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Moving forwards? Palynology and the human dimension

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ABSTRACT

For the greater part of the last century, anthropogenic palynology has made a sustained contribution to archaeology and to Quaternary science in general, and pollen-analytical papers have appeared in *Journal of Archaeological Science* since its inception. The present paper focuses selectively upon three areas of anthropogenic palynology, enabling some assessment as to whether the field is advancing: land-use studies, archaeological site study, and modelling. The Discussion also highlights related areas including palynomorph identification and associated proxies. There is little doubt that anthropogenic palynology has contributed to the vitality of pollen analysis in general, and although published research can be replicative or incremental, site- and landscape-based studies offer fresh data for further analysis and modelling. The latter allows the testing of both palynological concepts and inferences and can inform archaeological discovery and imagination. Archaeological site

34 studies are often difficult, but palynology can still offer much to the understanding of
35 occupation sites and the discernment of human behaviour patterns within sites.

36

37 *Keywords:* palynology; land-use history; on-site studies; modelling

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41 **1. Introduction**

42

43 Since the employment of pollen analysis in human contexts over half a century ago (Firbas,
44 1937; Iversen, 1941; Fægri, 1944; Godwin, 1944), anthropogenic palynology has made a
45 sustained contribution to archaeology, archaeological science and the wider realms of
46 palaeoecology and Quaternary science (Behre, 1986; Birks et al., 1988; Edwards and
47 MacDonald, 1991; Bell and Walker, 2004; Roberts, 2014). From its first volume, pollen
48 analysis has featured in the pages of *Journal of Archaeological Science* (Dimbleby and Evans
49 1974; Greig and Turner 1974) – perhaps not a total surprise given that soils palynologist
50 Geoffrey Dimbleby was a first editor – and this has continued. The number of papers
51 containing a sole or substantial pollen content remained relatively constant over the first 20
52 years of the journal’s life and has increased since then (Fig. 1a-b); however, allowance must
53 be made for the increase in the number of all archaeological science articles published over
54 time (Fig. 1c), which itself reflects the health of the field in general. Caveats clearly apply to
55 the use of such data and the mode of extraction (see the caption to Fig. 1), but palynology
56 obviously represents a recognisable component in the journal’s profile and, indeed, following
57 Dimbleby, two of the outlet’s editors (Kevin Edwards 1983-92, and Chris Hunt 2011-14)
58 have also been palynologists as have other members of the editorial board.

59

60 This is not the place to produce an in-depth analysis of the metrics associated with
61 palynological papers within the *Journal of Archaeological Science*. As intimated, palynology
62 is a mainstay of palaeoecology and Quaternary science, and journals covering these fields
63 contain impressive numbers of palynological papers in their own right (Table 1). While many
64 of these articles are concerned with anthropogenic topics, or are of relevance to human
65 activity, that cannot be said to apply to the majority of them. In addition, there are journals
66 for which palynology is a strength or even dominant, most notably *Review of Palaeobotany*
67 *and Palynology*, *Grana* and *Vegetation History and Archaeobotany*.

68

69 We focus selectively upon three areas of anthropogenic palynology which enable us to assess
70 whether the field is advancing. This paper does not claim to be comprehensive and there are
71 areas which are not covered here at all, even if they could have relevance to the practice of
72 humanly-related palynology (e.g. automated pollen counting [Holt and Bennett, 2014],
73 genetics [Parducci et al., 2013], many related proxies [O'Brien et al., 2005; Meadows, 2014],
74 and, of course, dating issues [Whittle et al., 2011]). Similarly, we barely address the issue of
75 microscopic charcoal and fire which have a long and continuing history in palynology (cf.
76 Swain, 1973; Patterson et al., 1987; Bradshaw and Sykes, 2014; Sadori et al., 2015). It does,
77 however, cover key areas which could contribute to priority research questions identified for
78 palaeoecology (Seddon et al., 2014).

79

80 **2. Can traditional land-use employments of palynology still inform and surprise us?**

81

82 The investigation of the past relationship between vegetation and people has classically
83 involved the study of pollen and associated proxies (e.g. fungal spores, microscopic charcoal)
84 preserved within stratified, waterlogged deposits such as lake mud and peat (Fægri et al.,
85 1989). The spatial scale of the vegetation reconstructions possible through this method are
86 highly dependent upon the size of the pollen site under investigation; put very simply, small
87 diameter sites such as woodland hollows will provide information about fine-scale vegetation
88 patterns immediately around the sampling location, whilst large lakes record the regional
89 picture (cf. Jacobson and Bradshaw 1981; Prentice 1985; Sugita 1994; Bradshaw 2007). The
90 conventional methodological approach has been to make inferences based upon the analysis
91 of a single core that is deemed by the investigator to be representative of changes occurring
92 throughout the landscape in question. Research into multiple pollen profiles spread across the
93 same site (e.g. Edwards, 1983; Waller, 1998), or combining data across a network of
94 locations (e.g. Tipping, 2010; Ledger et al., 2014), whilst time consuming, can offer more
95 precise details about the spatial patterning in vegetation and the impact of prehistoric society
96 on land cover (e.g. Lechterbeck et al., 2014; Woodbridge et al., 2014).

97

98 Advances in the modelling and simulation of vegetation using practical tools that incorporate
99 knowledge about pollen production, transport and deposition (e.g. Sugita, 2007a, 2007b;
100 Gaillard et al., 2008), plus the widening availability of an expanding number of large pollen
101 datasets though on-line databases such as the European Pollen Database

102 (<http://www.europeanpollendatabase.net/>; Fyfe et al., 2009) and Neotoma
103 (<http://www.neotomadb.org/>), mean that the discipline may grow to rely less upon the
104 ‘traditional’ field- and laboratory-based empirical studies described above for all its answers
105 (see section 4 below). Nevertheless, conventional pollen analytical investigations still
106 continue to play a key role within the discipline, not least in the empirical testing of models
107 and simulations, the filling of gaps in the spatial and temporal coverage of vegetation
108 histories, refining existing patterns, and challenging ideas and knowledge. This can be
109 exemplified through a brief examination of selected aspects of recent pollen-analytical
110 research from some of the North Atlantic islands colonised by Norse/Viking settlers during
111 the late first millennium AD (Fig. 2).

112

113 In the Faroe Islands, pollen-analytical studies have played a crucial role in the re-examination
114 of the timing of first human settlement. On the basis of saga literature and the archaeological
115 record, the initial settlement (*‘landnám’*) of this island group has normally been ascribed to
116 the arrival of Norse settlers sometime during the early 9th century AD; this being despite
117 evidence to the contrary appearing in another contemporary literary source – *De Mensura*
118 *Orbis Terrae*, written around AD 825 – in which the Irish monk, Dicuil, stated that anchorites
119 had reached lands fitting the description of the Faroe Islands in advance of the ‘northmen
120 pirates’ (Tierney, 1967; Dugmore et al., 2005). Jóhansen (1971) was the first to present
121 palynological evidence for a possible pre-Viking presence, though the timing (given as ~AD
122 600-700) surrounding his discovery of *Avena* (cf. oats) pollen in a profile from ‘ancient
123 Celtic fields’ disturbed by burrowing puffins on Mykines (Jóhansen, 1979) was later brought
124 into question (e.g. Buckland et al., 1998). Yet the early cultivation of cereals was also
125 subsequently indicated at Eiði on the island of Eysturoy (Hannon et al., 2005) and especially
126 at Hovsdalar, Suðeroy, where optimising methods for the detection of cereal-type pollen
127 grains revealed a pollen curve for *Hordeum*-type (barley) extending back to ~AD 560
128 (Edwards et al., 2005a, 2005b). Most recently, the discovery of carbonised barley grains
129 appearing in peat ash of anthropogenic origin at Á Sondum on the island of Sandoy, and
130 radiocarbon-dated to the 4-6th centuries AD (Church et al., 2013; Fig. 3), delivers strong
131 archaeological evidence for an early human presence that offers justification for the
132 interpretation arising from the pollen-analytical evidence. This ‘process’ finds echoes in
133 palynological inferences surrounding the determination of a hunter-gatherer occupation of
134 certain areas within the Northern and Western Isles of Scotland, which, for a long time, had
135 no proven cultural reality (Gregory et al., 2005; Edwards, 2009).

136

137 In Iceland – where Norse settlement is dated to around AD 870 – an important landscape-
138 scale question that palynologists have been addressing is the spatial extent of tree birch
139 (*Betula pubescens*) woodland at the time of colonisation and how this became diminished
140 following the arrival of people. Common perception of past woodland coverage in Iceland
141 has been heavily influenced by a comment made by Ari the Wise in the 12th century
142 *Íslendingabok* (Book of the Icelanders) which stated that woodland at the time of *landnám*
143 stretched from the mountains to the seashore (Benediktsson, 1968). This is seemingly borne
144 out by some of the earlier studies (e.g. Einarsson, 1963; Hallsdóttir, 1987) in which pollen
145 diagrams typically demonstrate sharp declines in birch woodland during the 10th century
146 which have been directly linked to clearance. Not unexpectedly perhaps, this seems to be an
147 over-simplification of the picture, and as the number of pollen-analysed sites has expanded, it
148 has become clear that many exposed high altitude and coastal locations have always been
149 very open in character (Erlendsson et al., 2009). Furthermore, whilst human impact at
150 *landnám* did undoubtedly lead to an overall decline in woodland, the rates and patterns of
151 reduction are more variable than was first envisaged. For example, pollen data produced by
152 Lawson et al. (2007) for the inland district of Mývatnssveit shows a steady regional decline in
153 *Betula* pollen over a period of ~400 years following settlement, demonstrating a slow
154 drawdown on the woodland resource, possibly involving active management, rather than the
155 rapid destruction of otherwise valuable birch woodland (Fig. 4). This led the authors to
156 speculate that substantial patches of birch may have survived in many areas long after
157 *landnám*, but are simply not being widely detected because the pattern of sampling has
158 predominantly focused around the farms where human impacts would presumably have been
159 most intense.

