durham by means of a sequential application of cold HCL (10%),

138   hot KOH (10%), hot HF (49%), warm HCL (10%) and a brief application of a hot acetolysis

139   mixture (less than one-minute duration), the latter using a $C_4H_6O_3$ (90%) solution with H_2SO_4

140   (10%). Pollen samples were filtered through a 175 μm sieve at the KOH stage, thus

141   potentially reducing the number of charcoal particles above that size. After cleaning and

142   dehydration (via ETOH), samples were mounted in high-viscosity silicone oil for light

143   microscopic (LM) analysis. Both pollen and charcoal concentrations are calculated using an

144   added exotic *Lycopodium* spike (Stockmarr 1971). All Poaceae grains (including annular

145   dimensions where grains are 34 μm or larger) as well as microcharcoal particles were

146   measured along their maximum axis. The former procedure has been used to ascertain the

147   relative importance of cereal-like (wild) grass taxa in the assemblage, and particularly

148   *Glyceria fluitans* (cf. Albert and Innes, 2015), while measurements of microcharcoal are used

149   to assess the relative proximity of fires, with high proportions of smaller charcoal elements

150   indicating more distant fires (Blackford, 2000). Counts of 400 pollen grains were achieved in

151   most cases. Non-pollen palynomorphs (NPPs), mainly fungal spores, have been identified

152   (van Geel and Aptroot, 2006; Innes and Blackford, 2003). Most pollen and spore

153   identification and nomenclature follows Moore et al., (1991) and was achieved at x400

154   magnification on a standard light microscope, but higher magnifications were used to assess

155   pollen preservation in more detail, according to degradation and damage. There has been

156   considerable previous work on pollen preservation which has included a range of

157   observational criteria, including folding, crumpling, breakage and surface corrosion

158   (Cushing, 1967; Delcourt and Delcourt, 1980; Hall, 1981; Tipping 1987; Twiddle and

159   Bunting, 2010).   These criteria have been used to characterise the mode of pollen

160   deterioration - through transportation, *in situ* or progressive deterioration, and reworking and

161   redeposition of grains. Studies have included species-specific (Campbell, 1999) and

162   experimental approaches (Twiddle and Bunting, 2010). As the focus of this paper is the

163   overall condition of the pollen archive, we have not presented deterioration data for

164   individual taxa.

165   For this project, a specific aim has been to compare pollen preservation with the earlier

166   study (Dark, 1998c), and assess the potential for future work. Hall (1981) concluded that the

167 best indicators of deterioration were low pollen counts and high frequencies of deteriorated
168 grains. In this study, comparison to the assemblages quantified by the earlier work at the
169 same site can be added as the primary indicator of the deterioration since Dark's earlier
170 samples were taken. In this study, degrees of crumpling, corrosion and folding of pollen are
171 assessed using sub-samples of 50 grains, carefully examined at x1000 magnification in
172 immersion oil. Two classes of pollen degradation are recognized in this assessment, while
173 relatively non-degraded grains are termed "Type 1" reflecting a well-preserved state in
174 relation to each class (see Table 2). The first class of degradation is termed "damage", and
175 includes mechanical folding (type 2) and tearing (type 3) of grains, and may occur in
176 situations involving movement or compression of sediment. The second class of degradation
177 is termed "deterioration", and reflects an erosion of fine micro-sculpturing elements of pollen
178 exines (Type 2) or visible holes in the exine structure (Type 3) under x1000 magnification.
179 Such deterioration might result from either microbial (including fungal) agents or oxidation
180 (Lebreton et al., 2010) of the exterior of the grain.

181   Counts of pollen, fungal remains and algal spores made at x400 magnification were
182 calculated in terms of percentage of total land pollen (TLP, c. 400 grains) and are shown in
183 Fig.3. Pollen condition assessment counts are based on the 50-grain sub-sample analysed at
184 x1000 magnification, shown as percentages. All pollen, spore and charcoal data have been
185 plotted using the TILIA program (Grimm, 1993).

186

3. Results

188   The results of the pollen analysis are shown in Fig.3. Six pollen zones are recognised
189 based on changes in the main pollen taxa, with *Betula*, *Pinus*, *Salix* and Poaceae the major
190 contributors, and these are similar to those of the earlier work by Dark (1998c), who
191 recognised five major pollen zones. Her upper zone dominated by *Corylus* is missing from
192 this new study at SC24, showing that the later pollen record that Dark recorded is no longer
193 preserved. Most Poaceae grains in the SC24 profile are likely to derive from reedswamp
194 grasses, and *Phragmites* remains are present in unit 2 of the lithostratigraphy (Table 1). A
195 few grass grains can be identified as of *Glyceria* type (Albert and Innes, 2015). *Salix* values
196 in the deepest zone from SC24 are higher than those of Dark (1998c) and may represent
197 growth of *Salix* closer to the new sampling point, although the two sections are not far apart,
198 as willow growth can be very localised. Minor taxa include many wetland herbs in low

