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1 Degradation of the wetland sediment archive at Star Carr: an
2 assessment of current palynological preservation.
3

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16 **Abstract**

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

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33 **Keywords:** Star Carr; Mesolithic; Preservation; Palynology; Site deterioration

34

35 **1. Introduction**

36 It is now six decades since the publication of Grahame Clark's monograph on excavations
37 at the early Mesolithic archaeological site of Star Carr in the eastern Vale of Pickering in
38 North-East England (Clark, 1954). It was the location of the Mesolithic settlement that first
39 drew Clark to the site, as it lay on the edge of an Early Holocene lake (Candy et al., 2015;
40 Palmer et al., 2015), now termed Lake Flixton, and so promised to provide the
41 palaeoenvironmental data that he needed for his research on Mesolithic economy and land
42 use. The iconic status enjoyed by Star Carr since Clark's work, therefore, is due not only to
43 the prolific flint assemblages (Conneller and Schadla-Hall, 2003; Conneller et al., 2009), but
44 also to the remarkable preservation and diversity of organic material associated with the site,
45 which extended into the wetland sediments (Milner et al., 2011a). The organic components of
46 Early Mesolithic material culture, which do not survive on dry sites, were found in abundance
47 and in an excellent state of preservation, stratified within the waterlogged organic deposits
48 that accumulated in the palaeolake margin and in the reedswamp, fen and carr wetland
49 habitats associated with it. This stratification has allowed the use of palaeobotanical analyses,
50 including both macrofossil (Dark, 2004; Taylor, 2011) and pollen (Walker and Godwin,
51 1954; Cloutman and Smith, 1988; Dark, 1998a,b,c; Cummins, 2000), to reconstruct the
52 vegetation history around the site, providing an environmental context for the settlement at
53 Star Carr (Innes et al., 2011; Milner et al., 2013). This combination of preserved organic
54 cultural remains and multi-disciplinary study has made Star Carr the 'type' site for the British
55 early Mesolithic, and a model for subsequent studies in wetland archaeology (Milner et al.,
56 2011a;). Not only could questions of site function, economy and seasonality of occupation be
57 addressed, but the deeper understanding of the activities carried out at Star Carr allowed the
58 site to be the hub of conceptual models of early Mesolithic land use, territoriality and
59 interactions with the wider landscape (Clark, 1972).

60

61 *1.1 Condition of the sediments*

62 The continued existence of the palaeoenvironmental archive at Star Carr, and the potential
63 for further multi-disciplinary analyses there, depends upon the quality of preservation of the
64 waterlogged sediments and organic remains. Excavations in the mid 1980s (Schadla-Hall,
65 1987; Schadla-Hall and Cloutman, 1985; Mellars and Dark, 1998), however, showed that
66 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.

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 C₄H₆O₃ (90%) solution with H₂SO₄
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

187 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).

232 The pollen grains of *Pinus* species are considered more resistant than others to
233 degradation (Sangster and Dale, 1961). The data in Figs.3 and 4 show higher levels of *Pinus*
234 associated with low total concentrations of pollen, and higher percentages (60%+) of
235 deteriorated grains, with *Pinus* levels sometimes in excess of 50% of TLP. Maximum values
236 of 20% *Pinus* were reported by Dark (1998c) which has increased to 60% in SC24-e,
237 suggesting that 50% of all other pollen has been lost, if *Pinus* pollen remains present in the
238 same frequencies. *Juniperus*, a thin-walled grain that was present in Dark's (1998c) lower
239 pollen zones, is entirely absent in SC24. In comparison to the original analyses of Dark
240 (1998c), where only isolated crumpled/folded and deteriorated grains were noted, the present
241 analyses produce a high encounter rate of moderately (Type 2) damaged and deteriorated
242 grains. Moderately deteriorated pollen grains (with missing micro-sculpturing elements) are
243 also common, averaging 20% of the sub-sample analysed, in basal levels below 1030 mm
244 where degradation of pollen grains has been overall less severe.