160

161 The Norse diaspora led not only to the dispersal of people across the North Atlantic but also
162 the deliberate and accidental movement of flora and fauna (cf. Sadler and Skidmore, 1995).
163 Pollen analysis provides a powerful tool for tracing the introduction and spread of non-native
164 plants, and has been used in Greenland to advance the debate regarding what constitutes the
165 ‘Old Norse’ (anthropochorous) element within the modern flora. One of the most striking
166 features noted by Fredskild (1973, 1988) in his pollen diagrams from Qassiarsuk, south
167 Greenland, is the appearance and expansion of *Rumex acetosella* (sheep’s sorrel) after
168 *landnám* (AD 985), leading him to conclude that the species was introduced by the Norse
169 settlers. More recently, palynological studies representing a network of sites around Norse

170 farms located in the former Eastern Settlement of Greenland have allowed the production of a
171 series of maps at regular (100 year) intervals that trace the dispersal of the plant through the
172 wider landscape and confirm its status as a key biostratigraphic marker for settlement
173 (Schofield et al., 2013). The synthesised data do, however, reveal some subtleties. At certain
174 locations (e.g. Sissarluttoq; Fig. 5) the rise in *R. acetosella* pollen following *landnám* is
175 delayed, while in another instance the pollen from the plant is absent. This might indicate that
176 the plant was introduced – presumably from Iceland – at only selected locations from which
177 it subsequently spread rapidly to most of the other farmsteads. The variable abundances of *R.*
178 *acetosella* pollen depicted at sites on the maps also stimulate debate about what effect any
179 differences in the size, function or role of farms might have had on creating suitable habitats
180 for the plant to flourish.

181

182 The impact of Norse colonists across each of the North Atlantic island environments can be
183 recognised through a widely repeatable palynological ‘footprint’ for human settlement in
184 pollen diagrams (Edwards et al., 2011a). A defining aspect of this signature (Fig. 5) is an
185 increase in dung (coprophilous) fungal spores reflecting the introduction of domesticated
186 grazing animals (primarily sheep, cows and goats) to landscapes as part of the settlement
187 process (cf. Schofield and Edwards, 2011). Since the last major review of Quaternary pollen
188 analysis (Seppä and Bennett, 2003), significant progress has been made with the
189 identification, taphonomy, indicative value and quantification of such non-pollen
190 palynomorphs (NPPs) as part of the wider palynological method, and this has now become an
191 important aspect of investigations into land-use history. In particular, the analysis of fungal
192 spores which are typically present in sample residues alongside pollen, but were for long
193 ignored by palynologists (especially *Sporormiella*-type, *Sordaria*-type and *Podospora*-type),
194 can be demonstrated as a powerful proxy for tracing the past impacts of herbivory (e.g. van
195 Geel et al., 2003; Blackford and Innes, 2006; Cugny et al., 2010; Feeser and O’Connell,
196 2010; Schofield and Edwards, 2011; Baker et al., 2013). New advances in the extraction and
197 amplification of ancient DNA (aDNA) from sedimentary sequences are likely to proliferate
198 into archaeological science to aid identification of grazing animals (e.g. Giguet-Covex et al.,
199 2014). Applying aDNA to existing sequences with clear pollen and NPP indicators for human
200 management may result in great advances in understanding how people and animals shaped
201 their landscapes.

202

203 Human-environment interaction in the Anthropocene has been identified as one of six key
204 themes linked to priority research questions in palaeoecology (Seddon et al. 2014). The case
205 studies presented from the North Atlantic arena demonstrate that traditional studies of land-
206 use history through pollen analysis can continue to play a central role in advancing our
207 understanding of when human activities ‘began altering ecosystems at globally relevant
208 scales and how ecosystems responded in these human-mediated landscapes’ (ibid. p. 259).

209

210 **3. Palynology of archaeological sites**

211

212 Archaeological sites present many problems, but also opportunities, for the understanding of
213 past human environments and activities. In northern latitudes at least, soil palynology
214 represents the most frequently adopted approach to the pollen-analytical investigation of
215 archaeological sites. There is an extensive body of published research in the area and it would
216 be invidious not to note Dimbleby’s long and substantial contribution (summarized in
217 Dimbleby, 1985) that had its beginnings in soil pollen methodology (Dimbleby, 1957, 1961a,
218 1961b) and an appreciation of landscape-scale human modification (Dimbleby, 1962). This
219 work has laid a foundation for much subsequent research in a variety of archaeological
220 contexts (e.g. Bakker and Groenman-van Waateringe, 1988; Segerström, 1991; Kelso, 1994;
221 Tipping, 1994; Edwards and Whittington, 1998; Whittington and Edwards, 1999; Groenman-
222 van Waateringe, 2011).

223

224 The terrestrial deposits which characterise many archaeological sites are reflective of
225 taphonomic pathways which are far from the relatively well known systems typical of lakes
226 and mires (Tweddle and Edwards, 2010). By their very nature, archaeological sediments are
227 liable to have been disturbed and are typically heterogeneous, combining a mixture of
228 materials from different sources (Greig, 1981). This applies, for example, in the case of
229 artificially accreting soils (plaggens or anthrosols), whose pollen content may be derived
230 from the *in situ* vegetation (crops and weeds rooted in the soil itself), additions of waste
231 (turves, peat, straw, animal dung, etc.) to fields from house or byre, plus the pollen rain from
232 the surrounding vegetation communities and the background airborne component
233 (Groenman-van Waateringe, 1992; Buckland et al., 2009; Donaldson et al., 2009; Ledger et
234 al., 2015; Fig. 6). The environmental conditions under which pollen is preserved on
235 archaeological sites may, in many cases, also be sub-optimal (i.e. drier and less acidic) when
236 compared with the natural depositional contexts favoured for ‘conventional’ studies (section

237 2). As a consequence, palynologists working on archaeological sites must contend with
238 pollen depositional biases, and often low total pollen concentrations and poor pollen
239 preservation (Bottema, 1975; Hall, 1981; Hunt, 1994; Weinstein-Evron, 1994; Lebreton et
240 al., 2010), although much methodological work has focused upon understanding these issues
241 (e.g. Sangster and Dale, 1961, 1964; Havinga, 1967; Davidson et al., 1999; Bunting and
242 Tipping 2000; Tipping 2000).

243

244 Important taphonomic work has explored the representativeness and reliability of
245 palynomorph assemblages from caves (Weinstein, 1981; Weinstein-Evron, 1994; Coles et al.,
246 1989; Diot, 1991; Genty et al., 2001; Simpson and Hunt, 2009; Fig. 7) and fluvial sites
247 (Brush and Brush, 1972; Fall, 1987; Hunt, 1994). Cave deposits show consistent taphonomic
248 biases where an entrance flora is present (Coles and Gilbertson, 1994) and where animal
249 vectors are prolific (Hunt and Rushworth, 2005), but otherwise, pollen floras in caves reflect
250 closely the pollen rain within a few kilometres of the sampling site. In some parts of the
251 world, including central France, southeastern Spain, peninsular Italy and Libya, a substantial
252 proportion of our understanding of Middle and Late Quaternary vegetation and associated
253 environments, comes from caves. Such geographical areas cannot always furnish suitable
254 long lake and peat bog records and this is an example of how archaeological sites can be
255 useful in plugging significant palynological gaps.

256

257 Processes such as suffusion, recycling and bioturbation can relocate material through
258 archaeological deposits and soils, and these processes are a consistent cause for concern for
259 archaeopalynologists. This problem can sometimes be addressed by careful examination of
260 the condition of pollen grains preserved in the sediment. Intrusive or recycled pollen will
261 often be preserved in a visibly different condition to *in situ* organic-walled microfossils.
262 Ultraviolet fluorescence microscopy offers an underused method to assess the stratigraphic
263 integrity of pollen assemblages where mixing is suspected (Hunt, 1998; Yeloff and Hunt,
264 2005). With the advent of digital image analysis, this technique can be applied systematically
265 with little operator error (Hunt et al., 2007a). Pollen fluoresces in the visible wavelengths
266 under UV illumination. As pollen ‘ages’ taphonomically, the intensity of fluorescence
267 diminishes and colour progresses from blue, through yellow, to orange, red and finally
268 brown. Recycled material appears less bright and further towards the red end of the spectrum
269 than *in situ* material, whereas intrusive (modern) grains show as blue, and thermally mature
270 (burnt) material as intense light blue (*ibid.*) (Fig. 8).

271

272 It should be stressed that palynology is significantly more than basic pollen and spore
273 analysis. Organic particulates are generated by many natural processes and human activities.
274 Many of these particulates preserve well and are amenable to analysis using the palynofacies
275 technique (Hunt and Coles, 1988). Thus the feeding of crop residues to sheep or goats in a
276 Libyan farmstead led to characteristic palynofacies and pollen assemblages (Hunt et al.,
277 2001) and humanly-set fires within the Great Cave of Niah in Sarawak, Malaysian Borneo,
278 resulted in characteristic thermally-mature amorphous matter, caused by the heating of cave
279 sediments (Hunt et al., 2007b). In Ludden Dene, Halifax, UK, very distinctive coppicing, fire
280 and regeneration cycles are visible in pollen and palynofacies signatures from charcoal-
281 burning hearths (Ibbetson, 2011).

282

283 From earlier beginnings (Turner, 1965; Göransson, 1986; Edwards, 1993), there continues to
284 be a productive development of insights and methods (Mercuri, 2008; Waller et al., 2012;
285 Woodbridge et al., 2014) within the palynology of archaeological sites. Yet in a world where
286 traditional activities and land-use patterns are vanishing before the onslaught of globalisation,
287 there is still an urgent need to study ethnopalynological patterns caused by a wide range of
288 actions before these disappear forever. These include aspects of landscape management, and
289 agricultural, industrial and domestic practices.

290

291 **4. Modelling vegetation cover from pollen data**

292

293 Quantification of vegetation cover from pollen-analytical data has been a long-desired goal of
294 all groups who use such data. The use of pollen to address archaeological questions such as
295 the contextual environmental conditions for a particular site or type of site (e.g. Brown et al.,
296 2011), or the scale of woodland clearance during European prehistory (e.g. Fyfe et al., 2014),
297 requires the ability to transform pollen data into a meaningful quantity beyond the relative
298 abundance of different pollen taxa. This is hampered by several factors, notably the
299 differential production of pollen by different plant species and the varying spatial scale of
300 representation of pollen sequences. In essence, the relationship between pollen proportions
301 and the abundance of the source plants in the vicinity of a particular site is not linear (Sugita
302 et al., 1999).

