

POLLEN SOURCES ON A MODERN SEVERN ESTUARY SALT MARSH, AND IMPLICATIONS FOR THE INTERPRETATION OF HOLOCENE ESTUARINE POLLEN SEQUENCES

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INTRODUCTION

The peats and silts of the Severn Estuary have provided a rich source of evidence for Holocene vegetational and sea-level change, often involving analysis of their contained pollen grains (eg Smith and Morgan 1989; Aldhouse-Green *et al* 1992; Scaife 1995; Walker *et al* 1998; Caseldine 2000). Peat deposits are usually preferred for pollen analysis, because the pollen is abundant and well preserved, and the pathways of pollen transport to peat deposits are relatively well understood. In contrast, estuarine silts tend to contain relatively sparse and poorly preserved pollen, and the sources of pollen to the deposits are complex and little-studied (Dark and Allen 2005). Such silts accumulated chiefly under salt-marsh conditions on the margins of the estuary intermittently throughout the Holocene, and continue to form today. In many cases they show pronounced banding which has been found, on the basis of sedimentological and pollen analysis, to be annual (Allen 2004; Dark and Allen 2005).

Little research has been undertaken on pollen deposition in salt marshes, in Britain or more widely (but see Roe and van de Plassche 2005), hampering attempts to interpret pollen sequences from the minerogenic deposits that they generate. In this paper we report the results of a preliminary study of modern pollen deposition on a mudflat and the lower parts of a salt marsh at Northwick Warth and Aust Warth respectively, on the English side of the Estuary (Figure 1). This research forms part of a broader study of seasonal variability in modern pollen and sediment

deposition in salt-marsh and mudflat environments, to be published elsewhere. Here the focus is on the representation of salt-marsh plant communities in estuarine pollen sequences, and the ability to distinguish them in the pollen record from the vegetation on dry land and from the 'reservoir' of pollen stored in the estuarine water body. The implications of the similarity between cereal pollen and pollen of some salt-marsh grasses are also considered.

NORTHWICK AND AUST WARTHS

Northwick and Aust Warths (separated by Cake Pill) together form the largest (*c.* 0.7 km²) and most complex salt marsh surviving today on the margins of the severely macrotidal Severn Estuary, the remainder having been embanked at various times since the Roman period (Figure 2). This complex, linked to the wide mudflat known as Northwick Oaze, ranges for some 3.5 km along a slight embayment between Aust Cliff and New Passage on the eastern shore of the estuary.

The morphostratigraphy of the complex is described by Allen and Rae (1987), Strawbridge *et al* (2000) and Haslett (2006). A seabank divides the salt marsh from the enclosed marshes, now settled farmland, to the southeast. This land lies 0.8-0.9 m below the level of the highest marsh active today, and is marked by medieval ridge-and-furrow, affording a minimum age for the enclosure (Allen and Rae 1987, 1988). The marsh itself is in three, step-like parts that descend to seaward with clifflets a few decimetres high between (Figure 3). Adjoining the seabank is the

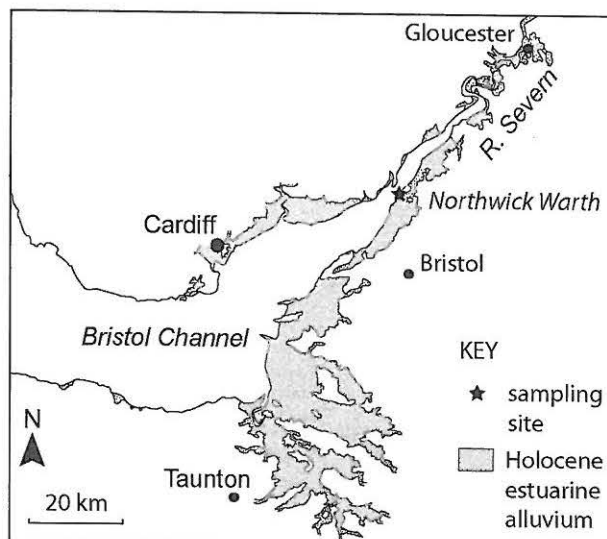


Figure 1. Map showing the location of Northwick Warth in the Severn Estuary.

highest marsh, standing close below the level of the highest astronomical tide (HAT) at Avonmouth (8.4 m OD). It is underlain by the Rumney Formation, a thick sequence of pale brown grading up into grey estuarine silts which, at the type-site (Allen 1987, 1996), began to form in early modern times. The narrow, intermediate marsh overlies the grey silts of the Awre Formation (Allen and Rae 1987), of latest nineteenth-century inception. The broad, outermost marsh is the lowest. It is underlain by the Northwick Formation (Allen and Rae 1987), a series of grey silts contaminated throughout by heavy metals. These beds began to form, patchily at first, in the mid-twentieth century and are estimated to be now 2 m or more thick in places. All three marsh elements can be traced along the length of the site and are continuing to grow upward as the result of tidal siltation, at rates that decline with increasing height in the tidal frame.