199   numbers, with Cyperaceae and *Filipendula* most abundant. These minor elements of the
200   pollen assemblage are very similar to those identified by Dark (1998c). Results suggest a
201   mosaic of wetland reedswamp, fen and carr vegetation with birch woodland on the dry land
202   around the site. There are few pollen types present throughout the profile that indicate human
203   impact on the environment, with only single grains of *Rumex acetosa* and *Plantago*
204   *lanceolata.* As the new SC24 profile has no radiocarbon control, precise correlation with
205   Dark's (1998c) pollen record is not possible but in general these new pollen results are very
206   similar to her's, with Early Holocene (pre-Boreal) *Betula* woodland the local dominant
207   vegetation outside the wetland. High *Filipendula* values near the base and the absence of a
208   *Corylus* rise at the top of our diagram confirms that this assessment covers much of the first
209   Holocene millennium, including the Mesolithic settlement phase, as does the dated diagram
210   of Dark (1998b), and so comparisons can be made between the two data sets, although
211   precise correlations are not possible. Microcharcoal results (Fig.4) are also comparable, as
212   might be expected from their proximity (Innes et al., 2004). Three microcharcoal peaks occur
213   in the new profile, as in the previous work, interpreted as showing human activity at the site.
214   Relatively little microcharcoal occurs in the upper part of the new sequence.

215

216   3.1 *Relative pollen degradation*

217   In monolith 322 and the upper part of monolith 321, field observation had shown the peat
218   to be severely dessicated (Fig.2). At these depths, very little preserved pollen was found.
219   Although similar depths above the peat base had been satisfactory for successful palynology
220   in Dark's earlier profile, those sampled for the present study in 2010 were unable to yield a
221   viable count. Only the lower 400 mm from tin 321, at depths of 725-1125 mm, contained
222   pollen, although preservation levels are variable. Within this broad zone of some
223   preservation, high levels of damaged grains have been recorded, with in some cases over 80%
224   of the 50 grain subsample being damaged. The deteriorated category, most likely to represent
225   post-depositional processes (Bunting and Tipping, 2000), includes many samples with over
226   60% deteriorated, and some over 80%. Whereas Dark (1998c) recorded less than 5%
227   deteriorated grains, high levels of deterioration and damage are present throughout this new
228   profile, including some horizons without preservation. Total pollen concentration values in
229   the section 725-1125 mm vary from sample to sample, with a range of 200,000 cm^{-3} in basal
230   layers to only 2,000 in some upper levels. Comparable data from Dark (1998c) average
231   200,000, with peaks at 800,000 and minima around 50,000 (Dark 1998c Fig. 11.3).

The pollen grains of *Pinus* species are considered more resistant than others to degradation (Sangster and Dale, 1961). The data in Figs.3 and 4 show higher levels of *Pinus* associated with low total concentrations of pollen, and higher percentages (60%+) of deteriorated grains, with *Pinus* levels sometimes in excess of 50% of TLP. Maximum values of 20% *Pinus* were reported by Dark (1998c) which has increased to 60% in SC24-e, suggesting that 50% of all other pollen has been lost, if *Pinus* pollen remains present in the same frequencies. *Juniperus*, a thin-walled grain that was present in Dark's (1998c) lower pollen zones, is entirely absent in SC24. In comparison to the original analyses of Dark (1998c), where only isolated crumpled/folded and deteriorated grains were noted, the present analyses produce a high encounter rate of moderately (Type 2) damaged and deteriorated grains. Moderately deteriorated pollen grains (with missing micro-sculpturing elements) are also common, averaging 20% of the sub-sample analysed, in basal levels below 1030 mm where degradation of pollen grains has been overall less severe.

In addition to the high levels of damage and deterioration (60%+) noted in those levels containing what appear to be inflated concentrations of *Pinus*, three distinct horizons lack countable levels of pollen, suggesting higher rates of degradation across all taxa. These horizons (bands 1-3 in Figs.3 and 4) are at 1015, 925-990 and 740-755 mm. Preservation was also very poor at 810 mm, although a low count was possible. Further evidence for degradation may be inferred from the unidentified fern spores (Pteropsida indet. cf. Filicales), which are considered resistant to oxidation and can be common in soil pollen analyses (Havinga, 1964; Tipping, 2000). The highest values (20-40% of TLP+taxon) are expressed at the boundaries of bands of very low concentration, where levels of severely degraded (Category 3) grains also increase. Dark (1998c) also recorded high values of Pteropsida, although these were in the upper levels of Trench A, M1 (top 400 mm of the profile), from a period classed here as non-polliniferous. In zones where Dark found abundant Pteropsida spores, this study shows uncountably low pollen frequencies, and in levels where Dark (1998c) found low background levels of generic ferns spores (<2%) with occasional peaks, our samples recovered twenty years later contain 5-20%, as with the *Pinus* data suggesting loss of other taxa.

4. Condition of the pollen archive

263   The lower 120 mm section of the sediment profile is minero-organic and has a moderately

264   well-defined boundary to the overlying peat. Field estimation of water content while using

265   the Troels-Smith scheme to record the lithostratigraphy (Table 1) during sample collection

266   showed that these lowest levels were clearly saturated and levels of preservation of both

267   macro- and microscopic material are good (section A on Fig. 2). Above these basal levels

268   (section B on Fig.2), however, handling of the peat showed that water content dropped

269   sharply and although the peat was still damp, it was far less so than in section A. It also

270   showed the peat in the upper tin 322 and in the top levels of tin 321 to be dry (section C on

271   Fig.2) and hardly damp at all to the touch. The peat from the top of tin 322 to the surface was

272   extremely dry. Comparing the assessment profile with the descriptions and photographs of