303

304 Approaches to the transformation of pollen to vegetation abundance began in the 1960s
305 (Davis, 1963) and were developed over subsequent decades (Andersen, 1970; Prentice and
306 Parsons, 1983; Prentice, 1985). A resurgence of interest in such approaches was triggered in
307 the early 2000s with the development of the Pollen-Landscape Calibration (POLLANDCAL)
308 network (Gaillard et al., 2008). Significant advances have been made in the transformation of
309 pollen proportions to estimated plant abundance, resulting in the development of a
310 'Landscape Reconstruction Algorithm' (LRA), as described by Sugita (2007a, 2007b). A
311 major advantage of the LRA is that the spatial scale of representation is formally recognised,
312 and indeed is included within the output of the approach, in what is described as the 'relevant
313 source area of pollen' (RSAP). This is best thought of as the distance at which background
314 pollen loading (the regional pollen rain) is constant between sites in a region, and is formally
315 defined in modern pollen-vegetation studies as the distance beyond which the correlation of
316 pollen to vegetation abundance does not change or improve (Sugita, 2007b).

317

318 The modelling approach has been described and discussed at length elsewhere (e.g. Sugita
319 2007a, 2007b; Gaillard et al., 2008; Sugita et al., 2010; Nielsen and Odgaard, 2010; Fyfe et
320 al., 2013; Marquer et al., 2014), but it marks perhaps one of the most significant advances in
321 the analysis of pollen data in recent decades. The LRA comprises two components (Fig. 9).
322 The REVEALS model estimates taxon abundance within the broad region (50-100 km radius
323 around a site) using pollen count data from sites that are taken to be representative of the
324 regional pollen rain (e.g. large lakes). This regional taxon abundance is then used as one input
325 parameter for the LOVE model, which subtracts the background component to estimate
326 vegetation abundance within the source area of target (smaller) sites that are more
327 representative of local plant communities. The LRA requires not only pollen count data from
328 sites that are regional and local in character, but also estimates of the relative pollen
329 productivity (RPP) of the taxa being quantified (Broström et al., 2008), and figures for the
330 fall speeds of the different pollen types involved. The approach has, to date, been evaluated
331 using modern pollen-vegetation comparisons in both northern Europe and North America
332 (e.g. Hellman et al., 2008; Sugita et al., 2010) and much recent work has been focused on
333 specific assumptions inherent within the models. The global application of this model-based
334 approach is limited by the availability of PPEs (pollen productivity estimates) from regions of
335 interest, and much work is currently in progress or being initiated to develop these parameters
336 from areas beyond northwest Europe and North America, such as southern Africa (Duffin and
337 Bunting, 2008), China (Xu et al., 2014) and Greenland (Bunting et al., 2013).

338

339 The output of the LRA is thus an estimate of plant abundances within a broad region, and
340 within a given radius of the target pollen site. Preliminary results of the application of the
341 LRA to pollen data from Exmoor, southwest Britain, provide insights into spatial patterning
342 of upland vegetation (Fig. 10). It is possible to distinguish *Calluna*-, Poaceae- and
343 Cyperaceae-dominated moorland communities and to estimate how much woodland persisted
344 into the medieval period. Results from the REVEALS model have been interpreted to suggest
345 that landscapes were more open in the past than had previously been assumed from pollen
346 proportions alone (Soepboer et al., 2010; Nielsen et al., 2012; Fyfe et al., 2013; Marquer et
347 al., 2014; but see Davis et al., 2015). Application of the full LRA to landscape research is still
348 in its infancy, with few published studies (Nielsen and Odgaard, 2010; Fredh et al., 2012; Cui
349 et al., 2013; Hultberg et al., 2015), none of which specifically target archaeological questions
350 *per se*, and the arrangement of plants *within* the RSAP of a target site (i.e. maps of vegetation
351 cover) cannot yet be determined. One difficulty that still needs to be overcome is that
352 different vegetation patterns may result in the same pollen loading at a particular place in the
353 landscape, leading to problems of equifinality (Caseldine et al., 2008; Bunting and
354 Middleton, 2009).

355

356 An alternative, complementary, approach to the LRA has been to tackle the problem in
357 reverse, by starting with hypothetical vegetation arrangements in a landscape (managed
358 within a GIS) and calculating pollen loadings at selected points or locations (Figs. 9, 11).
359 These simulated pollen loadings can then be compared to empirical pollen count data in order
360 to assess the plausibility of hypothetical vegetation arrangements (e.g. Caseldine and Fyfe,
361 2006; Fyfe, 2006; Stedingk and Fyfe, 2009). This has been formally described as the Multiple
362 Scenario Approach (MSA: Bunting and Middleton, 2009). Through this method, 'swarms' of
363 vegetation arrangements can now be modelled and compared to empirical data, to assess the
364 'best fit' through a data/model comparison. The MSA still requires PPEs, estimates of the fall
365 speed of pollen and modelling of a sufficiently large landscape so that the background pollen
366 component is included, but it does offer palynologists a means of testing, rejecting and/or
367 validating different landscape scenarios (Tipping et al., 2009).

368

369 Both the spatial and temporal scale of pollen data is of critical importance in accurately
370 modelling past vegetation. As described above, the LRA first models regional vegetation
371 (using REVEALS) within a radius of 50-100 km around the pollen site, and then moves on to

372 consider the 'local' vegetation (using LOVE). The spatial scale of 'local' vegetation is
373 dependent on a range of factors, including the size of the sampling site, and the physical
374 arrangement of plants in the landscape (Bunting et al., 2004). It is important that the scales
375 chosen for vegetation reconstruction match the hypothesised impact of people in the
376 landscape: for instance, small-scale ephemeral woodland clearance is unlikely to be
377 distinguished in a regional analysis. The temporal scale of vegetation disturbance is also
378 important. Much recent work around the impact of early Neolithic peoples (e.g. Whittle et al.,
379 2011; Whitehouse et al., 2014) has emphasised the short biographies of monument
380 complexes. Unless pollen sequences are sufficiently temporally resolved (through high-
381 resolution pollen analysis; cf. Turner and Peglar, 1988; Innes et al., 2004; Edwards et al.,
382 2008) and precisely dated, modelling work is unlikely to be helpful in detailing the impact of
383 short-lived 'events' in the archaeological record. The LRA also necessitates a shift in the
384 sampling framework for landscape reconstruction. It is insufficient to have a narrow focus on
385 a small number of pollen sites which have local pollen source areas, as modelling of the
386 wider regional vegetation is also essential. Sugita et al. (2010) have demonstrated that groups
387 of small sites can be used to derive a regional average for vegetation cover, but few regions
388 across Europe, or indeed beyond, possess dense networks of sites which are either
389 sufficiently well resolved or with appropriately detailed chronologies to allow such an
390 approach to be successful at this time.

391

392 Where does this currently leave us, with respect to using a pollen modelling approach to
393 advance archaeological knowledge? Caseldine et al. (2008) and Fyfe et al. (2010) considered
394 the role of such research in integrated projects and the usefulness of the output. They were at
395 pains to stress that the output is a virtual reconstruction of the past that can be considered
396 plausible, whether derived from pollen data (e.g. the LRA) or tested against it (the MSA).
397 Whilst the term 'landscape' has been used here, the output of either the MSA or the LRA is
398 not a landscape reconstruction, but might be better described as a pseudo-landscape, a partial
399 and credible representation of a fraction of the lived experience of communities who had a
400 mutual relationship with the plants around them. Within the constraints of model robustness
401 and data availability, the modelling approach allows us to reject, if necessary, fundamental
402 ideas about the structure of prehistoric or historical landscapes; the recognition of the extent
403 of openness across northwest Europe through application of the REVEALS model is an
404 excellent example of this which should lead to reconsiderations of the structure of Mesolithic
405 environments and interactions (Nielsen et al., 2012; Fyfe et al., 2013; Marquer et al., 2014).

406 Visualisation of plausible pseudo-landscapes, particularly of contrasting vegetation
407 arrangements that might produce a similar pollen loading at a single site (e.g. Winterbottom
408 and Long, 2006), may play an important part in the 'thinking through', or (re-)interpretation of
409 archaeological site data, and thus become part of a new interpretive toolset.

410

411 **5. Discussion**

412

413 There is no doubting that anthropogenic palynology has contributed great vitality to the
414 science of pollen analysis. Although published research can be replicative or incremental, it
415 remains the case that site- and landscape-based studies continually offer fresh data for further
416 analysis and modelling.

417

418 The future of palynological analysis on archaeological sites is promising, albeit a difficult and
419 frequently frustrating exercise. Palynology can offer much to the understanding of occupation
420 sites, both in terms of the wider vegetational and environmental contexts and in discerning
421 patterns of human behaviour within sites. As stated earlier, scale is of key importance in any
422 modelling work that attempts to address human-environment relationships. If archaeological
423 site palynology is going to share in this aspect of the field (and sharing is not necessarily
424 mandatory for advancement of the sub-discipline), then the up- and down-scaling of models
425 may represent a fertile area of development (cf. Mercuri et al. 2015, p. 4). On- and off-site
426 palynology will undoubtedly continue to play a major role within integrated multi-proxy
427 analyses, and the advances that can be gained from the application of a suite of
428 complementary methods that already include NPPs, traditional archaeobotany and
429 micromorphology, are likely to expand out to include innovative new approaches such as
430 biomarkers (Linseele et al., 2013), sedimentary geochemistry (e.g. D'Anjou et al., 2012) and
431 aDNA (Giguët-Covex et al., 2014).

432

433 The analysis of NPPs has now become routine within many palynological studies and further
434 advances should be anticipated. Baker et al. (2013) note that certain coprophilous fungal
435 spores (notably *Sporormiella*-type) can now be regarded as clear bioindicators for the
436 presence of grazing animals within the landscape, but some doubt remains about other
437 'coprophilous' types which are often interpreted in the same manner. An empirical link
438 between the numbers of coprophilous fungal spores preserved in peats and lake muds, and
439 livestock numbers/densities, still needs to be established (Raper and Bush, 2009), while

440 further testing is required to confirm the extent to which different NPPs can be linked
441 specifically to the dung of certain animals or groups of herbivores (e.g. Richardson, 2001).

442

443 Although there is exhaustive high-quality monographic documentation of economically-
444 useful plants in some tropical regions (for instance Herrera and Urrego, 1996), global
445 coverage is uneven. In island SE Asia for example, the range of subsistence plants is vast and
446 many either produce totally undiagnostic pollen (e.g. *Oryza* [rice]), or are reproduced
447 vegetatively and do not flower (e.g. many *Dioscorea* spp. [yams]), or generate pollen which
448 does not preserve (cf. *Musa* spp. [bananas]). One avenue of research in this case might be to
449 investigate the weed floras and ancillary plants associated with cultivation systems.

