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Mid-Holocene Vegetation History and Human Impact in the Middle Severn Estuary: palaeoenvironmental data from the coastal submerged forest at Woolaston, Gloucestershire

by Alex Brown
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Mid-Holocene Vegetation History and Human Impact in the Middle Severn Estuary: palaeoenvironmental data from the coastal submerged forest at Woolaston, Gloucestershire

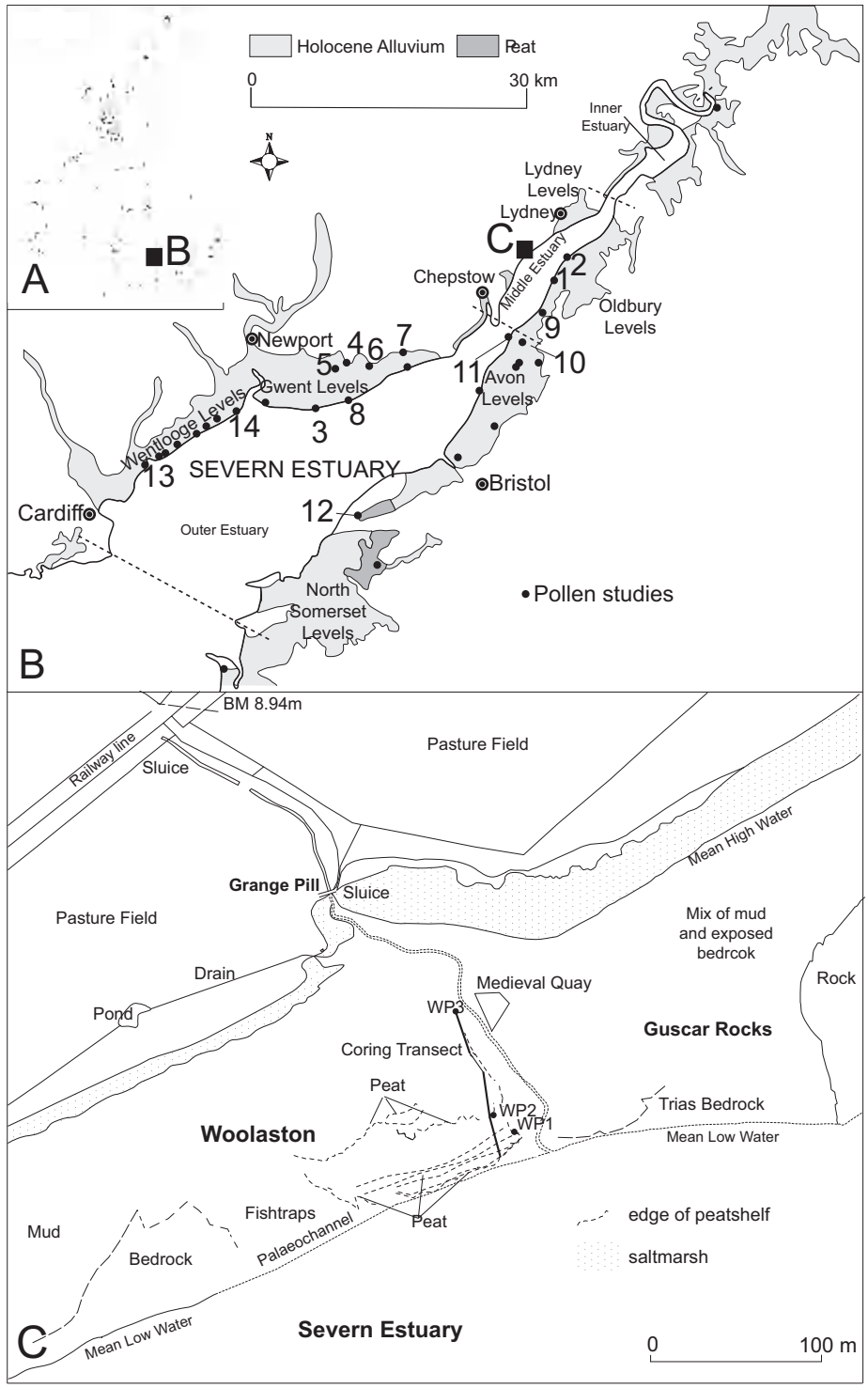
By ALEX BROWN

Introduction

Distributed along the shores of the Severn Estuary and inner Bristol Channel are extensive coastal lowlands known collectively as the Severn Estuary Levels (Fig. 1). Now largely reclaimed and drained, and under pasture, these wetlands comprise a sequence of estuarine muds and semi-terrestrial/terrestrial peats of Holocene date, that have accumulated as a result of an upward, but fluctuating trend in post-glacial sea-levels (Allen 1987; Allen and Rae 1987). Outcropping widely along the intertidal zone, they represent some of the best exposures of Holocene sediments in north-west Europe, including extensive submerged forest beds and ombrotrophic mires. The Severn Estuary is also noted for the density, variety and quality of preservation in wetland archaeology. Human exploitation of the intertidal marshes and peatlands is well documented from the late Mesolithic to the post-medieval (e.g. Coles and Coles 1986; Rippon 1997; Bell *et al.* 2000; Bell 2007). Despite early pollen studies (Godwin 1940; Hyde 1936) the potential for reconstructing coastal vegetation history was not exploited until the late 1980s with the work of Smith and Morgan (1989) at Goldcliff East.

Key palaeoenvironmental studies have now been undertaken at numerous locations along the foreshore and embanked wetlands of the outer estuary (Fig. 1). These include detailed investigations associated with widespread late Mesolithic activity identified on the bedrock island at Goldcliff West and East (Bell *et al.* 2000; Bell 2007). Pollen studies have been produced from the interior of the Welsh Levels at Barland's Farm, Vurlong Reen (Walker *et al.* 1998) and Caldicot (Nayling and Caseldine 1997), the latter linked to extensive evidence for Bronze-Age activity identified from a complex of palaeochannels. This author has undertaken detailed palaeoenvironmental reconstruction on the interior Gwent Levels at Llandevenny (Brown 2005), associated with artefactual evidence for late Mesolithic and early Neolithic occupation of the wetland edge. Important developer funded work has also taken place east of Cardiff along large stretches of the Wentlooge Levels, including palaeoenvironmental analysis in advance of the Cardiff International Railfreight Terminal (Walker *et al.* 2002) and the Wentlooge Sewers (Yates *et al.* 2001).

On the English side of the estuary Gilberston *et al.* (1990) report on several pollen sequences from the Avon Levels, including a late-glacial/Holocene sequence from the Gordano Valley, Somerset. These are supplemented by recent palaeoenvironmental work in advance of industrial development on the Avon Levels, particularly around Avonmouth and Severnside. Deep Holocene sediment sequences and associated pollen data are reported on by Cater *et al.* (2003) along the route of the Pucklechurch to Seabank pipeline, and more recent work at the Western Approaches


Holocene Alluvium
Peat
0
30 km
N
A
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Inner Estuary
Lydney Levels
Lydney
C
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Middle Estuary
12
Oldbury Levels
9
10
Newport
4
6
7
5
11
Avon Levels
Gwent Levels
8
3
14
Wentlooge Levels
13
SEVERN ESTUARY
Bristol
Cardiff
12
Outer Estuary
North Somerset Levels
Pollen studies
B
BM 8.94m
Railway line
Sluice
Pasture Field
Mean High Water
Grange Pill
Sluice
Pasture Field
Mix of mud and exposed bedrcok
Drain
Rock
Medieval Quay
Pond
WP3
Guscar Rocks
Coring Transect
Peat
Trias Bedrock
WP2
WP1
Woolaston
Mean Low Water
Fishtraps
Peat
edge of peatshelf
Mud
Palaeochannel
Bedrock
saltmarsh
C
Mean Low Water
Severn Estuary
0
100 m

Distributor Park (Ritchie *et al.* 2007). More widely within the English Severn Estuary, important palaeoenvironmental studies have been undertaken at Gravel Banks and Burnham-on-Sea (Druce 2001, 2005). Significant palaeoenvironmental studies have been produced from the central Somerset Levels, associated with numerous timber trackways and structures of Neolithic and later date (Dewer and Godwin 1963; Coles and Hibbert 1975; Beckett and Hibbert 1978 and 1979; Hibbert 1977 and 1980; Caseldine 1980 and 1984; Coles *et al.* 1988), and to the west from Bridgwater Bay, including from palaeochannels at Walpole containing early Neolithic timber structures (Hollinrake *et al.* 2002; Hollinrake and Hollinrake 2006a and b). In addition, pollen studies are available from contemporary Holocene deposits in the Bristol Channel at Porlock (Jennings *et al.* 1988), Minehead, Somerset (Jones *et al.* 2004), and Westward Ho!, Devon (Balaam *et al.* 1987).

