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The form and fate of Scotland's woodlands

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ABSTRACT

This review is an attempt to reconstruct both the natural distribution and composition of Scotland's woodlands, and the spatial pattern, timing and causal mechanisms in their removal. The country is divided into several different geographical regions broadly typified by particular natural woodland types, and the Holocene environmental history of each region is critically reviewed, summarized and synthesized from the pollen-analytical literature. Particular attention is given to recent models of vegetation change, to new ideas concerning Mesolithic woodland manipulation, the Mesolithic/Neolithic transition and the current status of the elm decline, and to the interplay of climate change and human activity. Attention is drawn to the need for greater temporal precision and spatial resolution in reconstructions of prehistoric anthropogenic activity, and to the need for an increased sophistication and subtlety in the interpretation of land use from pollen analyses.

INTRODUCTION

This paper will attempt to describe the original form and the eventual fate of the woodlands that once covered most of Scotland, and to discuss the chronology and processes of woodland removal and the appearance of the 'cultural landscapes' that replaced them. Such a synthesis appears long overdue. This contribution will try to :

(a) provide a critique of the available database for reconstructing changes in woodland;
(b) make available to an archaeological audience a directory of sites, some of which have been published in journals not readily consulted by readers of these *Proceedings*;
(c) review weaknesses in the present database, techniques and interpretative methods;
(d) draw out many of the current themes being addressed by those working in Scotland;
(e) present suggestions for future work.

This paper places almost as much emphasis on the formation of Scotland's natural tree cover as on its destruction. This is partly to provide recently synthesized data for the archaeologist working in Scotland, stressing the variety and contrasts of the native woodlands, but also because this variation may have had important implications for human settlement, Whittington's (1979, 82) 'partial conditioner'. Whether or not differences in woodland type had the rather deterministic constraining influences conjectured, it will become clear that differences in woodland cover do exercise quite serious limitations on our ability to discern human impact.

There are necessary limitations in the scope of this review. It is deliberately insular, with few glances to regions outside Scotland. Analysis is restricted, broadly, to the prehistoric period, up to

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the early centuries after Christ. The vast majority of the data pertain most directly to this period, and while there are very good individual analyses of the historic period (O'Sullivan 1974; 1976; Edwards 1978; Whittington, Edwards & Cundill 1990; Dumayne 1992), it is difficult to form an impression of changes throughout Scotland (Whittington 1980; Yeoman 1991). All ages given are presented as (uncalibrated) radiocarbon years BC/AD. The major tree types are referred to by their common or English names.

METHODS OF RECONSTRUCTION

Undoubtedly the most successful technique for exploring vegetation history has proven to be pollen analysis (palynology). No other technique provides the two key elements of being able to synthesize patterns of vegetation in space and time. Pollen sites depict the landscapes around them at varying levels of spatial resolution, from very small spatial scales, when archaeological deposits (ditch fills or buried soils) are analysed (Dimbleby 1985), to the other extreme, such as the sediments of very large lochs, such as Loch Lomond (Dickson *et al* 1978), which receive pollen from very great distances. Just as comparisons cannot readily be made between different proxy indicators of vegetation, such as mollusca and pollen, because they reflect that vegetation at different spatial resolutions (Dimbleby & Evans 1974), so it is unwise to make much of apparent contrasts in vegetation or land uses depicted from pollen analyses with very different pollen 'catchments' or 'recruitment areas'.

This paper has as its prime concern the need to understand the 'ebb and flow through time' of Scottish woodlands. This discussion deals with entire landscapes. It is most appropriate to concentrate attention on sites which reflect changes at regional scales, that is, at scales greater than, say, a few hundred metres from the pollen site. What emerges is, then, a generalized picture of landscape development, but this can be advantageous, since it is this scale of resolution that is often lacking from archaeological studies.

The second prime advantage of pollen analysis is the degree to which temporal change can be elucidated. The types of site that provide the most appropriate spatial resolution, peats and lake sediments, tend to accumulate in clear stratigraphic sequences, and more often than not provide continuous records through time. These sediment accumulations can then be examined at different temporal scales dependent on the purpose of investigation, by adjusting the frequency with which the sediments are sub-sampled. Palynology's chief advantage seems to be its considerable flexibility in both spatial and temporal resolution. However, as will become clear, these two immensely valuable attributes have barely begun to be explored in Scotland.