245 In addition to the high levels of damage and deterioration (60%+) noted in those levels
246 containing what appear to be inflated concentrations of *Pinus*, three distinct horizons lack
247 countable levels of pollen, suggesting higher rates of degradation across all taxa. These
248 horizons (bands 1-3 in Figs.3 and 4) are at 1015, 925-990 and 740-755 mm. Preservation was
249 also very poor at 810 mm, although a low count was possible. Further evidence for
250 degradation may be inferred from the unidentified fern spores (Pteropsida indet. cf. Filicales),
251 which are considered resistant to oxidation and can be common in soil pollen analyses
252 (Havinga, 1964; Tipping, 2000). The highest values (20-40% of TLP+taxon) are expressed at
253 the boundaries of bands of very low concentration, where levels of severely degraded
254 (Category 3) grains also increase. Dark (1998c) also recorded high values of Pteropsida,
255 although these were in the upper levels of Trench A, M1 (top 400 mm of the profile), from a
256 period classed here as non-polliniferous. In zones where Dark found abundant Pteropsida
257 spores, this study shows uncountably low pollen frequencies, and in levels where Dark
258 (1998c) found low background levels of generic ferns spores (<2%) with occasional peaks,
259 our samples recovered twenty years later contain 5-20%, as with the *Pinus* data suggesting
260 loss of other taxa.

261

262 **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 be 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.

360

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365

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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.

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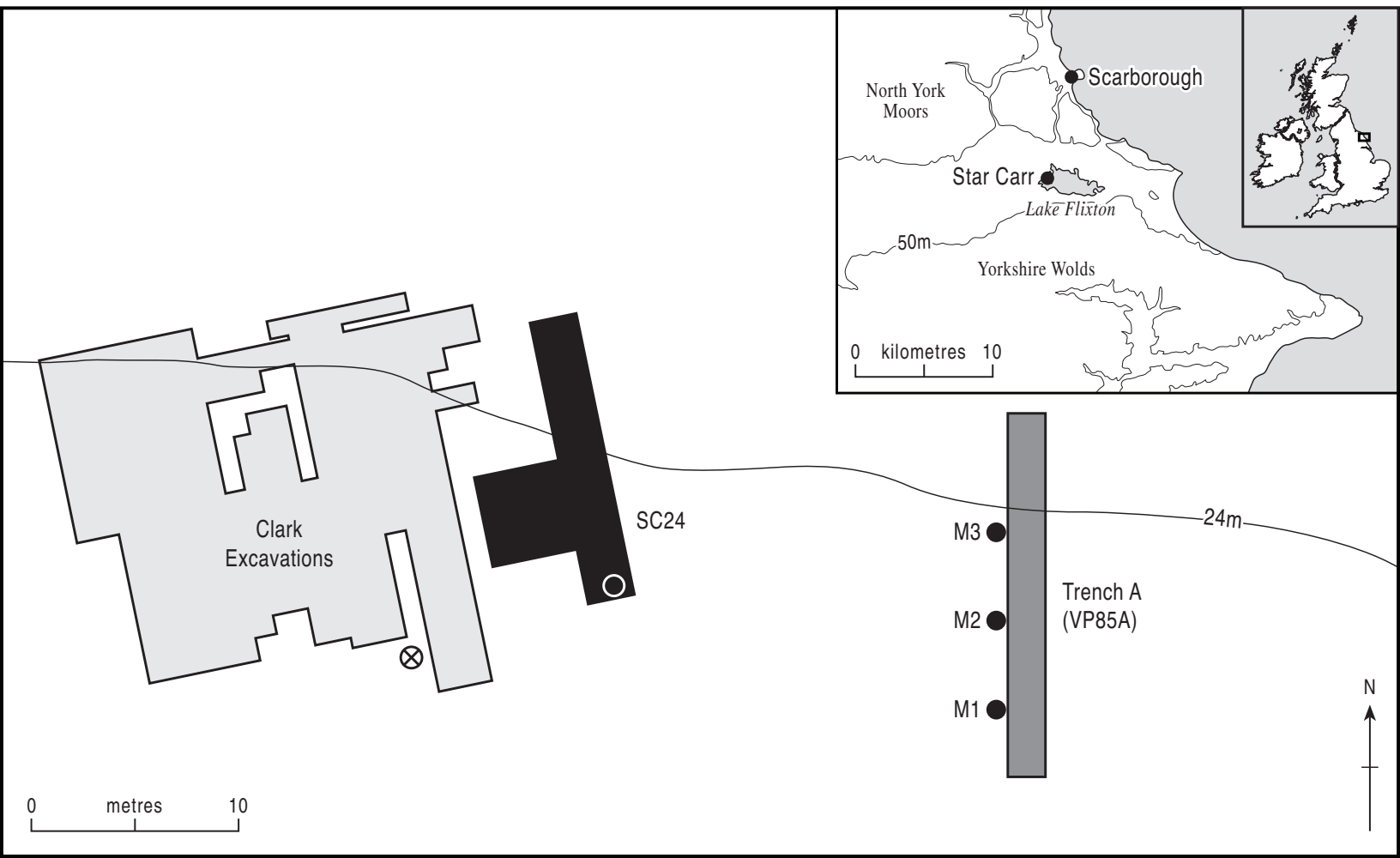
Table 1. Lithostratigraphy of the sediment profile at SC24. Notation follows Troels-Smith (1955). Surface altitude is 24.36m OD.