The salt-marsh vegetation has been surveyed previously by Smith (1979), at a time when all but the lowest marsh was grazed by cattle. The vegetation (recorded in October 1978) was divisible into four zones running along the combined length of the warths: the highest marsh, corresponding with the Rumney Surface, was dominated by *Festuca rubra* (red fescue), *Agrostis stolonifera* (creeping bent), *Elytrigia atherica* (= *Agropyron pungens*, sea couch) with *Hordeum secalinum* (meadow barley) and *Lolium perenne* (perennial rye-grass) in some areas. The narrow

intermediate marsh, on the Awre Surface, was dominated by *Festuca*, *Agrostis*, *Elytrigia* and *Puccinellia maritima* (common saltmarsh-grass) with *Glaux maritima* (sea-milkwort), *Triglochin maritimum* (sea arrowgrass) and *Spergularia media* (greater sea-spurrey), while the low marsh, overlying the Northwick Surface, had an upper zone of *Puccinellia*, *Spartina anglica* (common cord-grass), *Aster tripolium* (sea aster), *Suaeda maritima* (annual sea-blite) and *Salicornia* sp. (glasswort), grading gradually into a lower zone dominated by *Spartina*. A similar overall zonation was noted in a survey of the northern part of the salt marsh in 1997, although detailed results are not published (Strawbridge *et al* 2000).

Spartina has been present in the Severn Estuary since at least 1913, when it was planted in the intertidal zone between the rivers Yeo and Kenn (Carter 1974). Rapid spread was possible by uprooted rhizomes washing along the coast (Hubbard 1968), and the plant came to dominate substantial areas of low marsh in the Estuary by the second half of the twentieth century.

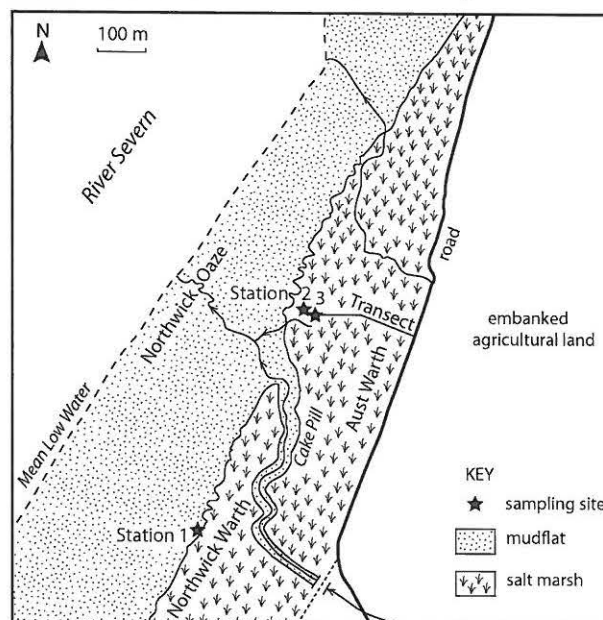


Figure 2. Map showing the location of the sampling points and transects at Northwick and Aust Warths.

For some years, Aust Warth, north of Cake Pill, has not been grazed, and the composition of the vegetation has diverged slightly from that at Northwick Warth, where grazing continues. The current vegetation at Aust Warth will be described

below on the basis of the new vegetation survey undertaken there.

We chose Aust Warth for two stations at which we trapped suspended tidal sediment and airborne pollen, linked to a botanical transect, because here the vegetation has been least disturbed by recent grazing and the lowermost marsh is rapidly spreading upward and outward in a transitional relationship with the adjoining mudflat (Figure 2). One sampling station (Station 3) lies on the transect c. 0.5 m below the mean high-water of spring tides (MHWST). The need to secure samples that included estuarine silts (to ensure representation of all of the main potential sources of pollen to the salt marsh) ruled out the choice of a higher location, as the spring tides during the periods of our sampling were relatively low (7.1, 7.3, 7.6 m OD). The other marsh station (Station 2) lies near the ragged marsh edge at c. 1.5 m above the level of mean high-water of neap tides (MHWNT). The mudflat off Aust Warth was judged too treacherous for the establishment of a sampling site, which instead we positioned on the mudflat adjoining Northwick Warth (Figure 2) at an altitude of 3.15 m OD, that is, just below MHWNT (Station 1). In sharp contrast with Aust Warth, the lower marsh here is bounded to seaward by a bold, rapidly retreating mud cliff c. 1-2 m high.