A BRIEF HISTORY

Pollen-stratigraphic investigations in Scotland have a long history, and the country has attracted many of the leading practitioners of the technique. This is probably due in no small measure to the abundance of suitable sites for investigation. Early attempts at describing and explaining the history of peat development, by Lewis (1905–11) and Samuelsson (1910), drew on very limited pollen analyses to confirm and expand on the composition of wood-rich layers within blanket peats, 'Forestian' strata. But it was not until Erdtman's visits in the early years of this century (1924; 1928; 1931) that investigations from a vast array of sites, though each little more than a 'thumb-nail sketch', made clear that Scotland's woodland history was both spatially and temporally diverse.

Sporadic visits were made by palaeobotanists in the 1930s and 1940s (Elton 1938; Blackburn

1940; Heslop-Harrison 1948; Heslop-Harrison & Blackburn 1946; Fraser & Godwin 1955). From the late 1950s, S E Durno, working with the Soil Survey of Scotland (now the Macaulay Institute of Soil Research), produced with extraordinary rapidity a series of analyses which fully illustrated the diversity of the wooded landscape (Durno 1956; 1957; 1958; 1959; 1960; 1961; 1965; 1967; 1970; 1976). The analyses could be published rapidly because they often had very few samples, but Durno opened up debate concerning the extent and nature of natural woodlands, the age and cause of the upland blanket peat cover (Durno & Romans 1969) and the role of fire in woodland history (Durno & McVean 1959). He followed the early work of Knox (1954) in highlighting the effect of anthropogenic change on Scottish vegetation, by identifying purposeful woodland clearance (the 'landnam' or land-taking of Iversen 1941) close to two archaeological sites, at Dalnaglar in Perthshire and Peel Hill in Lanarkshire (Durno 1965). These two studies represent early and admirable attempts at liaison between archaeologist and palaeoecologist (eg, Coles & Scott 1962).