Consequently, a good record already exists for the archaeology and palaeoecology of the outer estuary and Bristol Channel. However, less attention has been focused on the middle estuary. Outcrops of Holocene sediment are known at Oldbury Flats (Allen 1998), Hills Flats (Allen and Fulford 1996), Sharpness and Lydney (Lucy 1877). At Woolaston two peats, each with submerged forests, separated by estuarine silts are exposed infilling a broadly north-west–south-east running palaeovalley. The Woolaston submerged forest was first studied in the late 1980s, as part of research aimed at producing the first prehistoric oak tree-ring chronology from England, generating a 228 year oak sequence from 4096–3869 BC (Hillam *et al.* 1990). No further palaeoenvironmental analyses were undertaken despite the potential of linking any study with a dendrochronologically dated submerged forest.

This study represents one of the few pollen-based analyses of a coastal submerged forest sequence, and the first detailed palaeoecological study within the middle Severn Estuary. Previous studies on the east foreshore of the middle estuary at Oldbury Flats (Druce 2005) and Hills Flats (Brown 2006) have either been of low resolution or have tended to focus on the peats at the exclusion of the intervening estuarine silts. Here the peats are comparatively thin and short-lived, providing a rather fragmented picture of mid-Holocene vegetation. In addition, the proximity of the Woolaston sequences to the wetland edge (maximum of *c.*30 m) presents the opportunity to investigate vegetation history and human impact on both the wetland and dry ground. Quantification of the microscopic and macroscopic charcoal content of the sediments is presented in combination with the pollen and macrobotanical record. Microscopic and macroscopic charcoal provide indications about local and regional fire histories and human environmental impact. This is of value for comparison with sequences from the outer estuary where significant evidence for burning of mid-Holocene coastal woodland and reedswamp is apparent, in cases associated with abundant artefactual evidence for contemporary human activity (Bell 2007). This study provides new insights into the role of human and natural agencies in patterns of vegetation change within a coastal landscape previously understudied.

Fig. 1. (opposite) Location and context of Woolaston, Gloucestershire.

B (line drawing by Margaret Mathews, modified by A. Brown). Numbered sites are key Severn Estuary pollen studies mentioned in text (1 Oldbury Flats; 2 Hills Flats; 3 Goldcliff West and East; 4 Llandevenny; 5 Barland's Farm; 6 Vurlong Reen; 7 Caldicot; 8 Redwick; 9 Littleton-on-Severn; 10 Pucklechurch to Seabank pipeline; 11 Gravel Banks; 12 Gordano Valley; 13 Cardiff International Rail Freight Terminal; 14 Wentlooge Sewers).

C. EDM survey by S. Buckley, modified by A. Brown, showing the intertidal zone at Woolaston, extending from the saltmarsh to low water mark. Outcrops of peat are indicated by the hashed lines. Mud covers large areas of the intertidal zone except where peat and bedrock outcrop.

Site Location and Context

Woolaston (OS Nat. Grid ST 592981) lies on the west bank of the middle Severn Estuary, approximately 7.5 km upstream of Chepstow (Fig. 1A–C). The middle Severn Estuary comprises those areas of coastal, embanked and intertidal wetland extending north for *c.*15 km from the 1st Severn Crossing to Sharpness. Woolaston comprises a thin *c.*100 m wide strip of intertidal zone, inundated twice-daily, bounded landward by stepped saltmarsh of the Rumney, Awre and Northwick Formations (Allen and Rae 1987). The Holocene sediments are exposed over a distance of *c.*100 m of foreshore south-east from Grange Pill, outcropping between +2.3 and -2.7 m above OD, decreasing in OD height towards low water mark. They are largely covered by modern mud deposits, but are exposed where they are eroded as small cliffs between 10 and 30 cm high, indicated by the hashed lines on the EDM (Electronic Distance Measurer) survey (Fig. 1C).

Geology

The bedrock comprises an uneven platform of Triassic mudstones and sandstones (Mercia mudstone). Immediately east of Grange Pill exposures of Trias are visible at low tide, forming the west edge of the Guscar Rocks. The bedrock descends to the south-west beneath the Holocene deposits to an elevation of *c.*-2.7 m above OD, visible at low water mark along the heavily eroded lower foreshore. The Holocene sediments are completely eroded away *c.*100 m south-west of Grange Pill, exposing Trias rising in elevation on the south side of the palaeovalley.

Archaeology

Previous research at Woolaston has recorded numerous archaeological contexts on the foreshore, largely medieval in date (Fig. 1). These include the remains of a medieval quay, located on the northern banks of Grange Pill. The quay consists of two stone and timber structures, an upper and lower quay, extending over 35–40 m alongside the pill, with construction dendrochronologically dated to the mid 12th and early 13th century (Fulford *et al.* 1992). The quay forms part of a larger medieval landscape, focused on Woolaston Grange, including a chapel that formed the centre of the estates of Tintern abbey at Woolaston. Survey by Townley (1998) along the foreshore from Stroat to Woolaston also identified a series of wooden structures, including several undated, but most probably medieval, fishtraps, located 100 m south of Grange Pill within a palaeochannel (Fig. 1C). A recent survey of the intertidal zone during 2004 produced little archaeological evidence for prehistoric activity (Brown *et al.* 2005). A few unstratified flint flakes of indeterminate date were recorded, none in primary contexts. Six were recorded from the edge of the saltmarsh north of Grange Pill, all of a yellowish-brown flint derived from battered, water-worn and frost-fractured gravels and cobbles. One flake was also retrieved close to the saltmarsh edge south of the pill.

Methods

Pollen and charcoal particle analysis

Sub-samples of sediment 1 cm thick and *c.*1 cm^3 in volume were taken for pollen and charcoal particle analysis. Samples were taken at intervals of 1–4 cm, with closer interval sampling at 2 mm from banded organic/estuarine sediments in monolith sequence WP2. Samples were chemically prepared using standard laboratory techniques (Moore *et al.* 1991), with the addition of tablets

containing *Lycopodium* spores to enable calculation of pollen concentrations and microscopic charcoal area. Samples were analysed under a Leica DME trinocular microscope at ×400 magnification, with critical determinations at ×1000 magnification. A minimum of 300 pollen grains and fern spores was identified per sample, excluding aquatics and *Sphagnum*. All taxa follow current nomenclature established in Bennett *et al.* (1994). Indeterminable grains were recorded according to the categories established in Cushing (1967). Pollen percentages are expressed as a percentage of total land pollen, excluding aquatics and *Sphagnum*, which are expressed as a sum of the total land pollen plus aquatics and *Sphagnum*. Pollen data were zoned and diagrams constructed using the Psimpoll version 4.10 computer programme (Bennett 2002). Pollen zonation is based on a comparison of the results of binary splitting by sum of squares, optimal splitting by sum of squares, and constrained cluster analysis (CONISS). Microscopic charcoal was quantified using the point count method (Clark 1982).

Macrobotanical analysis

Sub-samples of sediment 1 cm thick and with a minimum volume of 50 ml displacement by water were taken for macrobotanical analysis at intervals of 1–8 cm from monolith tins WP1–3. Sediment was washed through a nest of sieves of 1 mm, 500 µm and 250 µm mesh size. All samples were analysed under a Meiji EMT binocular microscope at ×10–20 magnification. Botanical remains were identified using published guides (Berggren 1969a, b; Anderberg 1994) and the macrobotanical reference collection in Plant Sciences, University of Reading. Vascular plant nomenclature follows Stace (1991). The macroscopic charcoal content of sieved samples is expressed as the total number of fragments within four size classes (250–500 µm; 500 µm–1 mm; 1–5 mm and 5–10 mm).

Radiocarbon dating

The Natural Environment Research Council (NERC) funded four AMS dates through the Oxford Radiocarbon Dating Service (ORADS). Samples consisted of peat bulks 1 cm thick, charcoal of *Phragmites australis* or identified seeds of individual species. All radiocarbon dates are quoted in radiocarbon years BP, followed by the laboratory code and the calibrated BC range at the 95 per cent confidence level (Table 1). The calibration curve used is that of Reimer *et al.* (1998), using the OxCal version 3.10 computer programme (Bronk-Ramsey 2005).

Table 1. Radiocarbon dates from sequences WP1, 2 and 3.