SEDIMENT SOURCES AND DEPOSITION IN THE UPPER SEVERN ESTUARY

One of the main challenges in interpretation of pollen sequences from estuarine sediments is the many potential sources of pollen to the deposits (Dark and Allen 2005). In addition to pollen production from the *in situ* salt marsh, pollen arrives via the atmosphere, rivers, and the tidal water body. River transport may bring pollen from a considerable distance inland, and also pollen derived from eroded soils and sediments in the catchment. The estuarine water body, with its vigorous currents and high levels of turbulence, contains a substantial 'reservoir' of pollen that may have remained in suspension for years, as well as actively eroding earlier Holocene sediments and pre-Holocene beds. The relative contribution of pollen from each source varies seasonally. Airborne and *in situ* pollen deposition

are confined to the flowering season, but inputs of reworked pollen occur all year. By sampling the estuarine silts in different seasons the relative contribution of pollen from each source may be determined.

FIELDWORK

Field-based research involved determination of the detailed marsh surface topography and selection of appropriate pollen sampling stations; a survey of the vegetation; and seasonal collection of sediment samples for pollen analysis.

Topographic survey

An EDM survey was undertaken on 7th May 2004 to establish the topographic profile of the salt marsh at Aust Warth. A transect was established running from made ground at the landward edge of the high marsh (immediately by the road) out to the mudflat (Figure 2). Readings were taken at 10 m horizontal intervals. Sampling stations 2 and 3 were marked in the low marsh by pushing wooden stakes into the sediment. The mudflat sampling station (Station 1) was established south of Cake Pill, c. 5 m from the cliffed edge of the salt marsh, marked by a wooden stake, and its height recorded also. The survey was undertaken in relation to a temporary benchmark on a concrete structure sited on the marsh (Haslett 2006). The EDM data were later transferred to ArcInfo and OD heights calculated.

Vegetation survey

A vegetation survey was undertaken on 1st September 2004 along the transect running through stations 2 and 3. Quadrats 1 m² were sampled at 10 m horizontal intervals and vegetation cover/abundance estimated using the Domin scale (Figure 3). A record was also made of which plants were in flower on this and other sampling visits. The mudflat at Station 1 was unvegetated, but the adjacent salt-marsh edge was dominated by *Spartina anglica*.

Pollen sampling

Various methods of pollen sampling have been used in the past for comparison with local vegetation, usually involving use of moss polsters,

surface sediment, or traps for airborne pollen (see overview in Moore *et al* 1991). The first two of these suffer from the fact that the period over which the pollen was deposited is uncertain, and the latter sample only pollen in the air. As the estuarine water body provides a major potential source of pollen deposited on the salt marsh, this had to be included in the sampling regime used here. A trapping regime was designed to collect all of the possible sources of pollen to the salt-marsh surface over fixed periods of time (48 hours, four tidal cycles), and which could withstand the passage of the tide.

Simple robust traps consisted of shallow plastic trays (24 cm in diameter and 3 cm deep) and deeper plastic beakers (12.6 cm diameter and 13 cm deep). Two trap types were used to allow for factors that might result in sediment loss: tidal scouring (most likely in the shallow trays) or trapping of estuarine organisms such as crabs (in the beakers), which could result in post-depositional sediment disturbance/winnowing. The trays were anchored to the surface using tent pegs, and the beakers were sunk into the sediment with the top just proud of the surface. On the salt marsh care was taken to avoid flattening the vegetation surrounding the trap to cause minimal change to the sediment-trapping properties of the surface. Both types of trap successfully collected sediment during every sampling period, trapping between 60 and 520 ml of silt (measured when settled). All material contained in the traps was collected – sediment and water (representing a combination of estuarine water and rainfall). Subsequent analysis of sediment from both types of trap revealed no significant difference in character of the sediments collected in the two types of trap. The results reported here are from the tray samples only (as beaker samples were not collected from stations 2 and 3 in January, and one of the September beaker samples was spoiled by the presence of two crabs).

Sampling was carried out during 2004 at the three times of year most likely to enable separation between pollen sources to the sediments:

January (traps laid out on 21st, collected on 23rd) – minimal airborne pollen, with the exception of hazel (*Corylus avellana*) and

possibly some grasses.

May (traps laid out on 5th, collected on 7th) – main flowering period for trees such as oak (*Quercus*).

Late August (traps laid out on 30th August, collected 1st September) – main flowering period for some grasses (including species growing on the salt marsh: *Elytrigia atherica*, *Spartina anglica*), members of the Chenopodiaceae (*Salicornia* sp., *Suaeda maritima*, *Atriplex prostrata*), *Aster tripolium*, and sporulation of ferns.