450 Monocultures are typical in conventional Western farming, but are unknown within many
451 tropical systems, where complex polycultures, often involving many perennial plants, are
452 practised. In some cases, long-established forms of arboriculture/forest management produce
453 economically useful plants (Hunt and Rabett, 2014). Many of these systems are threatened by
454 logging and mineral extraction and investigation is urgently necessary to identify their
455 palynological signature.

456

457 When it comes to the identification of key subsistence plants within anthropogenically-
458 modified plant communities, then palynology is unlikely to be as precise as macrofossil
459 analysis (Birks and Birks, 2000; Dickson and Dickson, 2000; Bosi et al., 2015). The
460 determination of Cerealia pollen grains especially remains a contested topic (Edwards and
461 Hirons, 1984; Göransson, 1986; Edwards, 1989; Poska and Saarse, 2006; Behre, 2007;
462 Brown, 2007; Tinner et al., 2007), but there is no doubting that the recording of cereal-type
463 pollen grains has raised many questions, some of which have been verified by archaeobotany
464 (Church et al., 2013; Edwards, 2014; Henriksen, 2014). Pollen genetics may eventually assist
465 in resolving debates and uncertainties, as well as revealing new research horizons.

466 Meanwhile, just as it has done since the early days of palynology (Firbas, 1937; Grohne,
467 1957; Beug, 1961, 2004; Andersen and Bertelsen, 1972. Andersen, 1979; Köhler and
468 Lange, 1979), advances in the identification of cereal – morphological, statistical and
469 methodological – continue (Edwards and McIntosh, 1988; Edwards et al., 2005b; Tweddle et
470 al., 2005; Joly et al., 2007; López-Merino et al., 2015), while approaches being developed for
471 Poaceae differentiation may also assist in this (Mander et al., 2013, 2014).

472

473 Moving beyond cereals, uncovering evidence for the cultivation of plants through pollen
474 analysis continues to prove difficult in many cases due to the restricted level of taxonomic
475 precision which can be achieved through routine counting using a transmitted-light
476 microscope. A fundamental problem is the separation of the pollen of crop plants from that of
477 other species within the same genus or family where these include several taxa that inhabit
478 different natural and cultural environments (the Fabaceae being a case in point). In addition,
479 of those cultivated plants which can be confidently identified (e.g. *Fagopyrum* [buckwheats],
480 *Linum usitatissimum* [flax], *Vicia faba* [broad bean]), many are low pollen producers (Behre,
481 1981) and this further reduces their visibility in the palynological record. Recent advances
482 have been made, however, with the detection of woodland management techniques. For
483 example, modern pollen-vegetation studies in British woodlands have demonstrated that
484 pollen production for *Corylus avellana* (hazel) is significantly higher in the early years after
485 coppicing (as has long been surmised), yet flowering of *Alnus glutinosa* (alder) and *Tilia*
486 *cordata* (lime) is suppressed under the same conditions (Waller et al., 2012). In the tropical
487 Americas, methodological developments in the concentration of pollen of important cultigens
488 (e.g. *Mahinot esculenta* [manioc], *Ipomoea batatas* [sweet potato] and *Zea mays* [maize])
489 have made recognition of cultivation more reliable. Large pollen types (>53 microns) that are
490 typical of cultivars are separated from the rest of the pollen sample using an additional
491 sieving stage (Whitney et al., 2012), and then identified through rapid scanning of the coarser
492 fraction, whilst the fine fraction is counted as usual. Major advances in the identification of
493 pre-Columbian agriculture in the Amazonian basin have resulted through the enhanced ability
494 to identify the key crops from a combined palynological and phytolith approach, from both
495 archaeological sites and adjacent wetlands (Mayle and Iriate, 2014; Whitney et al., 2014).

496

497 **6. Envoi**

498

499 As we approach the centenary of Lennart von Post's public demonstration of the utility of
500 pollen analysis (von Post, 1916; Manten, 1967), it is instructive to reflect upon several key
501 issues of relevance to anthropogenic palynology as much as to the parent discipline. Once the
502 field equipment and basic laboratory infrastructure are in place, it is a relatively low-cost
503 science, dependent largely on associated fieldwork funding. By the same token, its best
504 practitioners need to be highly skilled as taxonomists and as ecologists in the widest sense
505 (embracing plant, human and landscape ecology). Apart from obvious collaborations with
506 archaeologists and those working in allied environmental disciplines, palynologists,

507 increasingly, must either be adept at, or able to join forces with statisticians and modellers. If
508 they have not come up through the ranks of empirically-based palynology, such valued co-
509 workers may not be especially knowledgeable concerning the strengths and weaknesses of
510 palaeoecology, and this puts the onus on the palynologist to be especially vigilant and not to
511 become unreasonably transported by the ‘wonders’ of ungrounded data manipulation.

512

513 Back in 1967, limnologist Ed Deevey observed (p. 65):

514

515 Von Post’s simple idea, that a series of changes in pollen proportions
516 in accumulating peat was a four-dimensional look at vegetation, must
517 rank with the double helix as one of the most productive suggestions
518 of modern times.

519

520 It seems to us that there has been no diminution in the quantity, nor, arguably, the quality of
521 output within the field. We may have concerns about the ability of palynologists and research
522 colleagues to be fully cognizant with the explosion of literature, but these may be the
523 perpetual worries of middle- and late-career academics.

524

525 The archaeologist Stig Welinder (1988, p. 129) commented somewhat forlornly that:

526

527 Pollen analysis is a science fascinatingly devoid of epistemological
528 theory compared to modern archaeology.

529

530 – but we would adopt a more positive perspective. After all, the purpose of archaeological
531 science might be seen as the use of science to inform archaeological enquiry, and this is most
532 usefully based in reality, however determined, prior to the use of derived information in the
533 service of advanced conjecture, theory, quantification or modelling. For its part,
534 palynological modelling, anthropogenic or otherwise, provides a fresh lens through which to
535 view and test both palynological concepts and inferences and, by extension, to inform
536 archaeological discovery and imagination.

537

538

539 **Acknowledgements**

540

541 We are delighted to share in this celebration of Richard Klein's contributions to this journal
542 and the discipline of archaeology. Such studies as *Quaternary Extinctions: a Prehistoric*
543 *Revolution* (1989), *The Human Career: Human Biological and Cultural Origins* (1999) and
544 *The Dawn of Human Culture* (2002) speak to us as palaeoecologists as much as they speak to
545 archaeological science and to archaeology more broadly. We are also happy to acknowledge
546 the support of two anonymous referees.

547

548

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1242 **Figure captions**

1243

1244 Fig. 1. Data relating to palynological publications (n = 211) contained in *Journal of*
1245 *Archaeological Science*, 1974-2014. Data were extracted using the advanced search facility
1246 within the Elsevier home page of the journal, searching for ‘pollen’ or ‘palynology’ within
1247 title, abstract or keywords of articles, review articles and short communications: (a) number
1248 of palynological papers within the journal per annum; (b) total number of papers within the
1249 journal per annum; (c) palynological papers as a percentage of total papers within the journal
1250 per annum.

1251

1252 Fig. 2. Map showing countries mentioned in the text (with the exception of Sarawak).

1253

1254 Fig. 3. The site of Á Sondum, Faroe Islands, is located beneath the grass-roofed building at
1255 the bottom right of the picture (photograph by K.J. Edwards). The lower diagram shows
1256 calibrated ^{14}C dates for archaeological contexts from Á Sondum compared to the time of
1257 appearance of *Hordeum*-type pollen from Hov (see text and Church et al., 2013 for further
1258 details). A – lower peat ash patch; B – upper peat ash patch; C – longhouse external midden;
1259 D – longhouse central hearth; E – *Hordeum*-type pollen percentages from the site of Hov
1260 (pollen sum c. 500 total land pollen (TLP); F – *Hordeum*-type pollen percentages from Hov,
1261 optimised pollen sum estimated at c. 1500 TLP.

1262

1263 Fig. 4. *Betula pubescens* (downy birch) growing on lava fields close to Mývatn, northeast
1264 Iceland (photo by K.J. Edwards). The graph on the right shows pollen percentage data for *B.*
1265 *pubescens* from Helluvaðstjörn, with confidence intervals at the 2σ level (see text and
1266 Lawson et al., 2007 for further details).

1267

1268 Fig. 5. Photograph at the top of the diagram shows a Norse building at Sissarluttoq, Eastern
1269 Settlement, Greenland (photo K.J. Edwards). The palynological spectra (selected taxa only)
1270 in the lower diagram span the time of Norse settlement (*landnám*) and come from lake mud
1271 contained in a small pond beside the ruins at Sissarluttoq. The introduction of people and
1272 domesticated animals into a pristine environment around AD 1000 (SSQ-1/2 zone boundary)
1273 resulted in a reduction in pollen from shrubs (e.g. *Salix*) and grazing-sensitive herbs (e.g.
1274 Apiaceae), and an expansion in anthropochores (e.g. Lactuceae), apophytes (e.g. *Rumex*

1275 *acetosella*), coprophilous fungal spores (HdV-55A, -113 and -368), and microscopic
1276 charcoal. The reverse pattern can be seen following abandonment of the site around AD 1400
1277 (SSQ-3/4 boundary). For the full dataset and discussion, see Edwards et al. (2011b).

1278

1279 Fig. 6. Anthropogenically enhanced plaggen soils can yield useful pollen data, demonstrated
1280 here using pollen sites in Greenland (Atikilleq, Vatnahverfi; Ledger et al., 2015) and the UK
1281 (Village Bay, Hirta, St Kilda; Donaldson et al., 2009). (a) coastal section at Atikilleq where
1282 the plaggen deposit could be traced over a distance of ~20 m (photo by J.E. Schofield); (b)
1283 the sampled section at Atikilleq comprising basal natural soil, plaggen (organic-rich sandy
1284 soil containing charcoal and charred bone fragments, ~21 cm thickness) and a surface
1285 capping of sandy soil and turf (photo by J.E. Schofield); (c) summary pollen spectra from
1286 Atikilleq indicating relatively high concentrations of pollen (dominated by Poaceae,
1287 Cyperaceae and *Ranunculus acris*-type) from the start of woodland reduction (*landnám*); (d)
1288 Consumption Dyke formed from field-gathered boulders and stones (constructed AD 1830)
1289 in Village Bay underlain by plaggen soils (soil profile 8 was in the centre of the picture,
1290 photo by C. Deacon); (e) soil profile 8, Village Bay (72 cm depth, photo by C. Deacon); (f)
1291 summary diagram from the Village Bay profiles showing the occurrence of some of the main
1292 pollen types (% TLP, upper scale beneath diagram) and total pollen concentration (grains cm⁻³
1293 wet sediment, lower scale).