273   Dark's work and of the original excavations, it was clear that there has been a distinct fall in

274   surface level, causing dessication and compaction of the sediments in this part of the site,

275   presumably resulting from dewatering and shrinkage of the peat. This compaction has

276   inflated the original concentrations and percentages of microcharcoal and other microfossils,

277   exacerbated by the general pollen decay. Future microcharcoal results, either percentage or

278   concentration, would therefore be skewed, not comparable to Dark's earlier data, and not an

279   accurate record of original microcharcoal deposition. Our assessment analyses show that

280   there are major problems with pollen preservation in most parts of the sequence. Quality of

281   preservation declines progressively higher in the profile, but not consistently, and there are

282   groups of levels in tin 321 (bands 1, 2 and 3) where preservation was so poor that pollen was

283   absent or at least uncountable. Significant levels of degradation or damage to pollen exines

284   are, however, ubiquitous and are extremely high in several horizons within the profile.

285   Sediments at the level of tin 322 are now virtually beyond use. Carbonate minerals reported

286   by Dark in her earlier analyses were not found in our work, and the chemical changes noted

287   by other studies (Boreham et al., 2011b) seem to have fundamentally altered the profile.

288   French and Taylor (1985) have shown that the destructive effects of dehydration and

289   oxidation begin immediately after sediments cease to be permanently waterlogged, even

290   seasonally, so that even the lower levels at Star Carr are unlikely to sustain well-preserved

291   pollen for very long. As Dark's (1998c) work did not include NPP analysis, no direct

292   comparison can be made with the fungal spores recorded in the present study, which are

293   therefore omitted from Fig.4. It should be noted, however, that the fungal spores recorded

294   throughout our counted levels show a much lower degree of surface degradation than the

295   pollen, even in the upper parts of tin 321, and so fungal spores in general may well be robust

296 and less susceptible to corrosion and deterioration. Further research is required on this
297 subject.

298

299 4.1 *Causes of pollen degradation at Star Carr*

300   The fact that recent pollen analyses of Star Carr peat sediments in Monolith 321 show
301 major degradation of pollen grains merits some consideration as to agencies of preservation
302 versus degradation. This can be done moreover in relation to hydrological (Brown et al.,
303 2011) and geo-chemical (Boreham et al. 2011a, 2011b) data so as to more strictly determine
304 factors of a geo-chemical as opposed to biological degradation over the past twenty years.
305 The relative importance of individual factors of degradation is not always easy to assess
306 (Bryant and Holloway 1983). Significantly, very low pH values determined to be pervasive in
307 the case of Star Carr peats would indicate also a situation of very low biotic activity, and
308 given a formerly near-pristine state determined in Dark's (1998c) analyses, a chemical
309 agency during the last two decades is more likely. In the latter case, preservation of pollen by
310 virtue of reduction in pre-drainage conditions in the valley is supported by regional
311 hydrological data (Brown et al., 2011).

312   Regarding important patterning in the pollen preservation data (Fig.4), that bands of poor
313 preservation are present at various depths hints at factors of degradation beyond simple
314 oxidation originating from surface layers, and might also result from oxidation originating in
315 fissures in the peat bed that are sometimes observable in the profile as light sandy or silty
316 clay layers (Table 1 and Fig.2). Such layers form from expansion and contraction following
317 dehydration and rehydration cycles, a property also observed in wood remains recently
318 recovered from the Mesolithic site (Milner et al., 2011b). Oxidation in the Star Carr peat
319 deposits is also measurable according to redox potential according to chemical analyses
320 (Boreham et al., 2011b), including pH, iron oxide (esp. Iron II versus Iron III) content along
321 multiple bore hole transects which lie between trench A and trench SC24. High redox
322 potential values (Boreham et al., 2011b), but not pH *per se* although this influences redox
323 (Boreham et al., 2011a), indicate severe oxidation, and most oxidised conditions are very
324 positively correlated with total deterioration of pollen. Both mechanical damage and, more
325 importantly, deterioration might be explained by a strong oxidizing reaction, given the
326 extreme values. Redox (mV) values in excess of 400 (cf. western 5 m of Transect 2 near
327 Monolith 321; Boreham et al., 2011a) appear to align with the pollen degradation Bands 2

328 and 3 reported in this study. Such a strong oxidizing reaction affecting the pollen is also
329 enabled by the very high acidity of the sediment matrix, although this in itself is not an agent
330 of degradation. It can be assumed that, because of the extremely acidic conditions that have
331 developed at Star Carr during the past two decades, biotic agents of pollen degradation have
332 been of lesser importance, as high acidity must have greatly reduced the rate of microbial
333 activity in these sediments.