Traps were left out for c. 48 hours, in principle allowing collection of material deposited by four high tides. During the January and May sampling intervals rainfall may have increased deposition of airborne pollen, but the weather was dry during the late August/September interval.

LABORATORY METHODS

In the laboratory the samples were allowed to stand for a week to allow as much as possible of the pollen to settle out of the water. The supernatant liquid was then poured off through a 10 µm sieve to trap any remaining suspended/floating pollen, which was then recombined with the bulk sediment. The bulk sediment was then thoroughly mixed before sub-sampling for pollen analysis.

Sediment samples of c. 2.5 g wet weight were prepared for pollen analysis using standard procedures (Berglund and Ralska-Jasiewiczowa 1986), including sieving with a 100 µm mesh to remove coarse particles, and micro-sieving with a 10 µm mesh to remove the finest particles. Pollen samples were mounted in glycerine jelly.

Pollen was counted using a Leica DMLB microscope at a magnification of 400x, with a magnification of 1000x for critical determinations. Wherever possible a minimum sum of 300 identifiable pollen grains and Pteridophyte (fern) spores was reached, but for three samples the counts were lower (minimum 236 grains). Pollen and spores were identified using the key of Moore *et al* (1991) and by comparison with the reference collection in the Department of Archaeology,

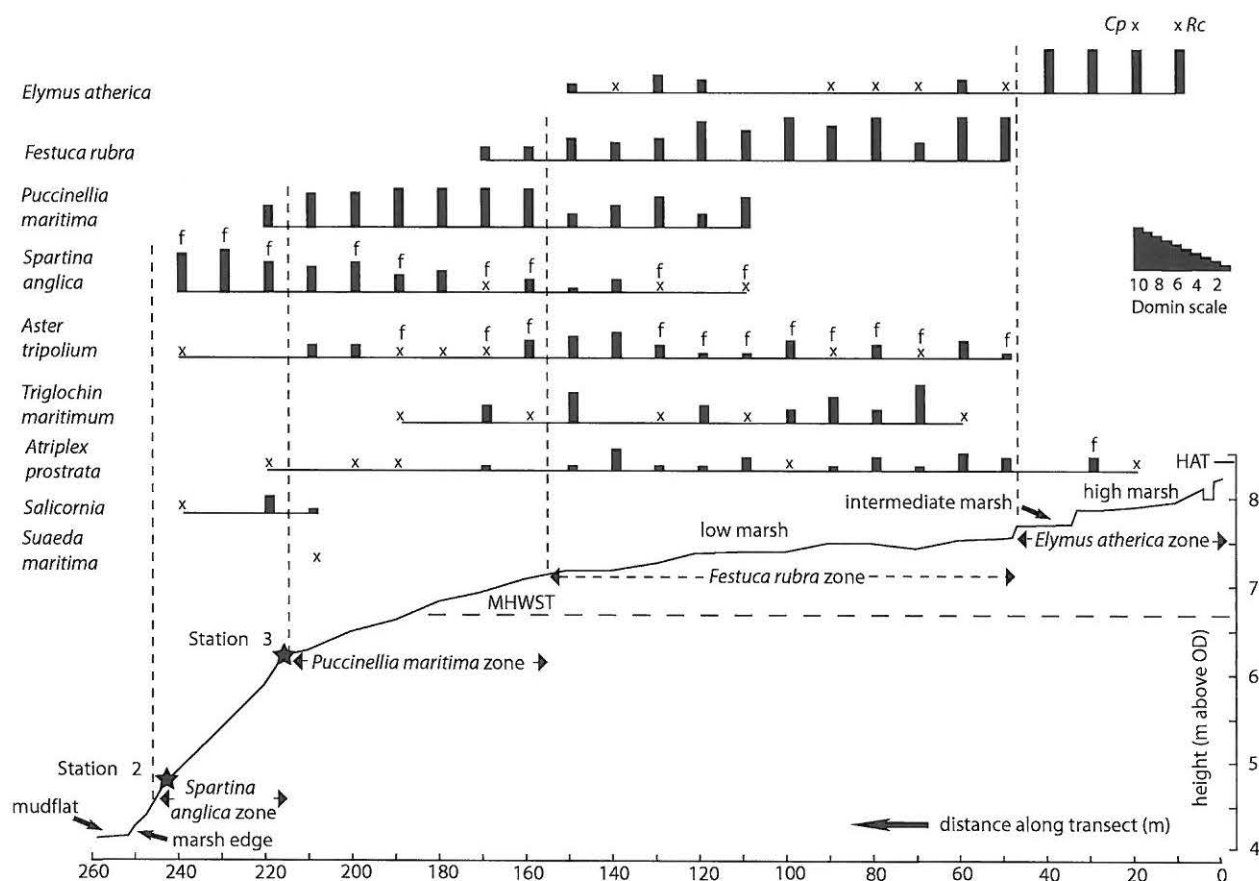


Figure 3. Results of the vegetation and topographic surveys at Aust Warth. Cover/abundance of each species is shown using the Domin scale: 1=1-2 individuals, 2=<1%, 3=1-4%, 4=5-10%, 5=11-25%, 6=26-33%, 7=34-50%, 8=51-75%, 9=76-90%, 10=91-100%. In addition x is used to denote presence just outside the quadrat. Flowering on 1st September is indicated by f, Cp=Cirsium palustre, Rc=Rumex crispus. Vegetation zones have been defined on the basis of the dominant taxa in different parts of the marsh.

University of Reading. Poaceae pollen grains were classified according to the criteria of Andersen (1979), with the additional category of *Phragmites*-type as defined by Faegri and Iversen (1989). Vascular plant nomenclature follows Stace (1991) and pollen and spore nomenclature follows Bennett *et al* (1994). Unidentifiable deteriorated pollen grains and spores were classified according to the categories of Cushing (1967).

Pollen percentage calculations are based on a sum including all identifiable pollen grains and Pteridophyte spores, excluding obligate aquatics and *Sphagnum* moss (which were rare and are not presented here). Calculations for the different categories of unidentifiable pollen grains are based on the main sum plus the sum of

unidentifiable grains.

RESULTS AND INTERPRETATION

Vegetation