1294

1295 Fig. 7. Part of the West Mouth of the Great Cave of Niah, Sarawak, taken from the rockfall in
1296 the southern passage in 2008 (photograph by C.O. Hunt). The pollen sample transect (line
1297 diagram) is in the Archaeological Reserve to the far side of the cave mouth, just beyond the
1298 shelter at that side of the cave. Percentage pollen fallout for major ecological groups per year
1299 on a transect running inside the cave from the entrance zone (data from Hunt and Rushworth,
1300 2005) show that the main source for pollen in the first 25 m of the transect is airfall, with
1301 assemblages closely mirroring those from taphonomic samples in the forests outside the cave.
1302 The influence of bat and bird vectors on pollen assemblages beyond 25 m into the transect,
1303 where swiftlet nests and bat roosts are abundant, can be seen in the high percentages of
1304 mangrove pollen and low frequencies of open-ground taxa.

1305

1306 Fig. 8. Fluorescence micrographs and intensity value graphs (red, green and blue light,
1307 relative to a greyscale from 0 [no light] to 256) for pollen and spores from the basal peats on

1308 Dooncarton Mountain, Co. Mayo, Ireland (Hunt et al. 2007). (a) image of two *Corylus* grains,
1309 the upper being recycled and showing a typical dull orange colour, the lower showing the
1310 brighter yellow colours typical of *in-situ* material; (b) intensity analysis of *in-situ* *Corylus*
1311 grain shown in (a); (c) intensity analysis of recycled *Corylus* grain shown in (a). Note that all
1312 three colour bands show lower intensity; (d) image of thermally mature (burnt) *Polypodium*
1313 grain showing the very bright pale blue fluorescence typical of burned material; (e) intensity
1314 analysis of the thermally mature *Polypodium* grain shown in (d). Note that the blue band
1315 shows high intensity, but that there is virtually no fluorescence in the red wavelengths. (For
1316 greater clarity, see the on-line colour version).

1317

1318 Fig. 9. Schematic diagrams illustrating the key inputs and modelling programmes used within
1319 the Landscape Reconstruction Approach (LRA) and the Multiple Scenario Approach (MSA)
1320 modified from Bunting and Middleton (2009). Both modelling approaches draw on pollen
1321 productivity estimates (PPEs) and fall speed of pollen, and use the same pollen dispersal and
1322 deposition models. The LRA requires raw pollen counts as input data; the MSA requires raw
1323 pollen count data for evaluation of simulated pollen proportions.

1324

1325 Fig. 10. LRA-based estimates of local vegetation cover within the NSAP (necessary source
1326 area of pollen) of sixteen sites (designated by abbreviations) on Exmoor (indicative
1327 photograph by Ralph M. Fyfe) for the time period 1500-1000 cal BP. For each site, the
1328 regional vegetation is estimated in REVEALS using the other 15 sites, followed by
1329 estimating local vegetation for that site using LOVE. The error bars represent 2σ confidence
1330 limits.

1331

1332 Fig. 11. A simulation of broad vegetation zones on Exmoor (upper panel). Zones are
1333 differentiated based on a combination of elevation and slope, and follow archaeological
1334 interpretations of the early medieval period (Rippon et al., 2006); vegetation is kept simple,
1335 with only five taxa. Forty-nine sets of simulated pollen loadings have been generated from
1336 within the inset box, and are illustrated in the lower panel. Full details of the simulation can
1337 be found in Fyfe (2006). (For greater clarity, see the on-line colour version).

1338

Table 1. Numbers of palynological papers appearing in selected journals since their dates of release.

Journal	Period covered	Number of palynological papers*	Mean number of palynological papers per annum**
<i>The Holocene</i>	1991-2014	627	26.13
<i>Quaternary Science Reviews</i>	1982-2014	608	18.42
<i>Quaternary International</i>	1989-2014	476	18.31
<i>Palaeogeography, Palaeoclimatology, Palaeoecology</i>	1965-2014	792	15.84
<i>Journal of Quaternary Science</i>	1986-2014	398	13.72
<i>Quaternary Research</i>	1970-2014	606	13.47
<i>Boreas</i>	1972-2014	336	7.81
<i>Journal of Archaeological Science</i>	1974-2014	211	5.15

* Based on the words ‘pollen’ or ‘palynology’ appearing within the title, abstract or keywords of articles, review articles and short communications, where these are ascertainable within the relevant search engines of the journal home pages. There is likely to be uncertainty in these figures.

** These figures are not normalized for annual journal length.

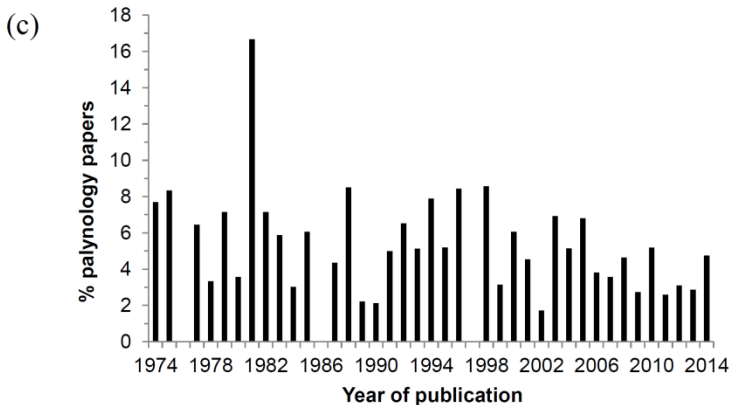
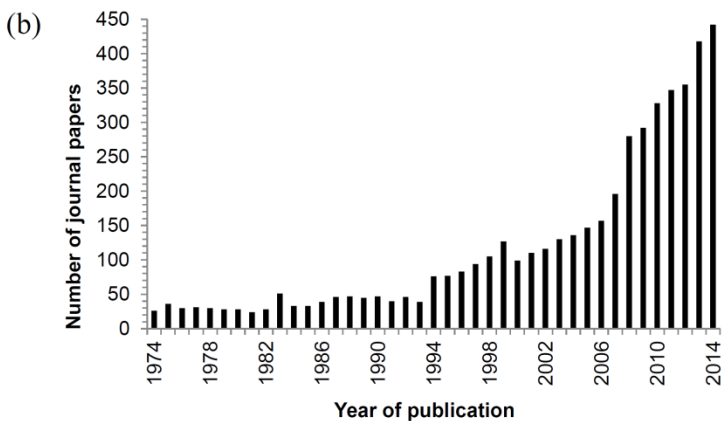
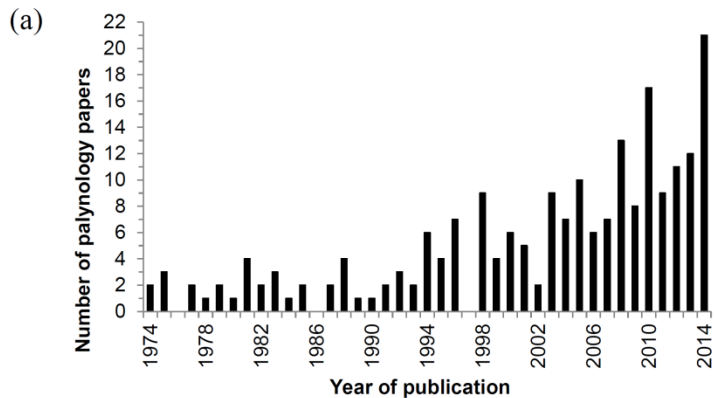


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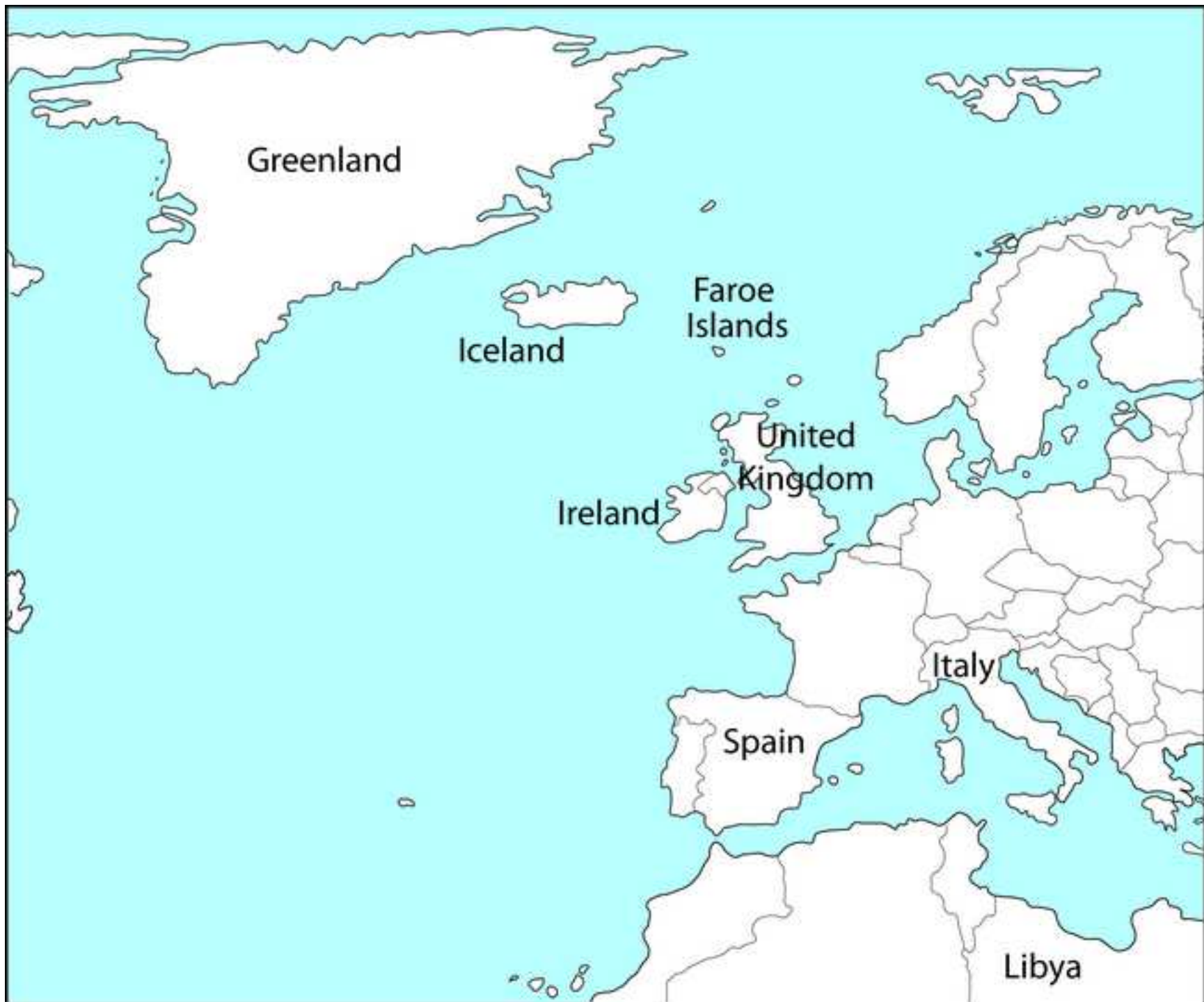