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 (<i>Phra.</i>)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



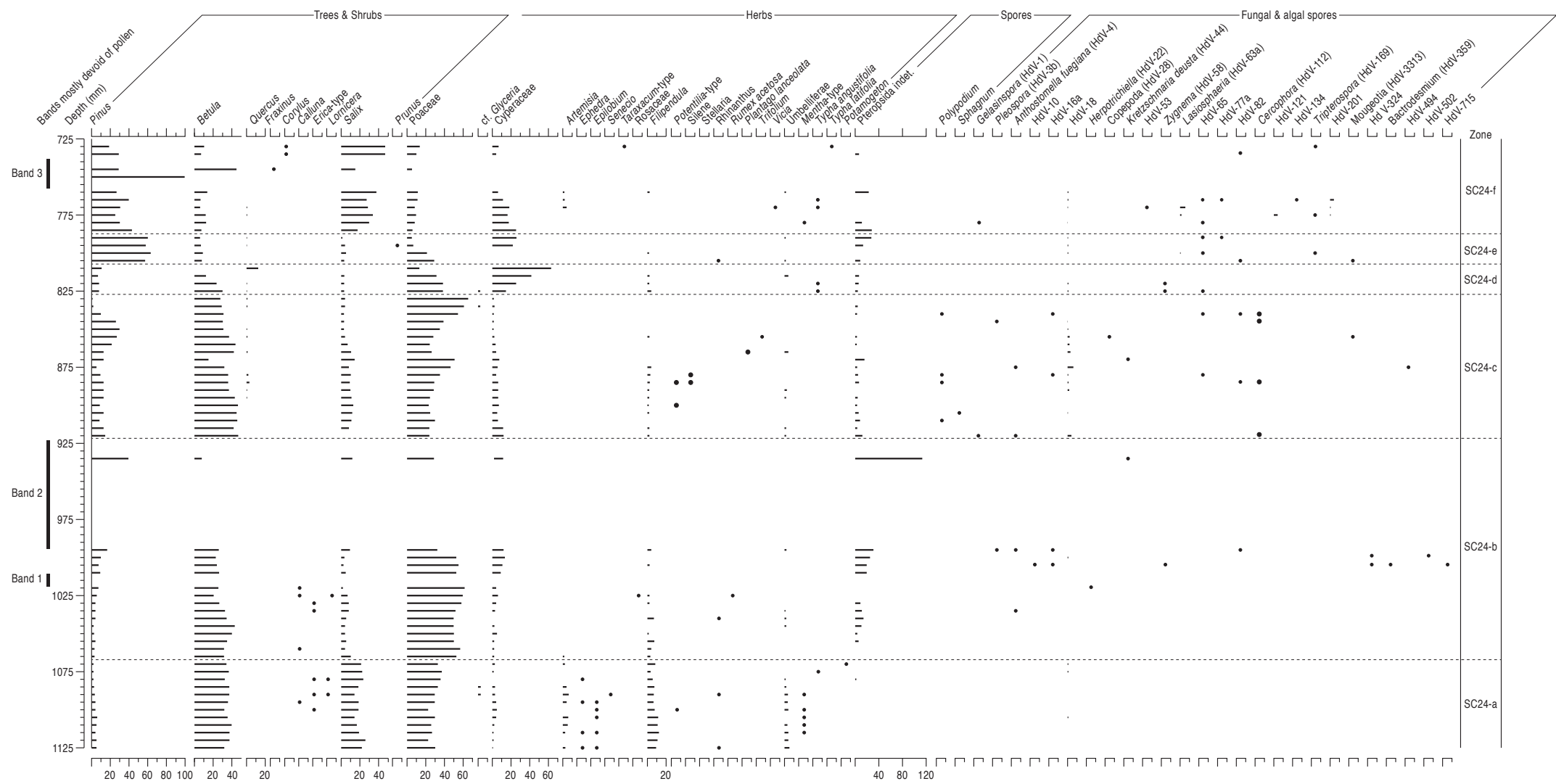
Figure

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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