Results of the vegetation survey are shown in Figure 3 in relation to the topography and sampling stations. The salt-marsh vegetation can be divided into a series of fairly well-defined zones reflecting height above sea level. The uppermost zone is dominated by *Elytrigia atherica* (sea couch, *Agropyron pungens*) with occasional *Atriplex prostrata* (spear-leaved orache, *Atriplex hastata*), and corresponds with the Rumney and Awre surfaces (or morphologically defined high and intermediate marsh) (7.7-8.2 m OD). There is then a sharp

horizontal boundary (over <2 m) to vegetation dominated by *Festuca rubra* (red fescue) accompanied by scattered *Aster tripolium* (sea aster), *Triglochin maritimum* (sea arrowgrass) and *Atriplex prostrata* (c. 7.2-7.7 m OD). Another sharp transition follows, to vegetation dominated by *Puccinellia maritima* (common saltmarsh-grass) (c. 6.2-7.2 m OD), but with continuing presence of *Festuca* and *Triglochin* at heights >7 m OD. *Spartina anglica* (common cord-grass) first appears at 7.4 m OD and increases gradually towards the estuary, becoming dominant at heights of 4.2-5.9 m OD, where it is accompanied by *Salicornia* (glasswort). Towards the marsh edge vegetation cover becomes patchy, disappearing entirely at 4.2 m OD. At the site of the transect, the transition from salt marsh to mudflat is gradual, but further south, at Station 1, the salt-marsh edge forms a small cliff and the mudflat surface is at 3.2 m OD.

This pattern of zonation is typical of Aust Warth, although the landward side of the marsh c. 300 m north of the transect comprises an area of *Phragmites australis* (common reed) reedswamp.

The quadrat data were collected on 1st September, by which time some of the smaller spring-flowering plants noted during the sampling visit in May were no longer visible. In particular, *Cochlearia anglica* (English scurvygrass) was abundant in the upper and middle part of the low marsh in May, accompanied by *Glaux maritima* (sea-milkwort) in the middle part. The horizontal positions of some of the vegetation boundaries also shifted between May and September, with the halophytes (salt-tolerant plants) occurring further inland in September than in May. For example, *Atriplex* was first recorded at 100 m along the transect in May, but appeared from 20 m in September. The dense mat of *Puccinellia* appeared 200 m along the transect in May, but began at 110 m in September.

During the January visit no plants were recorded in flower on the salt marsh. In early May, *Cochlearia* and *Triglochin* alone were flowering, while by late August *Spartina* and *Aster* were flowering, and a few plants of *Atriplex* remained in flower, most having set seed. *Elytrigia* and *Triglochin* had also set seed by this time. The sampling regime did not include the

flowering periods of *Elytrigia*, *Festuca* or *Puccinellia* in the 2004 season.

Overall, the vegetation zonation as recorded in 2004 is similar to that of Smith's 1978 survey (Smith 1979), taking into consideration the different times of year in which the records were made. However, Smith doesn't mention the presence of *Triglochin* at Aust Warth, whereas it is now quite abundant, suggesting that the plant was previously suppressed by grazing.