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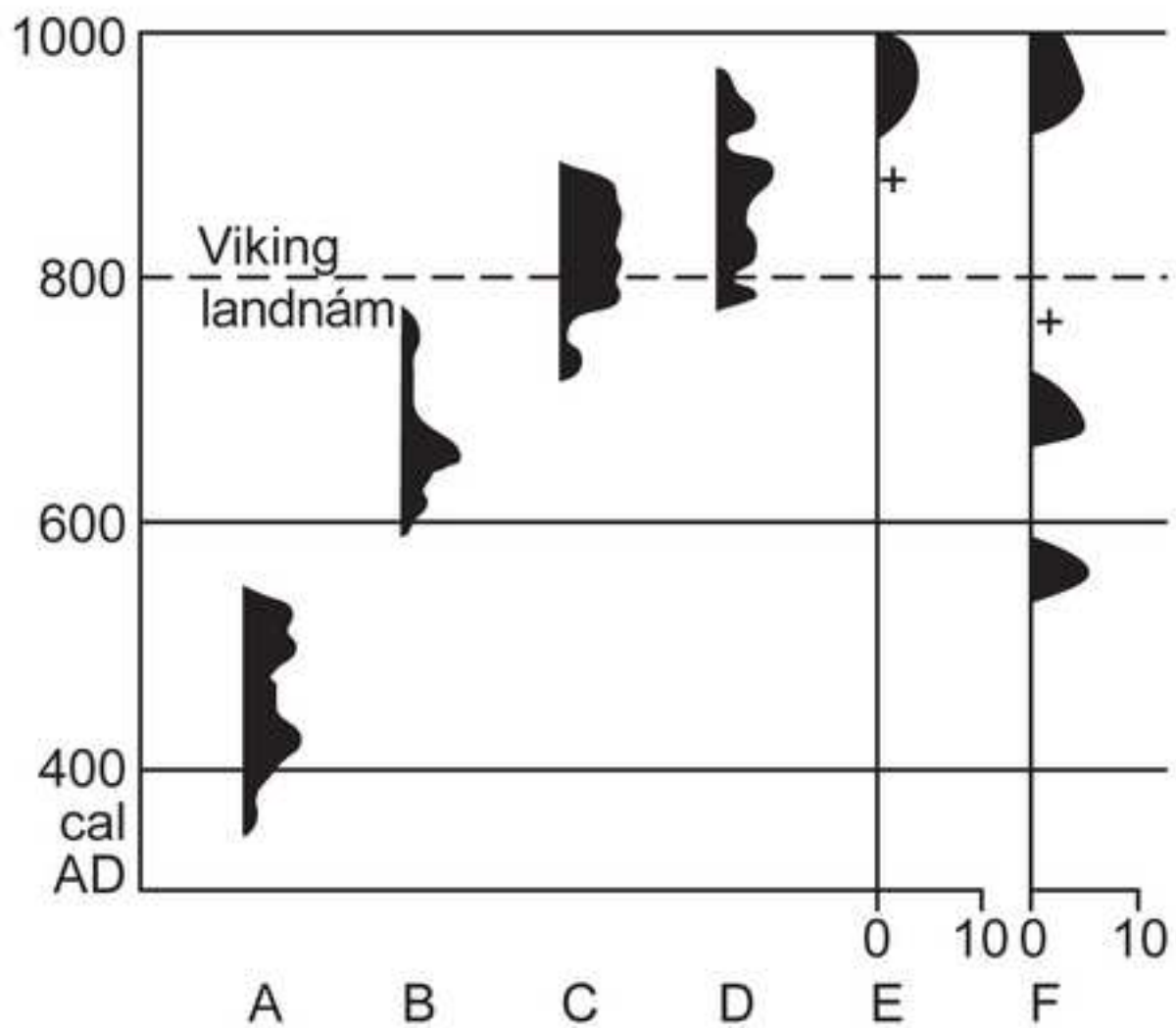


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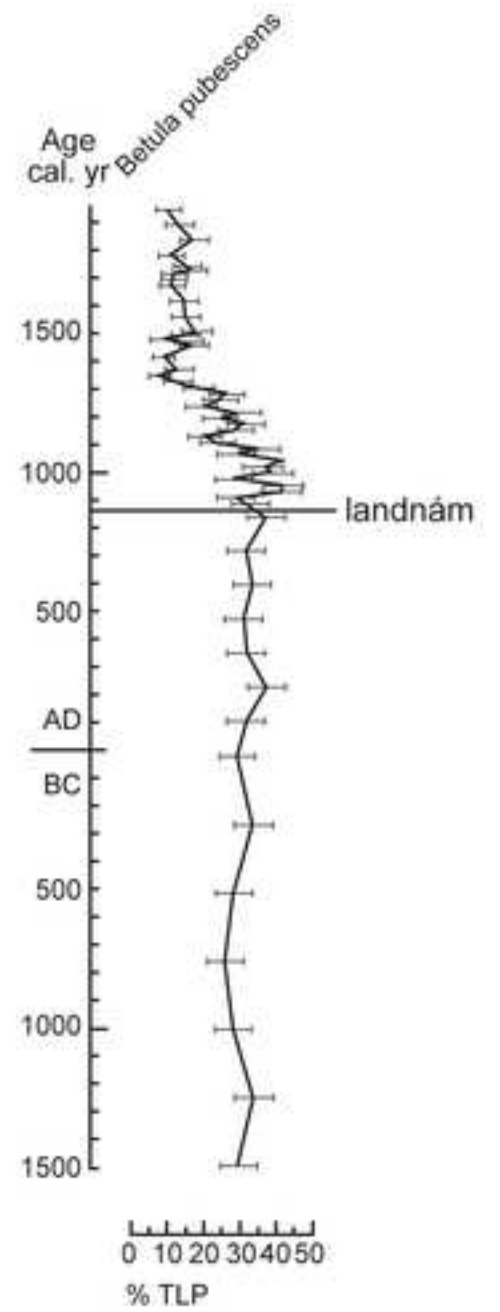


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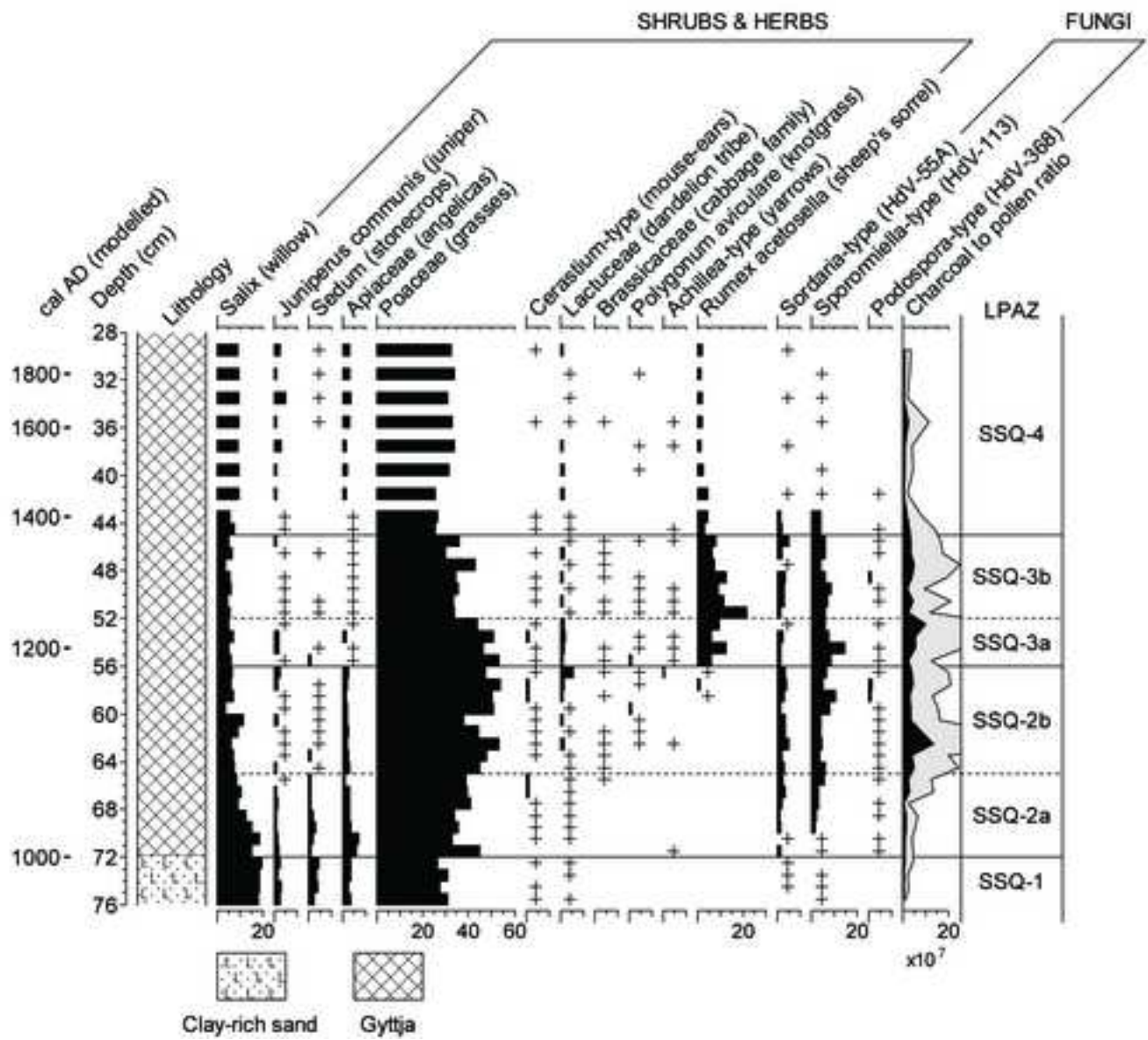