334

335 **5. Conclusions**

336 The assessment analyses in this study show that there are major problems with pollen
337 preservation in many parts of the SC24 sequence, with only the base of the profile still
338 maintaining a relatively close relationship to the more pristine spectra analysed earlier by
339 Dark (1998c), although some less reliable analysis may still practical in the lower 40 cm of
340 the profile. Our sequence, located very close to Dark's original profile although not a
341 duplicate section, shows clear evidence of substantial pollen deterioration since her work, to
342 the extent that most parts of the profile are no longer viable for meaningful pollen analysis.
343 While it is still possible to recover a pollen record that corresponds to the time of the
344 Mesolithic occupation, the more fragile pollen types will have been differentially removed,
345 preventing a reliable count, and all pollen types will have been affected by degradation.
346 Although there may be pockets of better preservation, the section assessed in this study is
347 likely to be representative of conditions at the wetland edge of the archaeological site as a
348 whole, although preservation levels may well be better in deeper sediments further into the
349 area of the palaeo-lake. Other more landward areas of the site, which appear even drier than
350 the sampled location, may well be completely degraded. Preservation conditions appear to
351 have been much better when Dark's analyses were completed and future deterioration is
352 likely to continue unless preventative action is taken at the site. Nothing can be done about
353 the damage that the pollen archive has already suffered, and any proposed palynological work
354 around the Star Carr site itself should be done urgently, although our study indicates that
355 degeneration has proceeded so far that it is already almost too late and any new pollen work
356 would have to be recognised as compromised and unreliable. It is very likely that, nationally,
357 the palaeoenvironmental resource at many other wetland archaeology sites, most of which
358 have received less attention than Star Carr, are at similar risk and require urgent research
359 attention before their palynological archive is destroyed.

References

Albert, B.M., Innes, J.B., 2015. Multi-profile, fine-resolution palynological and micro-charcoal analyses at Esklets, North York Moors, UK, with special reference to the Mesolithic-Neolithic transition. Veget. Hist. Archaeobot. 24, 357-375.

Blackford, J.J., 2000. Charcoal fragments in surface samples following a fire and the implications for interpretation of subfossil charcoal data. Palaeogeogr., Palaeoclimatol., Palaeoecol. 164, 33-42.

Boreham, S., Boreham, J., Rolfe, C.J., 2011a. Physical and chemical analyses of sediments from around Star Carr as indicators of preservation. J. Wetland Arch.11, 20-35.

Boreham, S., Conneller C., Milner, N., Taylor, B., Needham, A., Boreham, J., Rolfe, C.J., 2011b. Geochemical indicators of preservation status and site deterioration at Star Carr. J. Archaeol. Sci. 38, 2833-2857.

Brown, A.G., Bradley, C., Grapes, T., Boomer, I., 2011. Hydrological assessment of Star Carr and the Hertford catchment, Yorkshire UK. J. Wetland Arch. 11, 36-55.

Brunning, R., 2013. Somerset's peatland archaeology: managing and investigating a fragile resource: the results of the Monuments at Risk in Somerset Peatlands (MARISP) Project. Oxbow, Oxford.

Bryant, V.M., Holloway, R.G., 1983. The Role of Palynology in Archaeology. Adv. Archaeol. Meth. Theory 6, 191-224.

Bunting, M.J., Tipping, R. 2000. Sorting dross from data: possible indicators of post-depositional assemblage biasing in archaeological palynology. In: Bailey, G., Charles, R., Winder, N., (Eds.), Human Ecodynamics. Symposia of the Association for Environmental Archaeology No. 19, Oxbow, Oxford, pp. 63-68.

Campbell, I.D., 1999. Quaternary pollen taphonomy: examples of differential redeposition and differential preservation. Palaeogeogr. Palaeoclimatol. Palaeoecol. 149, 245–256.

Candy, I., Farry, A., Darvill, C.M, Palmer, A., Blockley, S.P.E., Matthews, I.P., MacLeod, A., Deeprose, L., Farley, N., Kearney, R., Conneller, C., Taylor, B., Milner, N., 2015. The evolution of Palaeolake Flixton and the environmental context of Star Carr: an oxygen and carbon isotopic record of environmental change for the early Holocene. Proc. Geol. Assoc. 126, 60-71.

Clark, J.G.D., 1954. Excavations at Star Carr. Cambridge University Press, Cambridge.

Clark, J.G.D., 1972. Star Carr – a Case Study in Bio-archaeology. Addison Wesley Modular Publications No. 10, Cummings, Reading, Mass.

Cloutman, E.W., Smith, A.G., 1988. Palaeoenvironments in the Vale of Pickering. Part 3: Environmental history at Star Carr. Proc, Prehist. Soc. 54, 37-58.

Conneller, C., 2007. New excavations at Star Carr. PAST 56, 3-5.

Conneller, C., Schadla-Hall, T., 2003. Beyond Star Carr: the Vale of Pickering in the 10th millennium BP. Proc. Prehist. Soc. 69, 85-106.

Conneller, C., Milner, N., Schadla-Hall, T., Taylor, B., 2009. The temporality of the Mesolithic landscape: new work at Star Carr. In: Crombé, P., Van Strydonck, M., Sergant, J., Boudin, M., Bats, M., (Eds.), Chronology and Evolution within the Mesolithic of North-West Europe. Proceedings of an International Meeting, Brussels, May 30th-June 1st 2007, Cambridge Scholars Publishing, Newcastle upon Tyne, pp. 77-94.

Conneller, C., Milner, N., Taylor, B., Taylor, M., 2012. Substantial settlement in the European Early Mesolithic: new research at Star Carr. Antiquity 86, 1004-1020.

424

425 Cummins, G.E., 2000. *Fire!* Accidental or strategic use of fire in the early Mesolithic of the
426   eastern Vale of Pickering. In: Young R., (Ed.) Mesolithic Lifeways. Current Research in
427   Britain and Ireland. Leicester Archaeology Monograph 7, Leicester, pp. 75–84.