Pollen analysis

Pollen assemblages from all three stations for the three sampling periods are compared in Figure 4. The most obvious point to emerge is the remarkable similarity of the pollen assemblages between stations (mudflat compared to salt marsh) and in different seasons. The dominant taxa are *Pinus sylvestris* (pine), *Quercus* (oak), *Alnus glutinosa* (alder), Poaceae (grasses), and Pteropsida (fern spores). Of these, only the grass pollen could have originated from the salt marsh itself, indicating that the contribution of pollen from the *in situ* vegetation is minor compared to that from the wider catchment.

Spartina was flowering during August/September and so would be expected to contribute to the samples from this period. Pollen of *Spartina anglica* is relatively large – c. 45-50 µm – in the size range of the *Avena-Triticum* group, and does reach its greatest abundance (although a maximum of only 2.5%) in the August/September salt-marsh samples. Like cereals, *Spartina* would seem to be strongly under-represented in the pollen record. Undifferentiated Poaceae pollen is most abundant in the January samples, when there were no grasses in flower on the salt marsh. Some species of grasses flower virtually all year round, so a contribution of atmospheric or waterborne pollen from the wider catchment is possible. It is likely, however, that most of the Poaceae pollen deposited on the salt marsh comes from the 'reservoir' of pollen in the estuarine water body that remains in suspension for periods of months or years.

With regard to the representation of other salt-marsh plants, most have pollen that cannot be