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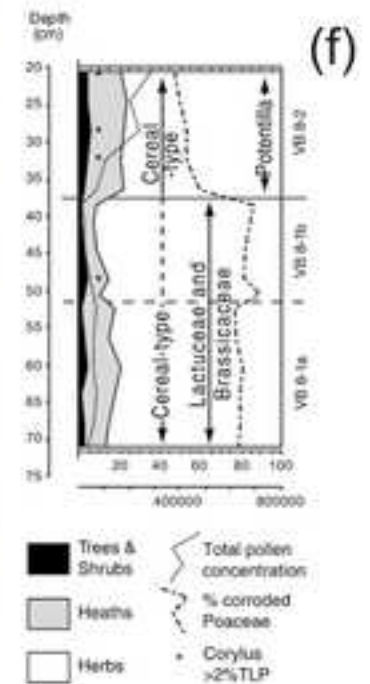
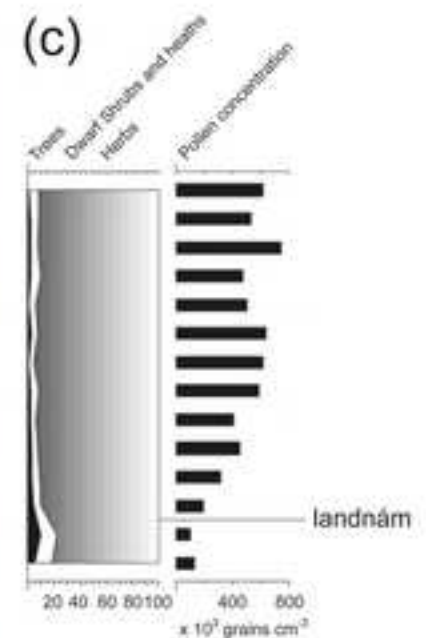


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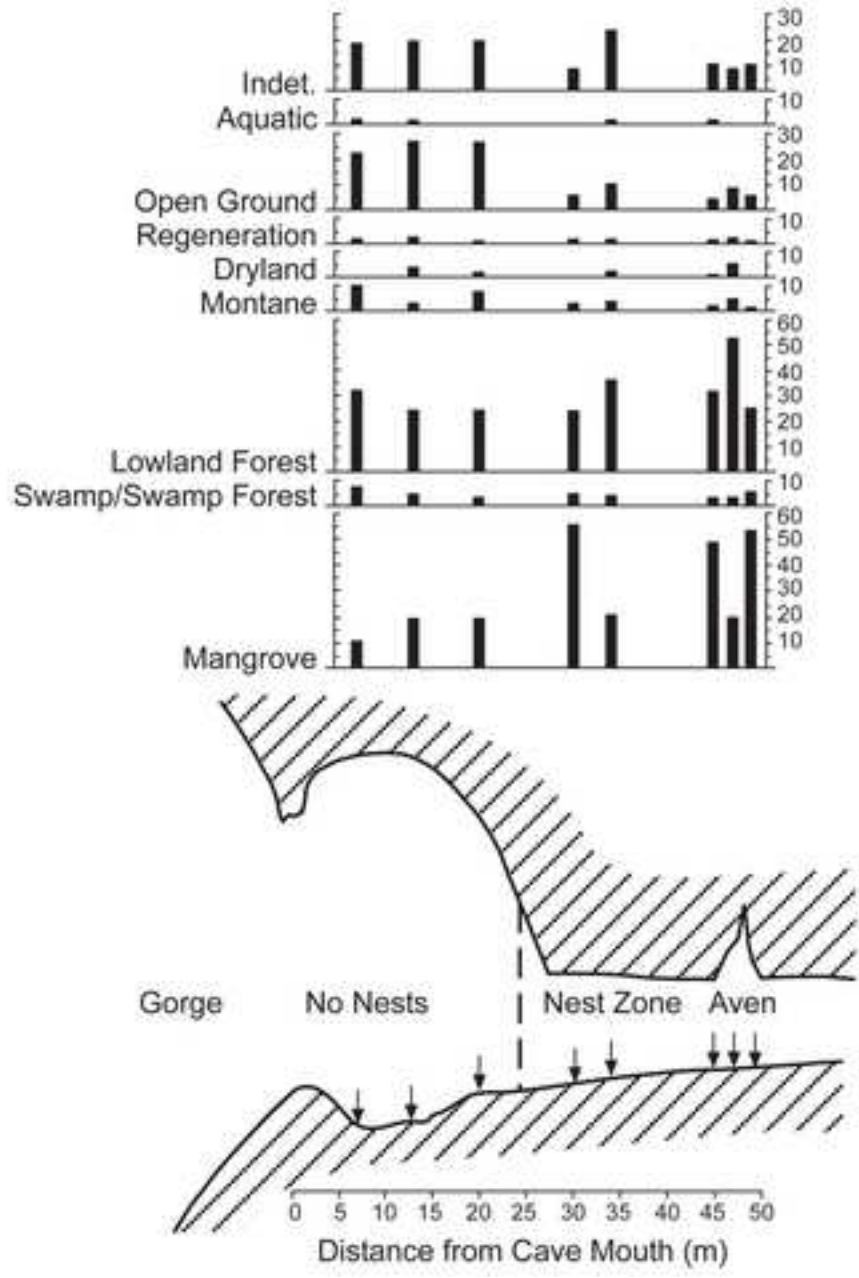


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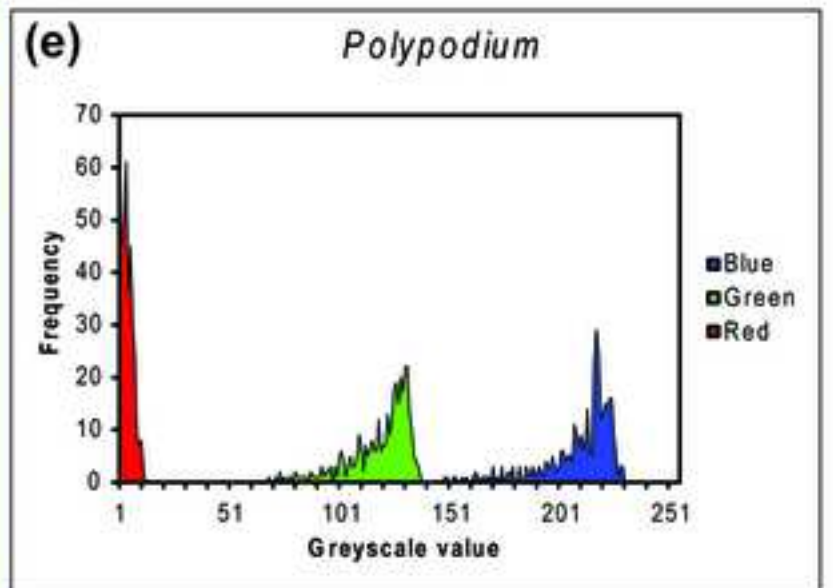
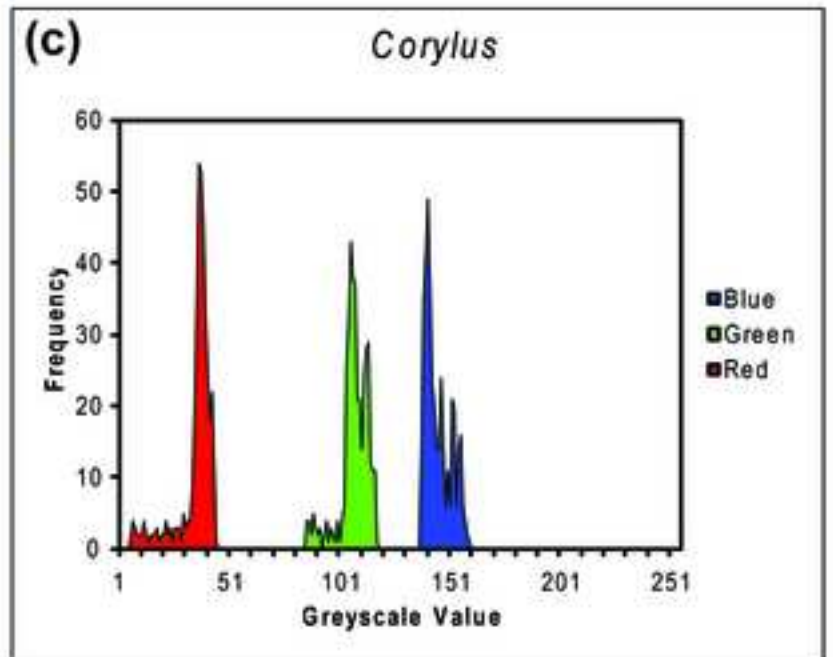
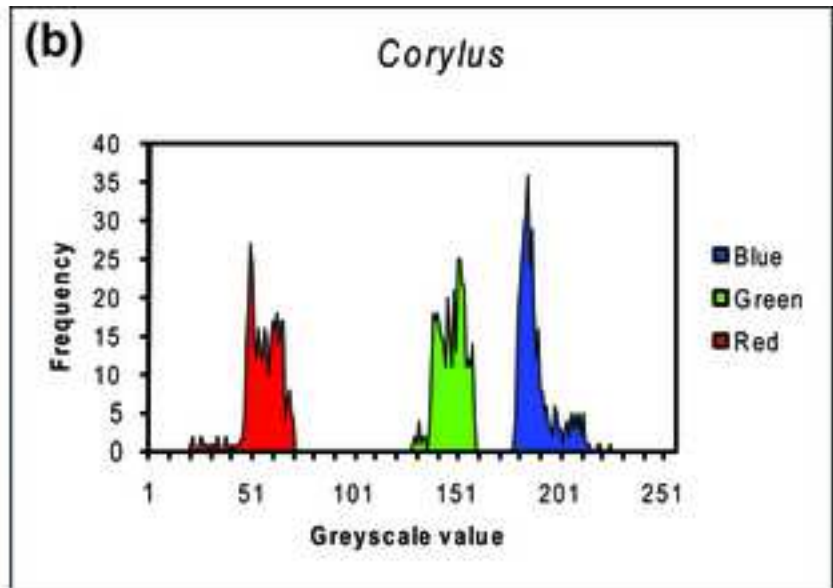
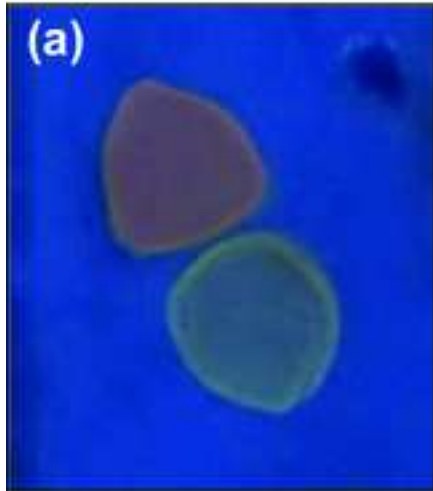
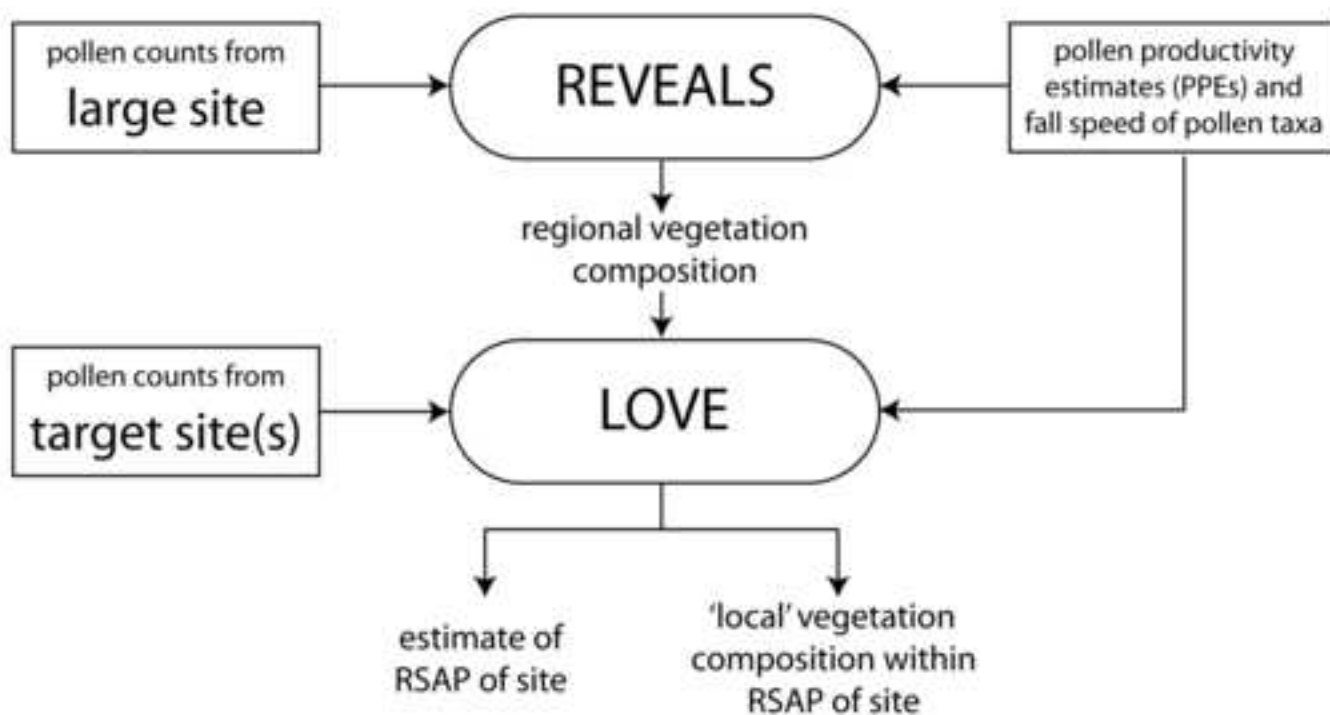