428

429 Cushing, E.J., 1967. Evidence for differential pollen preservation in late Quaternary sediments
430   in Minnesota. Rev. Palaeobot. Palynol. 4, 87-110.

431

432 Dark, P., 1998a. Introduction and methods. In: Mellars, P.A., Dark, P. (Eds.), Star Carr in
433   Context. McDonald Institute for Archaeological Research, Cambridge, pp. 111-117.

434

435 Dark, P., 1998b. Radiocarbon dating of the lake-edge deposits. In: Mellars, P.A., Dark, P.
436   (Eds.), Star Carr in Context. McDonald Institute for Archaeological Research, Cambridge,
437   pp. 119-124.

438

439 Dark, P., 1998c. Lake-edge sequences: results. In: Mellars, P.A., Dark, P. (Eds.), Star Carr in
440   Context. McDonald Institute for Archaeological Research, Cambridge, pp. 125-146.

441

442 Dark, P., 2004. Plant remains as evidence for seasonality of site use in the Mesolithic period.
443   Env. Arch. 9, 39-45.

444

445 Davis, A., Bishop, S., Cheetham, J., 2015. Hydrological modelling of the Flag Fen
446   archaeological site and wider landscape: main report. Final report for project 6187.
447   Historic England, Swindon.

448

449 Day, P. 1993. Preliminary results of high-resolution palaeoecological analyses at Star Carr,
450   Yorkshire. Cambs. Archaeol. J. 3, 129-133.

451

452 Delcourt, P.A., Delcourt, H.R., 1980. Pollen preservation and Quaternary environmental
453   history in the southeastern United States. Palynology 4, 215-231.

454

455 Emerick, K., 2011. The management of Star Carr. J. Wetland Arch. 11, 120-132.

456

457   French, C., Taylor, M., 1985. Dessication and destruction: the immediate effects of de-
458   watering at Etton, Cambridgeshire. Ox. J. Archaeol. 4, 139-155.

459

460   Grimm, E.C., 1993. TILIA Software. Illinois State Museum, Chicago.

461

462   Hall 1981. Deteriorated pollen grains and the interpretation of Quaternary pollen diagrams.
463   Rev. Palaeobot. Palynol. 32, 193–206.

464

465   Havinga, A.J., 1964. Investigation into the differential corrosion susceptibility of pollen and
466   spores. Pollen Spores 6, 621-635.

467

468   Holden, J., West, L.J., Howard, A.J., Maxfield, E., Panter, I., Oxley, J., 2006. Hydrological
469   controls of in situ preservation of waterlogged archaeological deposits. Earth-Science
470   Reviews 78, 59-83.

471

472   Innes, J.B., Blackford, J.J., 2003. The ecology of late Mesolithic woodland disturbances:
473   model testing with fungal spore assemblage data. J. Archaeol. Sci. 30, 185-194.

474

475   Innes, J.B., Blackford, J.J., Simmons, I.G. 2004. Testing the integrity of fine spatial resolution
476   palaeoecological records: micro-charcoal data from near-duplicate peat profiles from the
477   North York Moors, UK. Palaeogeogr. Palaeoclimatol, Palaeoecol. 214, 295-307.

478

479   Innes, J.B., Blackford, J.J., Simmons, I.G., 2011. Mesolithic environments at Star Carr, the
480   eastern Vale of Pickering and environs: local and regional contexts. J. Wetland Arch. 11,
481   85-108.

482

483   Lebreton, V., Messager, E., Marquer, L., Renault-Miskovsky, J., 2010. A neotaphonomic
484   experiment in pollen oxidation and its implications for archaeopalynology. Rev.
485   Palaeobot. Palynol. 162, 29-38.

486

487   Lowe, J.J., 1982. Three Flandrian pollen profiles from the Teith valley, Perthshire, Scotland.
488   II. Analyses of deteriorated pollen. New Phytol. 90, 371-385.

489

490   Mellars, P.A. 1998. Postscript: major issues in the interpretation of Star Carr. In: Mellars,
491   P.A., Dark, P., (Eds.), Star Carr in Context, McDonald Institute for Archaeological
492   Research, Cambridge, pp. 215-241.

493

494   Mellars, P., Dark, S.P., 1998. Star Carr in Context: New Archaeological and Palaeoecological
495   Investigations at the Early Mesolithic Site of Star Carr, North Yorkshire. McDonald
496   Institute Monographs. McDonald Institute for Archaeological Research, Cambridge.

497

498   Milner, N., 2007. Fading star. Brit. Arch. 96, 10-14.

499

500   Milner, N., Lane, P., Taylor, B., Conneller, C., Schadla-Hall, T., 2011a. Star Carr in a
501   postglacial landscape: 60 years of research. J. Wetland Arch. 11, 1-19.

502

503   Milner, N., Conneller, C., Elliott, B., Koon, H., Panter, I., Penkman, K., Taylor, B., Taylor,
504   M., 2011b. From riches to rags: organic deterioration at Star Carr. J. Archaeol. Sci. 38,
505   2818-2832.

506

507   Milner, N., Taylor, B., Conneller, C., Schadla-Hall, T., 2013. Star Carr: Life in Britain after
508   the Ice Age. Council for British Archaeology, York.