Sample i.d	Depth (cm)	Type of material	^{13} value	$^{14}C^{years}$ BP	Lab code	CAL BC 68.2% prob.	CAL BC 95.4% prob.
WP1–1	74–75	1 cm peat bulk	-28.2	6819 ± 33	OxA-13699	5725–5660	5775–5635
WP2–1	19.3–19.5	Charcoal	-26.7	5420 ± 40	OxA-14003	4335–4245	4350–4050
WP3–1	43–44	1 cm peat bulk	-26.1	5256 ± 35	OxA-13878	4220–3980	4230–3970
WP3–2	5–6	*Rubus idaeus/ fruticosus* seeds	-28.5	4910 ± 40	OxA-13879	3704–3656	3770–3640

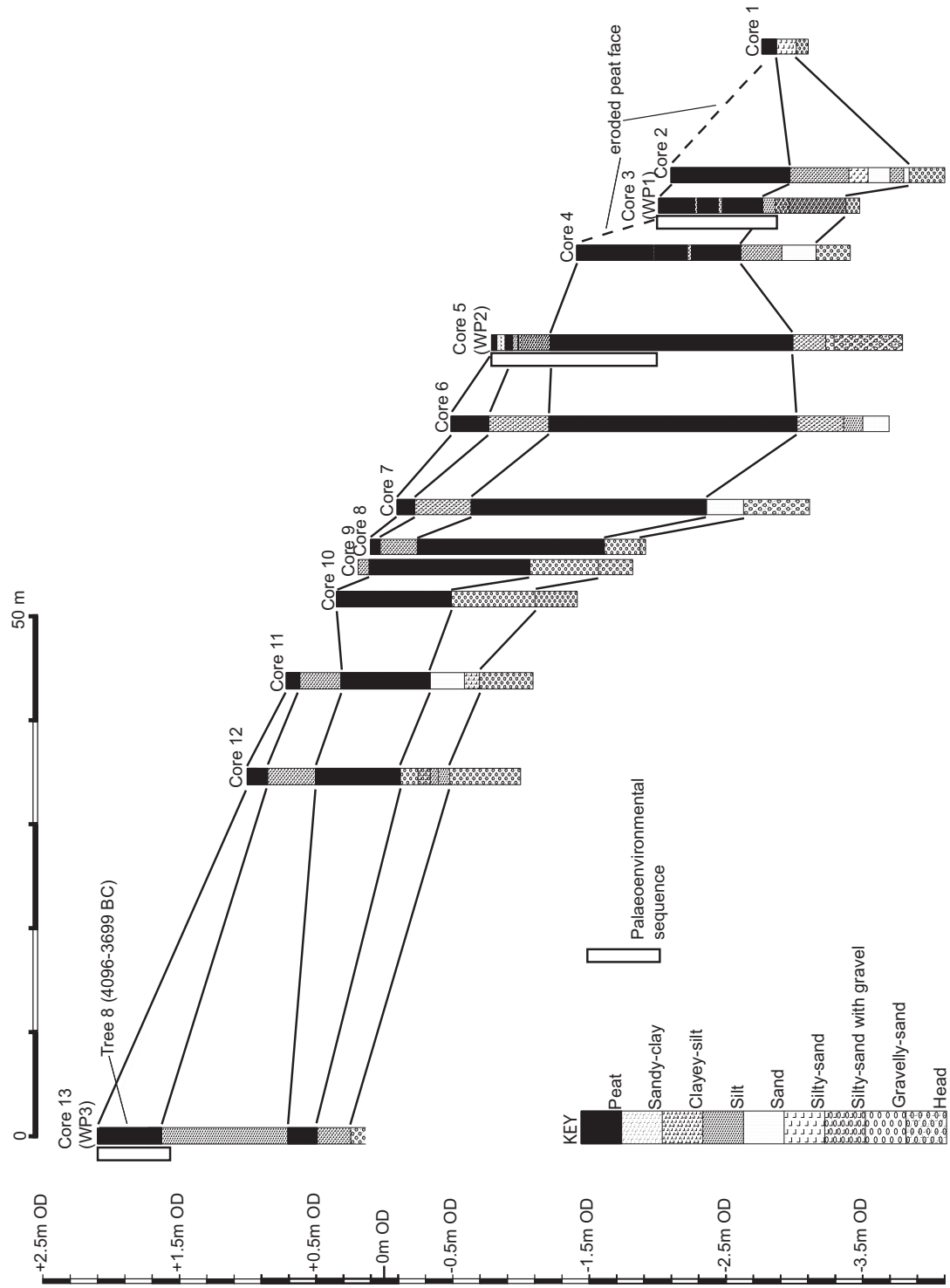

Fig. 2. Coring transect and location of palaeoenvironmental samples.

Results and Interpretation

Stratigraphic sequence

A detailed auger survey (Fig. 2) was undertaken to establish the nature of the sediments prior to palaeoenvironmental sampling (Brown *et al.* 2005). In summary, the sequence consists of an uneven bedrock platform overlain by head and a basal old land surface. This is sealed by a sequence of peats and estuarine silts of the middle Wentlooge Formation (Allen 1987), deposited from *c.*5775–3640 cal BC. There are two peat beds: a lower peat which seals the basal old land surface, and an upper peat, separated from the lower peat by estuarine silts. Both beds contain abundant stumps and timbers, the lower peat forest dominated by *Alnus* (alder), the upper peat forest by *Quercus* (oak). The upper peat is sealed by estuarine silts of the upper Wentlooge Formation, directly overlain by much later 17th-century sediments of the Rumney Formation (Allen 1987), the interface representing an erosional break in the sequence recorded widely throughout the Severn Estuary (Allen and Haslett 2006).

Palaeoenvironmental analysis

Samples were obtained from three locations on the intertidal zone using monolith tins inserted into the section faces of hand excavated pits. Each of the sampled monolith tins (Fig. 2) represents successive stages in the Holocene sequence, with minimal overlap between them. The stratigraphy of each sequence is detailed in Tables 2–4. All depths are measured in ordnance datum height (OD). Pollen, charcoal and macrobotanical data are described in outline only within the context of local pollen zones, highlighting the principal vegetation changes. The complete palaeoenvironmental data can be found in Brown (2005).

Sequence WP1 (Fig. 3)

Zone WP1–1 (-2.80 – -2.63 m above OD): pollen indicative of mixed deciduous woodland dominated by *Tilia* (lime), *Quercus* (oak), *Ulmus* (elm) and *Corylus avellana*-type (hazel), with limited stands of *Betula* (birch) and *Pinus sylvestris* (Scots pine). Pollen of *Alnus glutinosa* (alder) increases with the transition to peat, dated to 6819±33 BP (OxA-13699, 5775–5660 cal BC), reflecting encroachment of *Alnus* carr-woodland. An understorey of sedges is suggested by numerous *Carex* (sedges) seeds. A slight increase in pollen of Chenopodiaceae (goosefoots) and Poaceae (grasses) *c.*-2.7 m above OD, and an increase in macroscopic charcoal *c.*-2.69 m above OD, may reflect the effects of fire on the surrounding vegetation, though the association is ambiguous.

Zone WP1–2 (-2.63 – -2.48 m above OD): pollen of *Tilia* declines, most probably as a result of paludification, with mixed deciduous woodland remaining dominant on the dry ground. Increased presence of fern spores, Pteropsida (undifferentiated fern spores), *Polypodium* (polypodies) and *Dryopteris filix-mas* (male fern spore), may reflect a locally more open carr-woodland canopy.

Zone WP1–3 (-2.48 – -2.39 m above OD): spores of *Dryopteris filix-mas* increase, reflecting drier niches within the carr-woodland, perhaps growing on the stools of old trees and sedge tussocks (Peterken pers comm.). There is a minor marine inundation from -2.42 – -2.39 m above OD, represented by an indistinct band of estuarine clay, during which pollen indicative of saltmarsh increase slightly (e.g., Chenopodiaceae).