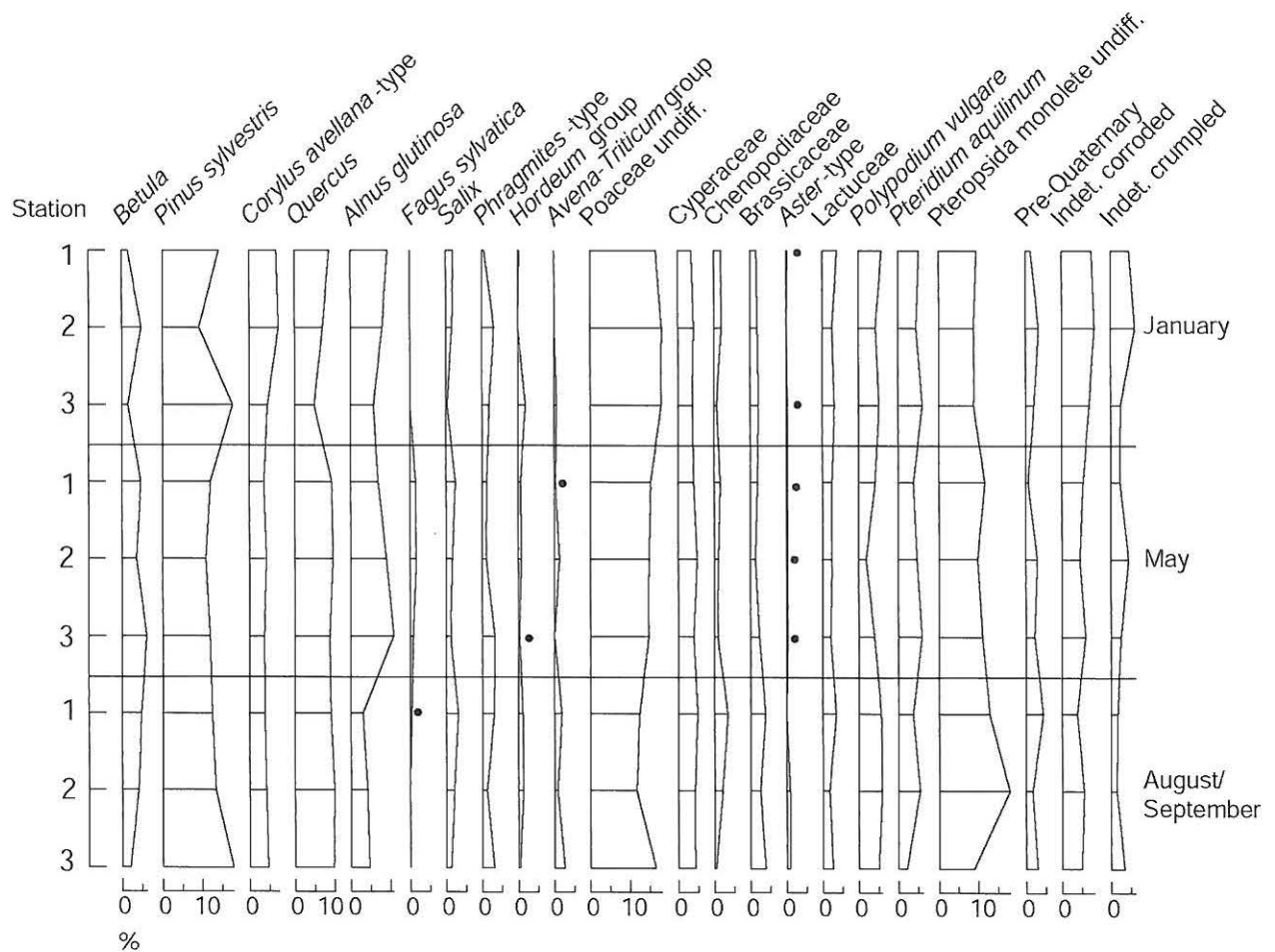


Figure 4: Pollen percentage diagram (selected taxa) for surface samples from Aust Warth and Northwick Warth. Dots indicate values < 0.5%. For pollen sums see text.

identified to species level. *Atriplex*, *Salicornia* and *Suaeda* are all members of the Chenopodiaceae family and cannot be distinguished on the basis of their pollen. Several members of the same family are common weeds of arable ground, eg *Chenopodium album* (fat-hen), although these are unlikely to form a significant component of the assemblages analysed here. The Northwick samples contained surprisingly little Chenopodiaceae pollen (maximum 3.4%), given that Stations 2 and 3 were both located within 120 m of *Salicornia* growth and scattered *Atriplex* and *Suaeda*. Although only *Atriplex* remained in flower during the August/September sampling period, higher Chenopodiaceae pollen percentages might still have been expected in the corresponding sample due to persistence of pollen from this and other members of the family flowering a few weeks earlier in suspension in the estuarine water body.

Significantly higher frequencies of Chenopodiaceae pollen (often c. 20%, but sometimes up to 80%) have been recorded from mid-Holocene silts from the Severn Estuary (eg Caseldine 2000; Dark and Allen 2005), in deposits too early to represent arable weeds. Chenopodiaceae pollen in estuarine contexts can therefore be taken as a good indicator of salt marsh, despite its surprisingly low representation in the modern samples analysed here.

Another good salt-marsh indicator in the pollen assemblages from Northwick and Aust is *Aster*-type, which almost certainly originates from *Aster tripolium*. *Aster*-type is barely recorded in pollen samples from January and May (when *Aster* was not in flower), and recorded in September only at stations 2 and 3 (within 50 m of flowering individuals of the plant). Again, however, pollen percentages are low, with a

maximum of only 0.9%.

Of the dry-land taxa, *Pinus sylvestris* is the most consistently abundant pollen type (mean for all samples 13%), showing little difference between stations and seasons. There are no pine trees within 1 km of the site, so this pollen must have undergone long-distance transport via wind or water. Pine is well known to be over-represented in pollen sequences due to its abundant production of buoyant pollen grains which can be dispersed over great distance by the wind (Bennett 1984). Furthermore, pine pollen has been found to be especially plentiful in estuarine sediments, probably due to its capacity to float for long periods on the water surface (Hopkins 1950; Traverse and Ginsburg 1966; Roe and van de Plassche 2005).

Fern spores are also abundant in the deposits, again in the absence of any obvious major local sources (hedgerows dividing the fields inland of the salt marsh contain some ferns, but there is no woodland within 1 km of the site). As expected, they are most abundant in the September samples, given that most ferns sporulate in late summer/early autumn. Overall abundance may again reflect the significance of the 'reservoir' of pollen/spores in the estuarine water body, where the relative resistance of fern spores to decomposition means that they are over-represented.

Of the less abundant taxa, seasonal differences are particularly clear in *Fagus sylvatica* (beech), reaching frequencies > 0.5% only in the May samples, and *Corylus avellana* (hazel) – most abundant (maximum 7.45%) in January. These patterns correspond well with the flowering periods of these plants, suggesting some airborne tree pollen deposition.

The frequencies of indeterminable corroded and crumpled pollen are greatest in January (maxima of 8.2% and 6.1% respectively). This is to be expected, given that pollen deposited at this time of year must – with the exception of at least some of the hazel and possibly grass pollen – have remained suspended in the water body for several months at least.

DISCUSSION

The results of this study, while preliminary, have a number of implications for interpretation of pollen data from deposits that accumulated in low marsh or mudflat environments. At sites low in the tidal frame, the predominant source of pollen and spores appears to be the estuarine water body, where they may have remained in suspension for prolonged periods, or have been reworked from earlier deposits. Thus the pollen and spores deposited on the mudflat/low marsh surface do not closely relate to the surrounding contemporary vegetation. Some elements of the salt-marsh flora may be distinguishable in the pollen assemblages (eg *Aster tripolium*), and contemporary arboreal vegetation on neighbouring dry land is represented to some degree, but their pollen signatures are muted compared to that from the pollen 'reservoir' in the well-stirred water body.