509

510   Moore, P.D., Webb, J.A., Collinson, M.E. 1991. Pollen analysis. Blackwell, Oxford.

511   Palmer, A.P., Matthews, I.P., Candy, I., Blockley, S.P.E., Macleod, A., Darvill, C.M., Milner,
512   N., Conneller, C., Taylor, B., 2015. The evolution of Palaeolake Flixton and the
513   environmental context of Star Carr, NE. Yorkshire: stratigraphy and sedimentology of the
514   Last Glacial-Interglacial Transition (LGIT) lacustrine sequences. Proc. Geol. Assoc. 126,
515   50-59.

516   Sangster, A.G., Dale, H.M., 1961. A preliminary study of differential pollen grain
517   preservation. Can. J. Bot. 39, 35-43.

518

519   Schadla-Hall, R.T., 1987. Recent investigations of the early Mesolithic landscape in the Vale
520   of Pickering. In: Zvelebil, M., Blankholm, H., (Eds.), Mesolithic Northwest Europe:

Recent Trends. Department of Archaeology and Prehistory, University of Sheffield, pp. 46-54.

Schadla-Hall, R.T., Cloutman, E.W., 1985. 'One cannot dig at random in a peat bog'. The eastern vale of Pickering and the archaeology of a buried landscape. In: Haselgrove, M., Millett, M., Smith, I.M., (Eds.), Archaeology from the Ploughsoil. Department of Archaeology and Prehistory, University of Sheffield, pp. 77-86.

Stockmarr, J. 1971. Tablets with spores used in absolute pollen analysis. Pollen Spores 13, 615–621.

Taylor, B., 2011. Early Mesolithic activity in the wetlands of the Lake Flixton basin. J. Wetland Arch. 11, 63-84.

Tipping, R. 1987. The origins of corroded pollen grains at five early postglacial sites in western Scotland. Rev. Palaeobot. Palynol. 53, 151–161.

Tipping, R., 2000. Pollen preservation analysis as a necessity in Holocene palynology. In: Huntley, J.P., Stallibrass, S., (Eds.), Taphonomy and Interpretation. Symposia of the Association for Environmental Archaeology 14, Oxbow Books, Oxford, pp. 23-33.

Troels-Smith, J., 1955. Characterisation of unconsolidated sediments. Danm geol Unders Series IV, 3, 38–73.

Twiddle C.L., Bunting M.J., 2010. Experimental investigations into the preservation of pollen grains: a pilot study of four pollen types. Rev. Palaeobot. Palynol. 162, 621-630.

van de Noort, R., Fletcher, W., Thomas, G., Carstairs, I., Patrick, D., 2002. Monuments at risk in England's wetlands. University of Exeter, Exeter.

van Geel B., Aptroot A., 2006. Fossil ascomycetes in Quaternary deposits. Nova Hedwigia 82, 313–329.

554 Vorenhout, M., 2011. In situ preservation and monitoring with particular application to Star
555   Carr, Yorkshire, UK. J. Wetland Arch. 11, 56-62.

556

557 Walker, D., Godwin, H. 1954. Lake stratigraphy, pollen-analysis and vegetational history. In
558   J.G.D. Clark, Excavations at Star Carr. Cambridge University Press, Cambridge, pp. 25-69.

559

560

561

562

563

564

565

566

567

568

569

570

571

572

573

574

575

576

577   Figure captions

578   Fig. 1   Location (insets) of palaeo-lake Flixton and the Early Mesolithic site of Star Carr in
579   North-East Yorkshire. The site of the present palynological investigation at the southern end
580   of archaeological trench SC24 is indicated by a white circle. Also shown are the locations of
581   Clark's original excavations (Clark 1954) and of previous palynological work. Dark (1998a)
582   analysed four pollen profiles, one on the southern edge of the Clark excavation area and
583   which is marked here by a circle containing a cross. The other three, M1 to M3, were twenty
584   metres to the east in her Trench A in a north-south transect through the marginal lake-edge
585   deposits. Trench A is the re-opened trench VP85A of Cloutman and Smith (1988) and Dark's
586   profiles are in broadly the same places as Cloutman and Smith's pollen diagrams A3 to A1.
587   Geophysical core transects of Boreham et al. (2011a, b) run between trenches A and SC24.
588   The current 24 m contour line represents the general position of the lake edge during the
589   Mesolithic occupation.

590   Fig. 2   Monolith tins for palynological analysis (the 50 cm long lower tin is numbered 321
591   and the 25 cm long upper tin 322) *in situ* in the section at the south end of trench SC24 at Star
592   Carr (see Fig.1). Adjacent holes in the section are the locations of sampling for other forms of
593   analysis. Note the very dry condition of the upper part of the section, with dessication cracks
594   and crumbly, oxidized peat. On monolith tin 321 section A constitutes the basal part of the
595   profile where pollen preservation is good, section B represents the part where analysis is
596   compromised but still practical, and section C is the part where pollen preservation is so poor
597   as to make analysis non-viable. Tin 322 and above are useless for analysis.

598   Fig. 3   Palynology of profile SC24. Pollen and spores are calculated as percentages of the
599   total land pollen sum, which includes trees, shrubs and herbs.

600   Fig. 4   *Pinus* pollen frequencies, expressed as percentages of total land pollen, pollen
601   preservation classification and microcharcoal concentration data from profile SC24. For
602   damaged and deteriorated pollen, class 1 means well preserved, class 2 means degraded so
603   that identification is difficult but still possible and class 3 means degraded so badly that
604   grains cannot be securely identified.