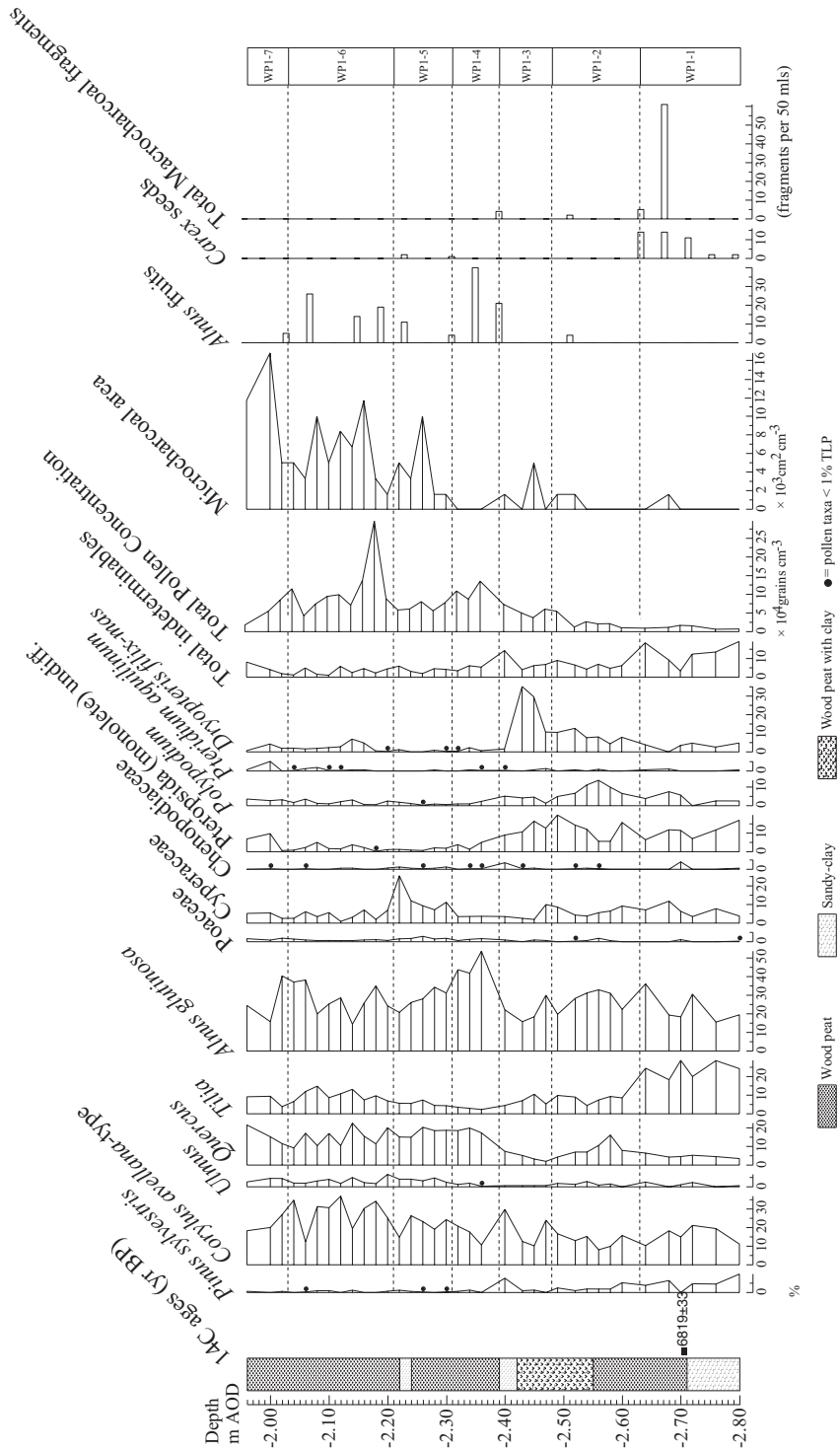

Fig. 3. Sequence WP1, selected taxa pollen, charcoal and macrobotanical diagram.

Zone WP1–4 (-2.39 – -2.31 m above OD): pollen and seeds of *Alnus glutinosa* increase, reflecting the local dominance of carr-woodland, subsequently declining in favour of *Quercus*, *Corylus*, *Ulmus* and *Tilia*. The increase in *Quercus* may reflect some colonisation of the drier margins of the wetland, combined with an increased influx of pollen from woodland on the dry ground.

Zone WP1–5 (-2.31 – -2.21 m above OD): pollen of Cyperaceae (sedges) and Poaceae increases, probably reflecting a locally wetter carr-woodland with an increased tall herb fen component. This occurs prior to a short phase of marine inundation from -2.24 – -2.22 m above OD, again represented by an indistinct band of estuarine clays.

Zone WP1–6 (-2.21 – -2.03 m above OD): locally drier conditions are suggested by an increase in spores of *Dryopteris filix-mas* and a decline in Cyperaceae. The increase in the local abundance of alder towards the end of the zone is reflected in the simultaneous rise in both pollen and seeds of *Alnus glutinosa* fruits.

*Zone WP1–*7 (-2.03 – -1.96 m above OD): slightly more open conditions are indicated by the subsequent decrease in pollen of *Alnus glutinosa* and *Corylus avellana*-type and an increase in fern spores.

Table 2. Sequence WP1, lithostratigraphic sequence.

0–26 cm	Dark reddish-brown wood peat containing abundant wood rootlets.
26–28 cm	Greenish-grey estuarine clay.
28–43 cm	Dark reddish-brown wood peat containing abundant wood rootlets.
43–46 cm	Greenish-grey estuarine clay.
46–59 cm	Dark reddish-brown wood peat with clay, including abundant wood rootlets.
59–75 cm	Dark reddish-brown wood peat containing abundant wood rootlets.
75–84 cm	Greenish-grey sandy clay.

Sequence WP2 (Fig. 4)

Zone WP2–1 (-1.95 – -1.72 m above OD): moderately high values for *Alnus glutinosa* and Cyperaceae pollen suggest the continued presence of *Alnus glutinosa* carr-woodland, with spores of Pteropsida and *Thelypteris palustris* (marsh fern) forming part of the herbaceous understory and *Dryopteris filix-mas* continuing to grow within the drier niches of the fen-wood.

Zone WP2–2 (-1.72 – -1.57 m above OD): increase in pollen and spores of Cyperaceae, Poaceae, Pteropsida, *Polypodium* and *Thelypteris palustris*, and a reduction in pollen of *Alnus glutinosa* suggest locally wetter conditions.

Zone WP2–3 (-1.57 – -1.37 m above OD): the high percentages of *Alnus glutinosa* pollen from -1.55 – -1.42 m above OD represent a phase of locally dominant carr-woodland. The subsequent decline from -1.42 m OD, at transition from wood to reed peat, represents a retrogressive hydroseral succession to reedswamp, with an increase in pollen of Poaceae (most-probably representing the common reed, *Phragmites australis*) and then Cyperaceae.

Table 3. Sequence WP2, lithostratigraphic sequence.

0–4 cm	Black oxidised wood peat.
4–10 cm	Dark greenish-grey organic clay containing occasional fragments of *Phragmites* rhizomes.
10–12 cm	Black reed peat with clay.
12–13 cm	Dark greenish-grey organic clay.
13.0–15.5 cm	Black reed peat with clay.
15.5–19.3 cm	Greenish-grey estuarine clay containing occasional *Phragmites* rhizomes.
19.3–19.5 cm	Structureless organic band.
19.5–19.7 cm	Greenish-grey estuarine clay band.
19.7–20.0 cm	Structureless black organic band.
20–43 cm	Greenish estuarine clayey silt containing ooccasional *Phragmites* rhizomes.
43–65 cm	Black reed peat containing moderately abundant *Phragmites* rhizomes.
65–117 cm	Dark reddish-brown wood peat containing abundant wood rootlets. Charred wood at the interface between wood and reed peat.

Zone WP2–4 (-1.37 – -1.04 m above OD): fluctuations in pollen of Cyperaceae and Poaceae and *Carex* seeds through this zone reflect fluctuating ground water, favouring the localised expansion and contraction of fen-swamp habitats (e.g. reedswamp). Chenopodiaceae and *Aster*-type (michaelmas-daisies) pollen increase *c.*-1.21 m above OD with the transition from reed peat to silty-clay, representing a phase of marine inundation and *in-situ* saltmarsh. *Pinus sylvestris* also increases, but is frequently over-represented in estuarine sediments owing to the profuse production, long-distance dispersal and buoyancy of its pollen grains (Bennett 1984), and is unlikely to have been growing locally in substantial quantities. An increased influx of *Quercus* pollen from the adjacent dry ground occurs. Pollen of *Pteridium aquilinum* (bracken), *Polypodium* and *Dryopteris filix-mas* perhaps reflects the ground flora element of nearby dry ground woodland. There is a marked increase in macroscopic charcoal *c.*-1.34 – -1.33 m OD (*c.*130 fragments). Several fragments are identifiable as charred reed stems, but are associated with several fragments of wood charcoal, most probably representing a phase of reed burning during which trees still extant within the reedswamp were also charred

Zone WP2–5 (-1.04 – -0.95 m above OD): characterised by an increase in pollen of *Potamogeton* (pondweed) and *Sparganium* (unbranched bur-reed), reflecting a transition between aquatic and swamp vegetation habitats. This may represent a eutrophic *Sparganium* swamp within shallower waters or at the water margins, and a *Potamogeton* aquatic habitat within areas of deeper or faster moving water. There are several peaks in charcoal, including a marked rise in microscopic and macroscopic charcoal within the second of the two organic bands (-0.973 – -0.975 m above OD), dated 5420±40 BP (OxA-14003, 4335–4245 cal BC). Microscopic charcoal fragments preserve cellular structure identifiable as a member of the Poaceae family, whilst macroscopic charcoal fragments include charred reed stems. This may reflect burning of a fringing *Phragmites*-Cyperaceae swamp. The spike in both micro and macroscopic charcoal is followed by a subsequent decline in arboreal pollen.