This 'reservoir' contains pollen from a wide area, including riverine inputs from the Severn catchment and tributaries such as the Wye, which discharges opposite Northwick Oaze. Pollen transport via rivers may explain the relatively high values for *Alnus glutinosa*, which occurs only sparsely within 1 km of the site, but is widespread along the river valleys of the Severn catchment. River discharge tends to be greatest in January (Allen and Duffy 1998), perhaps explaining the relatively high frequency of *Alnus* pollen in the January samples, at least a month before it began flowering. In contrast to the atmosphere, pollen and spores remain abundant in rivers and stream all year, and river transport is important for species that are poorly air-dispersed, such as ferns (cf Peck 1973). This probably explains why spores of *Polypodium vulgare* (polypody), *Pteridium aquilinum* (bracken) and Pteropsida undiff. are well represented in samples from all seasons.

There is no consistent difference between pollen assemblages from the unvegetated mudflat and the low marsh, suggesting that these two environments are indistinguishable on the basis of their pollen assemblages. Analysis of macroscopic plant remains may, however, allow them to be separated. Samples from higher on the marsh, where tidal inundation is less frequent, and hence the supply of water-borne pollen is reduced,

would probably show a greater proportion of pollen from the local salt-marsh vegetation.

Large grass pollen grains, classifiable as of cereal-type, occur in most of the samples. During the sampling period there was no cereal cultivation within 1 km of the site, so the cereal-type pollen may represent long-distance transport of contemporary cereal pollen by the atmosphere or rivers, non-contemporary cereal pollen suspended in the estuarine water body, or pollen of wild grasses such as *Spartina*, *Glyceria*, *Elytrigia* or *Hordeum* spp. growing in the salt marsh or elsewhere. Given that most cereals are self-pollinated and release very little pollen to the atmosphere, long-distance airborne transport is unlikely. Cereal pollen could, however, have been washed from cereal crops into streams and rivers and thus become incorporated into the estuarine waters, potentially then being deposited on the salt marsh/mudflat at any time of year. Given that much of the low marsh is dominated by *Spartina*, this is highly likely to be the source of at least some of the *Avena-Triticum* group pollen in the samples. The results from Northwick urge caution in interpretation of the presence of 'cereal-type' pollen in estuarine deposits, as there are several potential sources of such pollen, other than local cereal cultivation.

Although pollen of *Spartina anglica* is the most likely source of the *Avena-Triticum* group pollen in the modern samples analysed here, this will not have been the case in pre-modern samples. *S. anglica* arose c. 1890 in Southampton Water from *S. x townsendii*, which was the result of a cross between the native *S. maritima* and introduced *S. alterniflora* (Goodman *et al* 1969). The native *S. maritima* has pollen grains c. 40 µm in diameter (Marchant and Goodman 1969), smaller than *S. anglica*, but still within the 'cereal-type' size range. Therefore the potential remains for confusion between pollen of cereals and *Spartina* in Holocene estuarine sediment sequences.

This research represented a pilot study to assess methods of collection of pollen inputs to salt marshes, given the problem of twice-daily tidal inundation, and whether modern estuarine silts would contain quantifiable levels of pollen. Interpretation of the results is constrained by the

small number of samples, limited number of collection periods, and collection of samples only from the lower parts of the salt marsh. Future research will involve analysis of a greater number of samples from a wider range of locations (including the high marsh, where inundation is infrequent), and at monthly intervals, to allow an assessment of the pollen contribution of all elements of the marsh flora. Samples may also be taken from the upper 1 cm of sediment at each sampling site for comparison with trap data. In addition, attempts will be made to sample different components of the pollen rain (eg atmospheric supply) separately.

CONCLUSIONS

- Identification of the salt-marsh component of the pollen rain in estuarine sediment sequences is problematic due to non-specific pollen identification of most salt-marsh plants (eg members of the Poaceae family), but pollen of Chenopodiaceae and *Aster*-type appear to be good indicators of salt marsh.
- *In situ* vegetation seems to provide only a minor contribution to pollen deposition in low marsh contexts. The principal source of pollen to estuarine mudflats and low marsh deposits is the well-stirred estuarine water body. Pollen assemblages from such estuarine contexts thus do not provide an accurate reflection of contemporary surrounding vegetation.
- 'Cereal-type' pollen in intertidal deposits is most likely to derive from local growth of *Spartina*, or possibly river-borne pollen of cereals from the wider catchment. Local cereal cultivation cannot be inferred.
- The similarity of pollen assemblages from unvegetated mudflat and salt-marsh samples suggests pollen analysis is unlikely to allow separation of mudflat and low marsh contexts.

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