605

606

Table

Table 1. Lithostratigraphy of the sediment profile at SC24. Notation follows Troels-Smith (1955). Surface altitude is 24.36m OD.

Unit	Depth (cm)	Description
11	0 – 30	Crumbly, dessicated, disturbed surface peat with root penetration Sh2, Th^{1}2, nig. 2, strf.0, elas.0, sicc.3+
10	30 – 58	Dry amorphous silty peat with root penetration Sh3, Th^{1}1, Ag++, nig.3, strf.0, elas.0, sicc.3, lim.sup.0
9	58 - 60	Horizontal grey silty clay band As3, Ag1, nig.1, strf. 2, elas. 0, sicc. 3, lim. sup. 4
8	60 – 67	Dry brown amorphous silty peat with wood fragments Sh3, Ag1, Dl +, nig.3, strf.0, elas. 0, sicc.3, lim.sup.3
7	67 – 68	Horizontal grey silty clay band As3, Ag1, nig.1, strf. 2, elas. 0, sicc. 3, lim. sup. 4
6	68 – 72	Very dry brown amorphous silty peat with wood fragments Sh3, Ag1, Dl++, nig.3, elas.0, sicc.2+, lim.sup. 4
5	72 – 87	Brown, damp, silty amorphous peat with plant remains, wood fragments and occasional flint flakes Sh3, Dl1, Ag+, Dh+, Rudimenta culturae b2 nig.3, strf.0, elas.0, sicc.2+, lim.sup. 0
4	87 – 105	Amorphous silty peat with reeds Sh3, Th^2 (*Phra.*)1, Ag+, nig.3, strf.0, elas.0, sicc. 2+
3	105 – 108	Fine detritus mud Ld4, nig.3, strf.0, elas.0, sicc.2, lim. sup. 0
2	108 – 113	Dark brown sandy silty clay As2, Ga1, Ag1, Sh+, nig. 3, strf. 0, elas. 0, sicc. 2, lim. sup. 1
1	113 +	Medium coarse dark gravel with coarse sand Gg(maj)3, Gs1, nig. 3, strf. 0, elas. 0, sicc. 2, lim. sup. 3

Table 2. Definition of degradation types used in pollen analyses

_____

| Class of degradation	Damage definition	Deterioration definition
Type 1	Relatively pristine	Relatively pristine
Type 2	Folded exine	Removal of microsculpturing elements
Type 3	Torn and folded exine	Spheroid holes in the exine with removal of microsculpturing elements