Zone WP2–6 (-0.95 – -0.78 m above OD): characterised by a sharp rise in pollen of Poaceae, an increase in microscopic charcoal area, and an overall decrease in arboreal pollen. This is succeeded by a transition to sedge fen-swamp, represented by Cyperaceae pollen and *Carex* seeds, but with

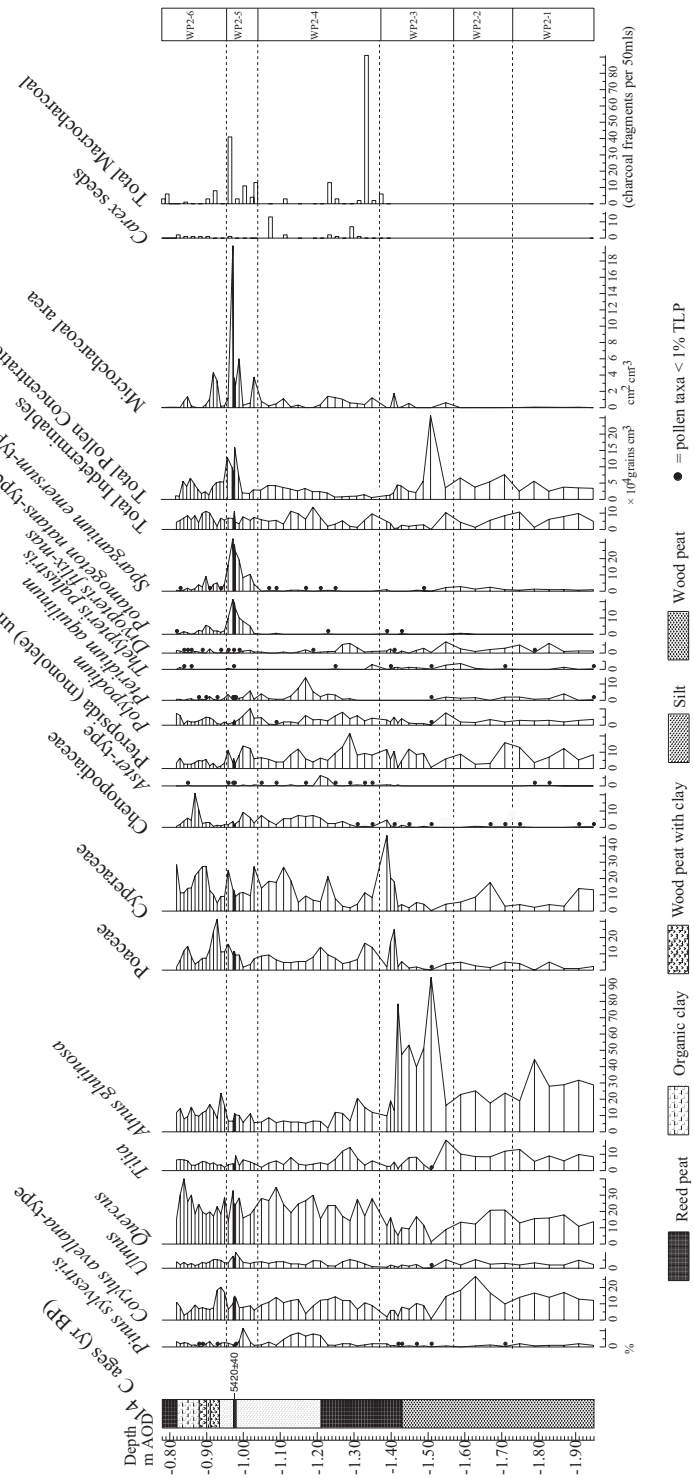

Fig. 4. Sequence WP2, selected taxa pollen, charcoal and macrobotanical diagram.

Alnus glutinosa and *Salix* (willow) forming increased components of the local vegetation. The marked rise in Chenopodiaceae pollen reflects nearby saltmarsh, occurring at the transition from organic clay to estuarine clayey silt. The peat from -0.82 – -0.78 m above OD was oxidised, and no pollen survived.

Sequence WP3 (Fig. 5)

Zone WP3–1 (1.60–1.69 m above OD): the transition to reed peat, dated just prior to 5256±35 BP (OxA-13878, 4230–3970 cal BC), is characterised by a decrease in *Alnus glutinosa* pollen and an increase in pollen of Cyperaceae and Poaceae and seeds of *Eupatorium cannabinum* (hemp agrimony) and *Carex*, most probably representing tall herb fen-swamp with isolated stands of *Alnus* carr-woodland. The first of two *Ulmus* declines occurs *c.*1.66 – 1.67 m above OD. The associated dendrochronological (4096–3699 BC: Brown *et al.*, 2005) and radiocarbon dates (4230–3970 cal BC) are similar to calibrated date ranges for the *Ulmus* decline from the British Isles (Parker *et al.* 2002). *Ulmus* percentages halve, though there is a similar downward trend in arboreal pollen values at this time, principally in response to a large increase in Cyperaceae. The decline occurs 2.07 m above OD prior to and after peaks in both micro and macroscopic charcoal, reflecting localised burning, though none of the charcoal was identifiable.

Zone WP3–2 (1.69–1.75 m above OD): gradual reduction of Cyperaceae fen-swamp succeeded by *Alnus*-dominated carr-woodland with the transition from reed to wood peat. The *Quercus* tree adjacent to monolith WP3 (Fig. 2) is dendrochronologically dated to 4096–3699 BC (Nayling pers comm.; Brown *et al.* 2005), indicating that *Quercus* rapidly invaded the wetland following peat formation (4220–3980 cal BC).

Zone WP3–3 (1.75–1.95 m above OD): *Alnus glutinosa* dominates the local vegetation. Pollen and plant macrofossils suggest a floristically diverse carr-woodland. Seeds of *Eupatorium cannabinum*, *Schoenoplectus lacustris* (common clubrush) and *Carex* (sedges), and spores of *Thelypteris palustris* suggest wetter areas within the carr-woodland, with *Quercus* colonising the drier areas. The second decline in *Ulmus* pollen (1.92–1.93 m above OD), is dated, on the basis of an average accumulation rate of the peat (10 years per 1.1 cm) to *c.*5050 BP 14Cyears BP. The decline is characterised by a two-thirds reduction in *Ulmus* pollen. This occurs concurrent with pollen and plant macrofossil evidence for an opening up of the woodland, lasting for perhaps *c.*150 years. The *Ulmus* decline is preceded by a gradual decline in *Quercus* and *Alnus glutinosa*, and an increased influx of *Tilia* pollen from the dry ground. There is a small increase in microscopic and macroscopic charcoal at the time of the decline, perhaps suggesting the possibility of vegetation disturbance in the vicinity at this time.

Zone WP3–4 (1.95–2.07 m above OD): open carr-woodland is suggested by the decrease in *Alnus glutinosa* pollen, and the increased representation of pollen and spores of Cyperaceae, Poaceae, Pteropsida and *Polypodium*, and seeds of *Urtica dioica* (common nettle), *Rubus fruticosus/idaeus* (blackberries and raspberries) and *Carex*. Cyperaceae, Poaceae and *Carex* also suggest wetter areas within the carr-woodland, whilst *Rubus fruticosus/idaeus* is frequently distributed on the drier ground *Urtica dioica* can often form a prominent part of the herbaceous ground layer of *Alnus glutinosa* carr-woodlands, but is also indicative of disturbed ground conditions, or where animals have defecated (Stace 1991). *Urtica dioica* may reflect a local succession of *Alnus glutinosa-Carex* woodland to *Alnus glutinosa-Urtica* woodland, although it is considered more likely to reflect a drier, herbaceous element of the carr-woodland. *Rubus fruticosus* may form a ground layer within drier areas of the carr-woodland, or an element in the dryland woodland, analogous to Rodwell's W10 '*Quercus*