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Landscape Reconstruction Algorithm



Multiple Scenario Approach

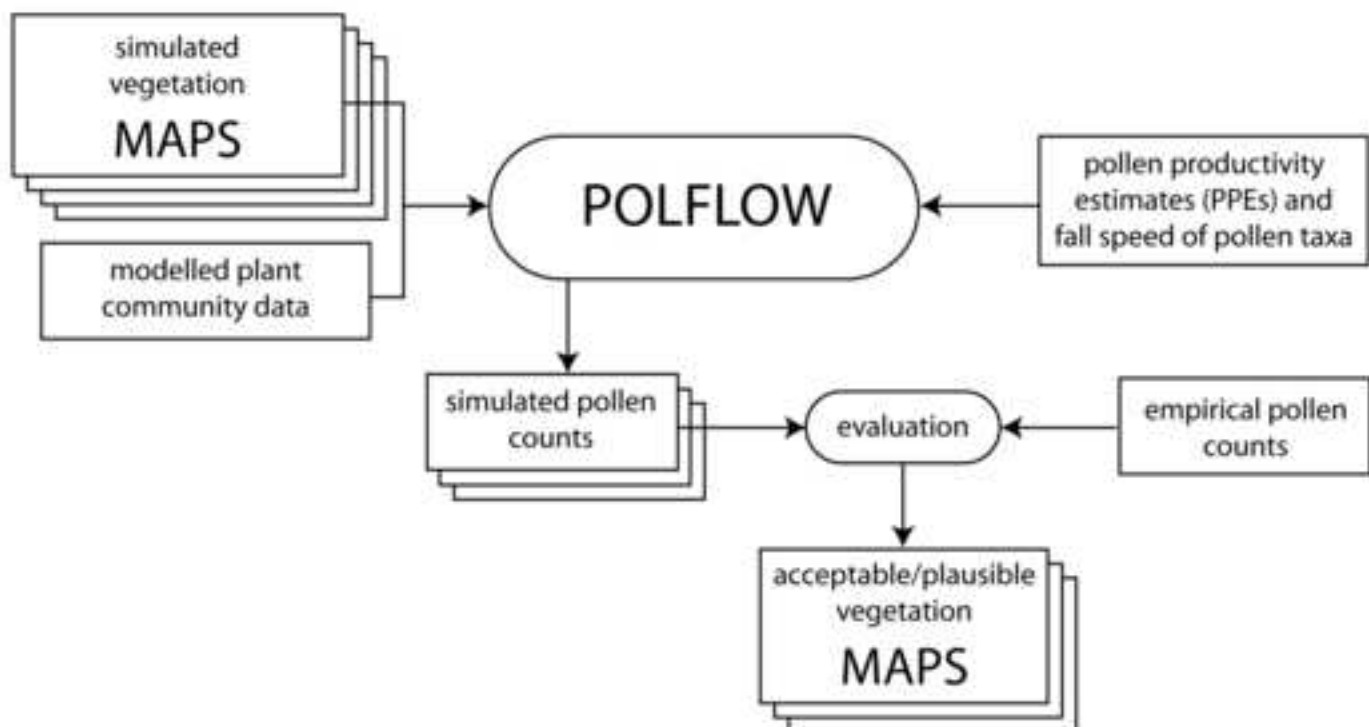


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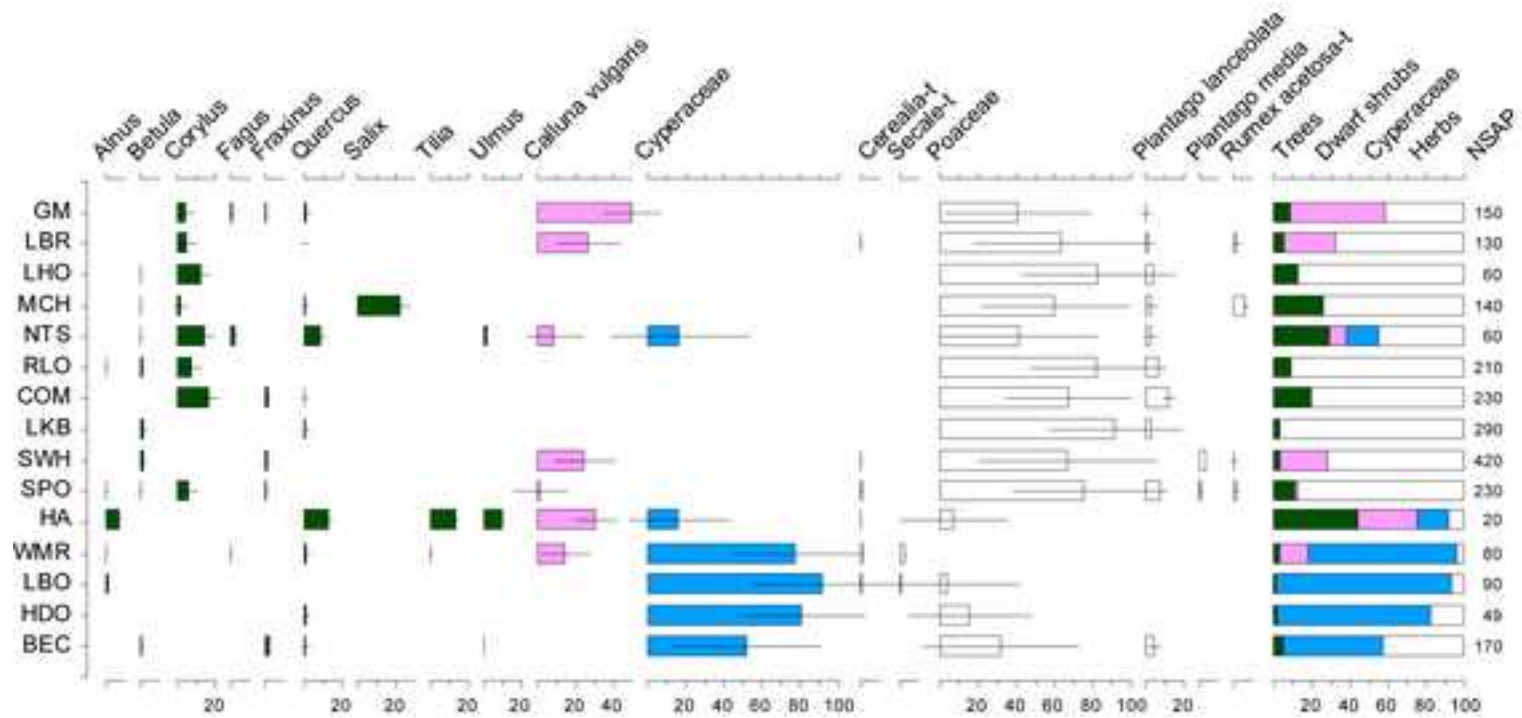


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