_____

Figure
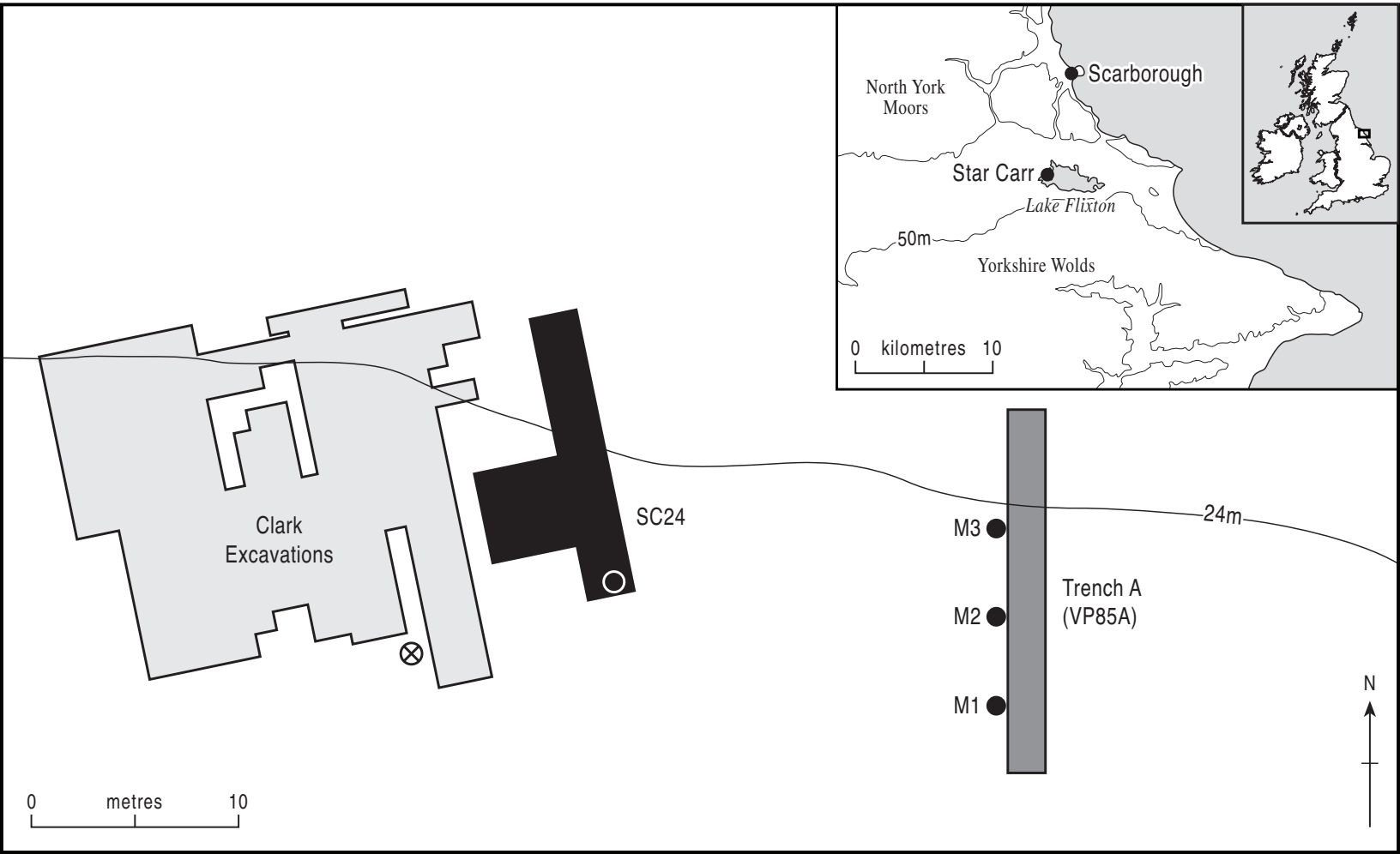
Figure

Star Carr SC24

Synanthropics indicated by larger circles, all percentages based on TLP
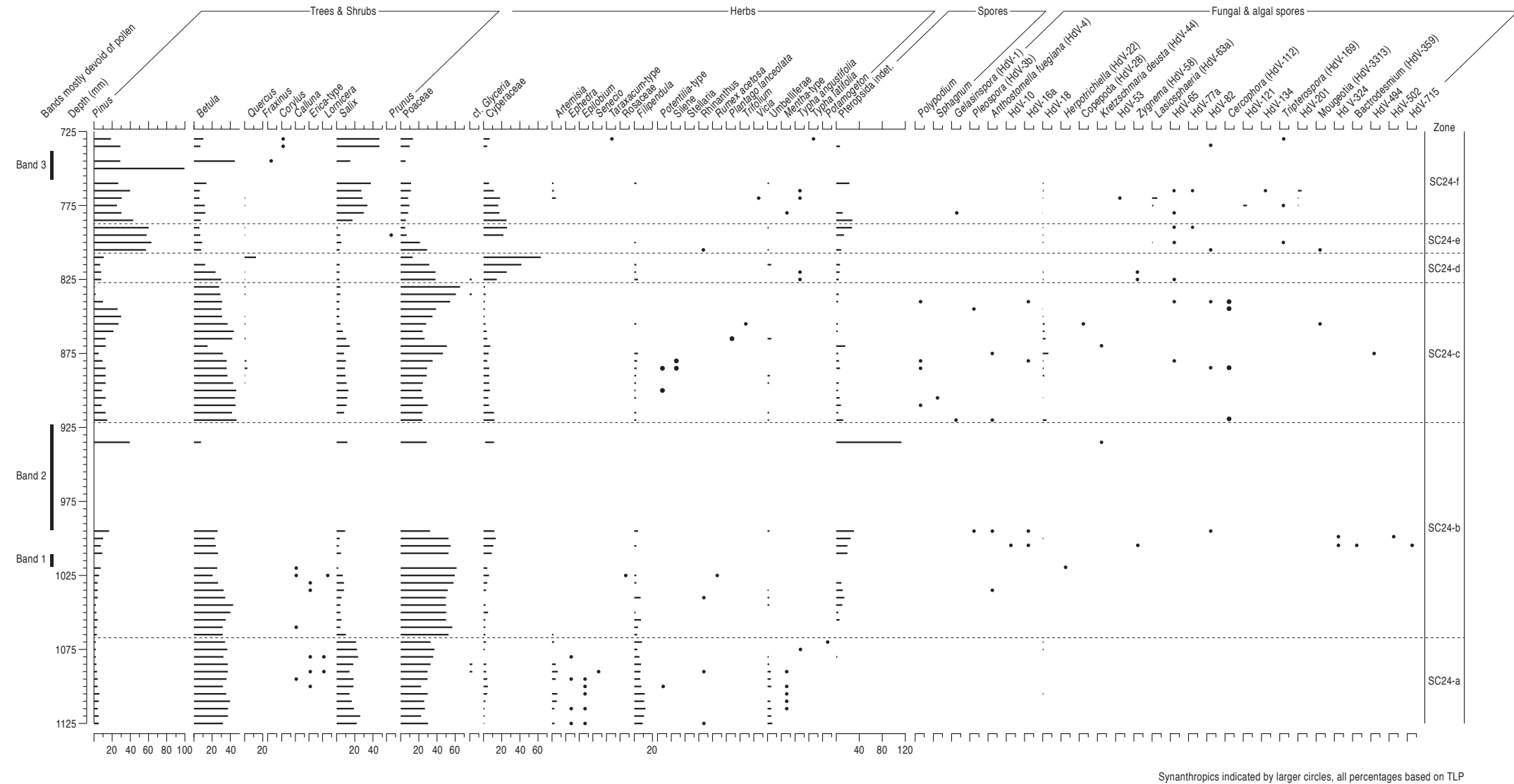
Figure

Star Carr SC24
relative pine pollen, pollen preservation and microcharcoal concentration

All percentages based on TLP