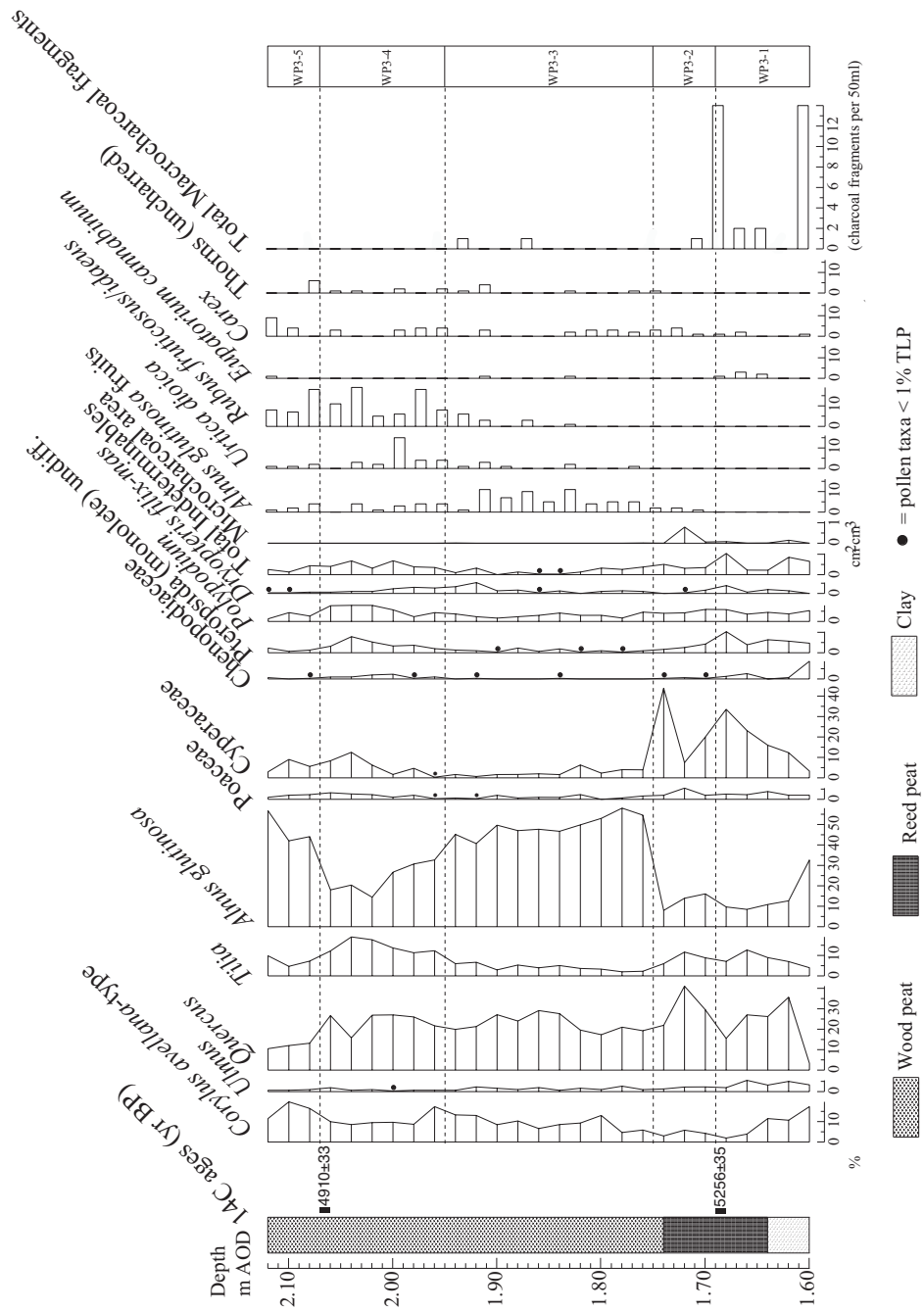

Fig. 5. Sequence WP3, selected taxa pollen, charcoal and macrobotanical diagram.

Table 4. Sequence WP3, lithostratigraphic sequence.

0–38 cm	Dark reddish-brown wood peat, including a dense wood/twig layer from 18–35 cm.
38–48 cm	Black reed peat containing moderately abundant *Phragmites* rhizomes.
48–52 cm	Greenish-grey estuarine clay containing occasional *Phragmites* rhizomes.

robur-Pteridium aquilinum-Rubus fruticosus' woodland, or the W25 '*Pteridium aquilinum-Rubus fruticosus*' under-scrub (Rodwell 1991). This most likely reflects a more open scrubby environment at the interface between the wetland and the dryland, with *Rubus fruticosus* colonising the dryer areas of the *Alnus glutinosa* carr-woodland. The difficulty with making comparisons with the W10 woodland is the under-representation of *Tilia* in present day communities compared to mid-Holocene climax woodlands, where *Tilia* is acknowledged to have formed an important component.

Zone WP3–5 (2.07–2.12 m above OD): an increase in *Alnus glutinosa* pollen suggests a re-establishment of *Alnus*-dominated carr-woodland. The upper peat is sealed by estuarine sediments, representing saltmarsh developing under a marine transgressive phase, radiocarbon dated to just after 4910±40 BP (OxA-13879, 3770–3640 cal BC). Many of the *Quercus* trees preserved in the upper peat represent long-lived components of the wetland-edge flora that died out by 3699 cal BC, most likely as the result of this marine transgressive phase. The similarity between the radiocarbon and dendrochronological dates suggests that there was little truncation of the surface of the upper peat.

Discussion

Coastal change

Exposures of interbedded silts and peats at Woolaston form part of an estuary-wide sequence of sediments that have accumulated over the last *c.*8000 years in direct response to rising Holocene sea-levels (Table 5). The early and late Holocene are silt-dominated, reflecting high intertidal

Table 5. Outline of the Holocene sedimentary sequence in the Severn Estuary (after Allen and Rae 1987).

Formation	**Composition**	**Date**	
Northwick	Grey estuarine clayey silts.	Late Holocene	Started forming late 20th century.
Awre	Grey estuarine clayey silts.		Started forming during 19th century.
Rumney	Pale brown estuarine clayey silts.		Started forming late 17th century.
Wentlooge			
upper	Pale-greenish to blue grey estuarine clayey silts.		Iron Age–Romano-British.
middle	Intercalated estuarine clayey silts and peats.	Middle Holocene	late Mesolithic–Iron Age: *c.*6000 to as late as 200 BC dependent on location.
lower	Pale-greenish to blue grey estuarine clayey silts.	Early Holocene	Before 6000 BC.

mudflats and saltmarsh accumulating under marine transgressive conditions. The mid Holocene is characterised by the development of extensive peat facies interbedded with the silt that formed during periods of stable or falling sea-levels, recording a complex and dynamic relationship between land and sea.

The lower peat at Woolaston is characterised by a long-lived phase (*c.*1000 years) of alder carr-woodland. Similar long-lived alder carr-woodlands have been recorded from pollen sequences on the Gwent Levels at Vurlong Reen (*c.*1800 years), Barland's Farm (*c.*1000 years) (Walker *et al.* 1998), and Goldcliff East (*c.*600 years) (Smith and Morgan 1989), likewise occurring in proximity to the wetland edge. These carr-woodlands were most probably maintained by a constantly high ground-water table sustained by steadily rising sea levels (Kidson and Heyworth 1973). Fluctuations in ground water are apparent in sporadic increases in pollen and seeds of grasses and sedges, accompanied by short-term declines in alder. At Woolaston, discontinuous clay bands in the lower peat reflect short-lived inundations, insufficient to halt peat growth, most probably representing exceptional high tides or storm surges. Subsequent retrogressive succession to reedswamp suggests a period of more rapid sea-level rise, resulting in rising ground-water levels that killed off the alder carr-woodland, later followed by marine inundation of reedswamp.

There are no reliable indications of when or for how long this marine transgressive phase lasted because of a lack of dates from the surface of peats in the middle estuary. Radiocarbon dates can provide a broad time-scale for inundation, but must be interpreted with care because of the possibility that later erosion may have truncated the peat surface. This is not improbable given the increasing evidence identified throughout the estuary for depositional breaks in the Holocene sequence (Allen and Haslett 2006). However, a single radiocarbon date of 5290±90 BP (Wk-7333, 4330–3960 cal BC) from the peat surface at Oldbury Flats, and a date of 5420±40BP (OxA-14003, 4350–4050 cal BC) 20 cm above the peat-silt interface at Woolaston do provide a broad time-frame for estuarine conditions within the middle estuary during the latter half of the 5th millennium cal BC.

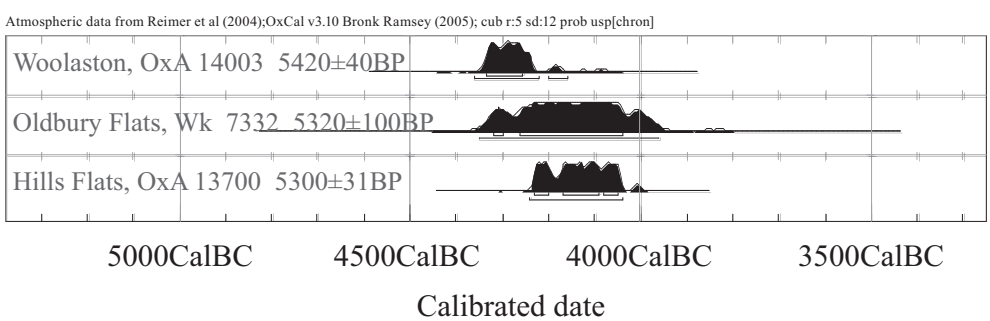

Fig. 6. Radiocarbon dates from the base of upper peats in the middle Severn Estuary.

Radiocarbon dates from the base of the upper peat at Woolaston, Oldbury Flats and Hills Flats (Fig. 6) suggest a broadly coeval marine regressive episode throughout the middle estuary between 4230 and 3970 cal BC. This is comparable with the earliest dates of between 4360 and 4000 cal BC from the base of the fourth peat on the Welsh foreshore (Allen 2005, appendix). Dendrochronological and radiocarbon dates demonstrate that marine regression at Woolaston occurred no later than the 4096 cal BC start date of the Upper Forest Peat 397 year oak sequence, and not before 4230 cal BC, halving the range (134 instead of 260 years) suggested by the

radiocarbon date (Table 1, WP3–1). Marine regression most likely occurred prior to 4096 cal BC, since the wood peat in sequence WP3 is underlain by 10 cm of reed peat (Table 4) that must have formed before parts of the wetland were dry enough for oak to invade. When regression occurred might further be suggested by applying an average accumulation rate for the compacted peat of 1.1 cm per 10 years, the reed peat potentially equating to *c.*90 years of peat growth. The accumulation data must, however, be treated with extreme caution, as they assume a constant accumulation rate through the sequence that otherwise ignores the variable accumulation and compression rates of different peat types.

Comparatively thin, short-lived reed peats developed along the broad eastern wetlands of the middle estuary (Oldbury Levels), without the evidence for a succession to the long-lived alder and oak woodlands seen at Woolaston and on the Gwent Levels (Druce 2005; Brown 2006; Jordan 2006). Instead, silts dominate, suggesting the Oldbury Levels experienced a rather different history to other parts of the estuary, perhaps relating to differences in palaeohydrology. Along the slender west bank of the middle estuary at Woolaston, reedswamp is rapidly succeeded by alder-carr and invading oak woodland from the adjacent dry ground. Oak trees from this forest formed a long-lived component of the wetland. Tree 8 lived for 397 years (4096–3699 BC), substantially extending the 228 year (4096–3869 BC) sequence of Hillam *et al.* (1990).

The death of the Upper Peat Forest, a result of marine inundation or rising ground-water levels, provides an absolute calendrical date of 3699 BC, but does not presuppose a similar date for inundation elsewhere within the middle estuary. Dendrochronological data from other Severn Estuary submerged forests (synthesised in Bell 2007) reveal that inundation was not a single process, with tree deaths between sites varying over time-scales of several decades to a few centuries. The upper peat at Littleton-on-Severn produced a radiocarbon date from 1–3 cm below the peat surface of 4971±31 BP (Wk-18362, 3900–3650 cal BC; Jordan, 2006), comparable to the upper peat date from Woolaston of 4910±40 BP (OxA-13879, 3770–3640 cal BC), nonetheless suggesting a coeval phase of marine inundation commencing between 3800–3640 cal BC.

The upper peat is sealed by estuarine silts of the upper Wentlooge Formation, in turn sealed by much later (17th century AD) estuarine silts of the Rumney Formation, recording an erosional break in the Holocene sequence recorded widely throughout the estuary (Allen and Haslett 2006). The degree of truncation of earlier sediments varies spatially. No further peats are recorded from Woolaston, with a slightly later date of 4230±110 BP (Wk-7331, 3100–2450 cal BC; Druce 2005) from the upper peat at Oldbury Flats. Later peats are preserved within the interior of the Oldbury Levels *c.*2300–1900 cal BC (Jordan 2006), comparable to dated peat horizons from the Avon Levels (Gilbertson *et al.* 1990; Gardiner *et al.* 2002), although peat continued forming within the inner and outer estuaries into the Iron Age (Hewlett and Birnie 1996; Walker *et al.* 1998). This reinforces the complex picture of coastal change apparent throughout the estuary, reflecting dynamic histories of inundation, regression and later erosion.

Coastal woodlands

Palaeoecological studies across the Severn Estuary (Fig. 1B), particularly those close to the wetland edge, demonstrate that the dry ground was heavily wooded throughout the late Mesolithic and early Neolithic. The pollen sequences of Smith and Morgan (1989), Caseldine (2000), Dark (2007) and Timpany (2005) from Goldcliff East and West indicate a deciduous woodland on the adjacent bedrock island dominated by oak, hazel, lime and elm with alder dominant within the wetland during phases of damp fen carr-woodland. Pollen sequences along the northern margins of the Gwent Levels at Barland's Farm, Vurlong Reen (Walker *et al.* 1998), Llandevenny (Brown 2005) and Caldicot (Nayling and Caseldine 1997), from the eastern shores

of the middle Severn Estuary at Hills Flats (Brown 2006) and Oldbury Flats (Druce 2005), and to the south from several locations on the Avon and north Somerset Levels (Gilbertson *et al.* 1990; Carter *et al.* 2003; Ritchie *et al.* 2006) suggest a similar wooded environment on the dry ground dominated by the same four taxa.

The importance of oak within deciduous woodlands on the dry ground is equally reflected in its contribution to woodlands within the wetland. Oak stumps and timbers form a significant component of forests that developed during periods of marine regression, emphasising its tolerance of waterlogged acidic soils and ability to colonise peatlands (Pigott 1991). At Woolaston, the Upper Peat Forest is dominated by oak stumps and timbers that rapidly invaded the wetland from the adjacent dry ground, and, as already highlighted, formed a long-lived component of the wetland flora. Macrobotanical data also indicate that hazel was able to survive within the wetter alder-dominated Lower Peat Forest. Timpany (2005) hypothesises that the spread of hazel onto the wetland may have resulted from the movement and burial of its nuts by small mammals and birds, and a similar mechanism can be applied to oak from the Upper Peat Forest.

Wood identification of the Upper Peat Forest was not possible because substantial modern mud deposits obscured much of the peat surface and all but the most prominent oak timbers. The macrobotanical data (Fig. 5) show a greater diversity in herbaceous understorey than the other sequences (Figs. 3 and 4), most probably reflecting a mosaic of drier and wetter niches within the Upper Peat Forest, perhaps also some gaps in the canopy that allowed more light to reach areas of the understorey.

Local variations in the percentage abundance of arboreal taxa highlight differences in the structure of mid-Holocene woodlands in the Severn Estuary. At Woolaston high percentages for lime pollen suggest this taxon is likely to have formed the dominant, or at least co-dominant component, with oak, of the dry ground flora. Lime is a common component of the flora in the few surviving ancient semi-natural woodlands of the nearby Wye valley (Peterken 2005; 2008) and south-east England (Rackham 1980). Unlike oak, lime is intolerant of waterlogged soils, and tends to be restricted to drier soils at the margins of the wetland, often considerable distances from sampling locations. Lime also flowers less profusely than other arboreal taxa, especially in dense woodland (Greig 1982), and is insect pollinated with large and sticky pollen grains that are poorly dispersed (Waller 1994), amplifying the tendency for it to be under-represented in pollen spectra. Lime pollen percentages peak at 25 per cent within the base of sequence WP1, and generally range between 5 and 15 per cent thereafter (Figs. 3–5). The proximity of the Woolaston sequences to the adjacent dry ground (maximum of *c.*30 m) means that taxa with poor pollen production/dispersal characteristics, such as lime, can contribute greater quantities of pollen to the sedimentary record, with sequences located further from the dry ground tending to favour arboreal taxa with better pollen production/dispersal characteristics.

High lime percentages are recorded from wetland edge pollen sequences at Llandevenny (Brown 2007) and Vurlong Reen (Walker *et al.* 1998) *c.*25 km to the south-west on the northern margins of the Gwent Levels. In all three cases, pollen sequences are located in close proximity to dry ground dominated by well-draining sandy soils developed on Upper Old Red Sandstone bedrock favourable to the expansion of lime. Even excluding applying a correction factor, lime makes a significant contribution to the dry ground woodland flora at these sites, and likely contributed equally to woodlands where similar edaphic conditions existed.

There is little apparent change to the structure of the dry ground woodland, apart from a decline in elm pollen frequencies (Fig. 5). Both declines fall within the date range produced by Parker *et al.* (2002) on 138 dated elm declines from the British Isles. Significantly, both include a halving of pollen values within only 1 cm. On the basis of an average accumulation rate of the compacted peat of 10 years per 1.1 cm (Brown 2005), both declines are rapid events, similar to that

demonstrated by Peglar (1993) at Diss Mere, and comparable to rates recorded during the modern elm decline (Perry and Moore 1987). The earlier elm decline is marked by a peak in charcoal, the latter by an opening up of the woodland flora and a small increase in charcoal, suggesting the possibility of some vegetation disturbance at the time of the decline.

Anthropogenic activity

The intertidal survey produced only very slight artefactual evidence for prehistoric human activity (Brown *et al.* 2005), comprising a few typologically undiagnostic unstratified flakes. This suggests a low level of transient activity during this period, although potential artefact-bearing deposits at Woolaston may have been eroded away, or remain buried beneath Holocene sediments. The low levels of archaeological evidence for human activity contrast with abundant evidence in the charcoal record for probable anthropogenic impact. Burning is apparent from the base of the peat in sequence WP1 (Fig. 3), dated between 5775 and 5635 cal BC, associated with a small decline in arboreal pollen, but is most evident in the top 65 cm of sequence WP2 (Fig. 4). Charcoal is largely absent during the phase of alder-carr woodland, but reappears with the succession to reedswamp and saltmarsh, increasing in frequency during the deposition of a series of strongly laminated clayey silt/organic bands. Peaks in charcoal are closely associated with increases in pollen of grasses argued to represent the common reed (*Phragmites australis*). Fragments of charred reed stem and grass microscopic charcoal accompanying these peaks support this interpretation, reflecting repeated *in-situ* burning of reedswamp.

Evidence for burning is apparent more widely throughout the estuary. Reed burning is recorded from Oldbury Flats, dated to 6330±90 BP (Wk-7326, 5480–5060 cal BC; Druce 2005), associated with stratified Mesolithic artefacts (Brown 2007; Brown and Allen 2007) and at Hills Flats, where a small quantity of unstratified Neolithic and Bronze-Age artefacts has been recorded (Brown 2006). At Llandevenny charcoal and charred seeds are concentrated within two occupation layers of late Mesolithic and early Neolithic date, interpreted as burning of the woodland edge to promote the growth of edible wild plants. This is accompanied by repeated burning of reedswamp within the fringing wetland during the late Mesolithic, and by more limited burning of raised bog during the Neolithic (Brown 2005). Significant charcoal spreads are also recorded from late Mesolithic occupation contexts on the island edge at Goldcliff, representing burning of both woodland edge and reedswamp. Charred trees have also been recorded from the submerged forests at Goldcliff and Redwick, the latter with no direct evidence for human activity, and more widely from the Bristol Channel at Westward Ho!, Devon, associated with abundant Mesolithic activity (Bell 2007). An increase in charcoal was also recorded from the base of the lowest and an upper peat at Burnham-on-Sea, dated to 6340±70 BP (Wk-5298, 5440–5080 cal BC) and 5370±70 BP (Wk-5299, 4360–4000 cal BC; Druce 1998). Within the Somerset Levels, charcoal horizons of late Mesolithic date are recorded from Shapwick (cf. Bell 2007) and Walpole (Hollinrake and Hollinrake 2006). Charcoal spreads, including reed charcoal, are also reported from peat deposits at Minehead sealing Mesolithic flints (cf. Bell 2007).

The accumulating evidence emphasises widespread burning within lowland landscapes during the late Mesolithic. Burning is less widely recorded from Neolithic coastal contexts, particularly on the Welsh side of the estuary, but continues at a lower intensity within the middle estuary at Hills Flats, Oldbury Flats and Woolaston. The decline in burning on the Welsh foreshore mirrors a decline in artefactual evidence for activity, suggesting a shift in settlement from the coast in the late Mesolithic to the interior margins of the Levels during the Neolithic. However, activity continues along the foreshore at Oldbury Flats and Hills Flats (Allen 1997; 1998), suggesting a link between continued activity and burning not otherwise apparent from the outer estuary.

One cannot exclude the possibility that burning was naturally induced, for example as a result of wild-fires. The absence of associated artefactual evidence at Woolaston undoubtedly weakens the argument that these fires were anthropogenic. However, at least half the sites from the estuary with evidence for burning are directly associated with artefactual evidence for contemporary human activity. It can be no coincidence that burning is apparent in almost all late Mesolithic contexts recently examined, both in on- and off-site contexts. The repeated nature of much of this burning, occurring, in cases, over several hundred years, is difficult to explain purely as a result of natural agencies. The virtual incombustibility of British deciduous woodland (Rackham 1980) is often cited as support for an anthropogenic origin for woodland fires, though not scientifically tested, whilst burning of reed beds is generally only possible in late winter/early spring, at intervals of up to 10 years when sufficient dead plant material had built up to ensure a consistent burn (Law 1998; D. Upton pers. comm.).

The improved fertility and recycling of nutrients in soils following fires result in the increased growth and diversity of herbaceous plant communities. This increased growth and diversity, and the open areas created by fires, are attractive to a wide range of herbivorous animals and wildfowl, and population densities of herbivores have been observed to increase by as much as 300–400 per cent in post-burnt areas (Mellars 1976). Such areas would have been attractive to past communities because of both the improved hunting and the increased availability of edible plant foods. In this way burning would also have functioned to ensure the geographical predictability of resources, perhaps located along seasonal pathways of movement through the landscape.

Conclusions

This is the first detailed study of mid-Holocene vegetation history and human impact within the middle Severn Estuary, and one of the few palaeoenvironmental studies of a dendrochronologically dated coastal submerged forest from the British Isles. The proximity of the Woolaston sequences to the wetland edge provides a record of vegetation for both the wetland and dry ground from *c*.5775–3640 cal BC. During this time the dry ground carried a heavy cover of mixed deciduous woodland chiefly comprising oak, elm, lime and hazel. Lime most probably formed the principal, if not at least, along with oak, the co-dominant component of the forest canopy. Importantly, this study, along with similarly high lime pollen values from other Severn Estuary wetland-edge sites, suggests lime was not just locally dominant, but was the principal/co-dominant component of the regional woodland. This supports previous studies that suggest this taxon formed an important component of mid-Holocene woodlands. The Woolaston submerged forest also reinforces recent studies of comparable submerged forests from the estuary that demonstrate oak was an equally important component of the wetland flora, rapidly invading the drier areas of the wetland.

Wetland vegetation was strongly influenced, as elsewhere in mid-Holocene coastal north-west Europe, by progressively rising sea levels. However, unlike the estuarine silt-dominated sequence on the east side of the middle estuary (Oldbury Levels), a thick alder-carr peat developed in proximity to the Woolaston wetland edge. This was maintained by persistent high ground-water levels that are expressed on the Oldbury Levels as high intertidal mudflats and saltmarsh, instead punctuated by comparatively thin, short-lived reed peats. The contrasting sedimentary sequences highlight the spatially variable and dynamic nature of mid-Holocene coastal wetlands. Contrasting areas of the Severn Estuary Levels experienced slightly different histories of inundation and regression within broad-scale patterns of coastal change. Radiocarbon dates suggest broad-scale marine inundation occurred *c*. the mid 5th millennium cal BC, followed by subsequent falling sea-levels and widespread peat development throughout the middle estuary between 4230 and 3970 cal BC. At Woolaston, the dendrochronological and radiocarbon dates have halved the date range

for marine regression to 134 years (4230–4096 cal BC). The dendrochronological data also contribute to recent studies of submerged forests throughout the estuary that record complex histories of coastal change.

Changes in vegetation along the wetland margin, some rapid, others more gradual, would have altered the physical nature of the wetlands, affording opportunities for human exploitation. The accumulating archaeological and palaeoenvironmental evidence from the Severn Estuary highlights a far more extensive occupation of the dry ground bedrock platform and inner marshes during the later Mesolithic than was previously appreciated. Repeated burning of coastal reedswamp and woodland edge environments is evident from numerous on- and off-site contexts of late Mesolithic date, contrary to previous hypotheses that burning was exclusively upland in nature. Burning continues within the middle estuary into the early Neolithic, reflecting continued exploitation of coastal contexts not widely recorded from the outer estuary. The evidence for burning of reedbeds at Woolaston during the late Mesolithic contributes to the growing evidence for burning of wetland-edge communities identified widely throughout the Severn Estuary. The absence of artefactual evidence associated with some fires weakens the argument that burning is exclusively anthropogenic in origin. However, the often repeated nature of burning, occurring during periods of maximum environmental perturbation, often over several hundred years, is difficult to explain purely as a result of natural agencies, and highlights the need to develop a critical approach towards assessing the evidence for burning in light of the range of natural and human agencies.

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