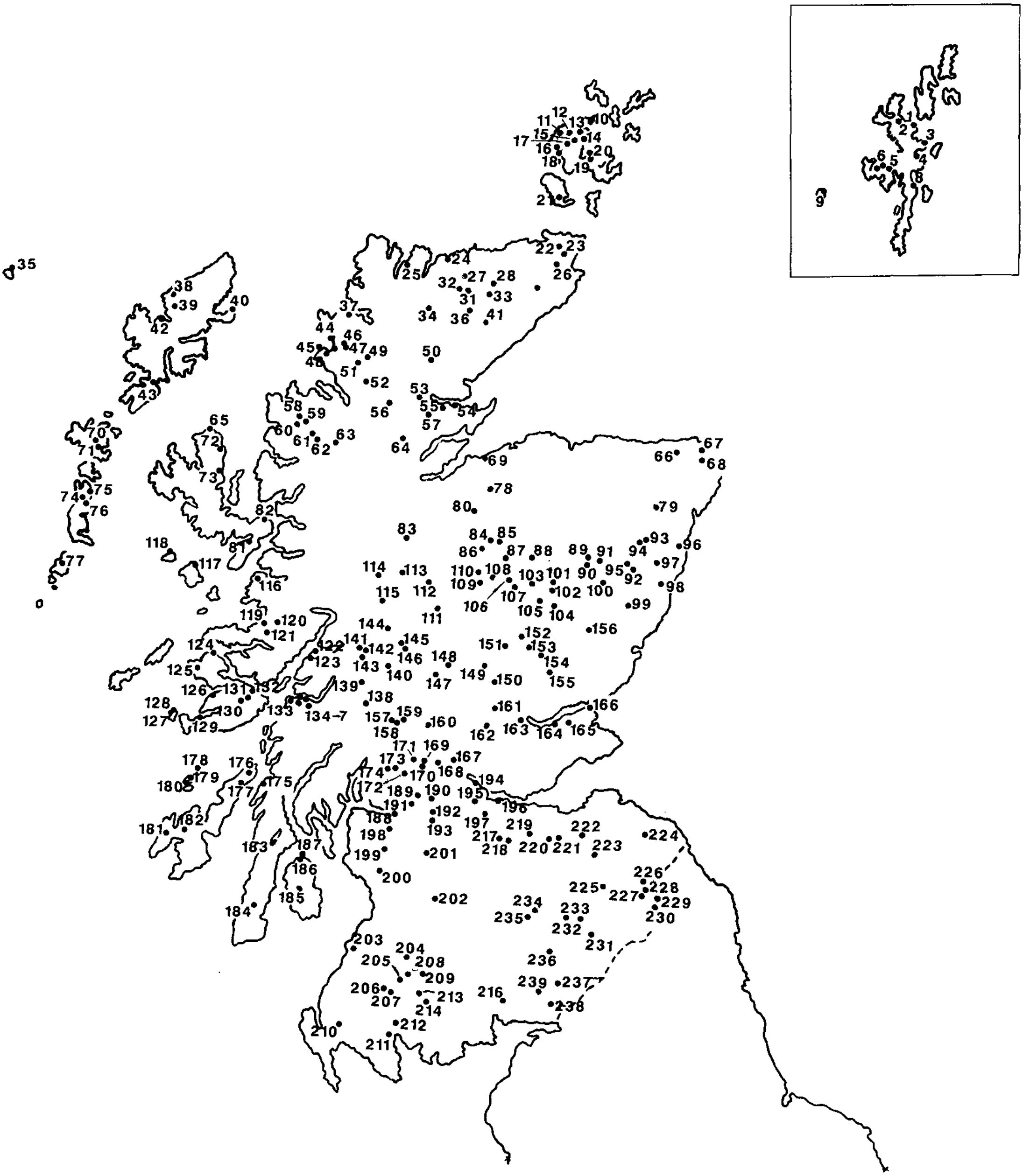
Durno's chronological controls were those of Godwin's in England and Wales (1940). The apparent synchroneity of temporal boundaries between pollen zones in the Godwin zonation scheme (Godwin 1956; 1975) had, however, been questioned for Scotland (Godwin 1943), and indeed, dissimilarities in woodland composition between England and northern Scotland could be demonstrated from Erdtman's work. Studies into the vegetational history of Scotland by the Cambridge 'school' of Godwin (Turner 1965; Moar 1969a; 1969 b; Birks 1970; 1972a; 1972b; 1975) were supported by extensive radiocarbon dating, and quickly showed that new schemes for dividing up the timescale of the Holocene Stage were necessary in Scotland. The routine application of radiocarbon dating to Scottish sediments which this discovery necessitated quickly followed (Pennington *et al* 1972; Birks 1977) and a new temporal framework emerged, together with a more methodologically sound approach (Birks & Birks 1980).

Although joint investigations between archaeologists and the palaeoenvironmental community are now commonplace in Scotland – and some outstanding contributions have shown the value of this collaboration – very little of this work has been disseminated to general texts on Scottish archaeology (eg, Ritchie & Ritchie 1990; Hanson & Slater 1991). There are exceptions, of course, as with Whittington's (1980) contribution to Parry & Slater's *The Making of the Scottish Countryside* and Walker's (1984a) more general assessment.

THE DATABASE AND ITS LIMITATIONS

The extent of the work undertaken on different aspects of Holocene vegetation history in Scotland can be graphically summarized (illus 1). The localities marked are sites where pollen analyses relating to regional woodland history have been undertaken. Excluded are analyses from archaeological deposits (above), and sites within coastal environments. The sites are detailed in the Appendix.

The map shows that few areas of the country have 'escaped' the attention of pollen analysts. Gaps in the spatial coverage are apparent, and with a few exceptions coincide with areas where vehicular access is difficult, such as in the extreme north-west of Sutherland and the north-west Highlands above the Great Glen: coring can be difficult without transport! Other areas where research has been neglected, such as the Banff and Moray coast and upper Clydesdale, cannot be explained either by the lack of roads or by an absence of deposits. The large number of sites in illus 1 would suggest that a comprehensive network of sites exists from which to draw reliable interpretations of woodland history. This is far from the case. In an effort to be comprehensive, this map has incorporated data of very uneven quality. In addition, the map includes sites in which the



ILLUS 1 Map of Scotland depicting the locations of published and unpublished work on different aspects of Holocene vegetation history (see Appendix, pp 51–4)

research was not principally concerned with woodland clearance. As the database is examined further, so gaps in our understanding of quite large areas of the country will become increasingly obvious.

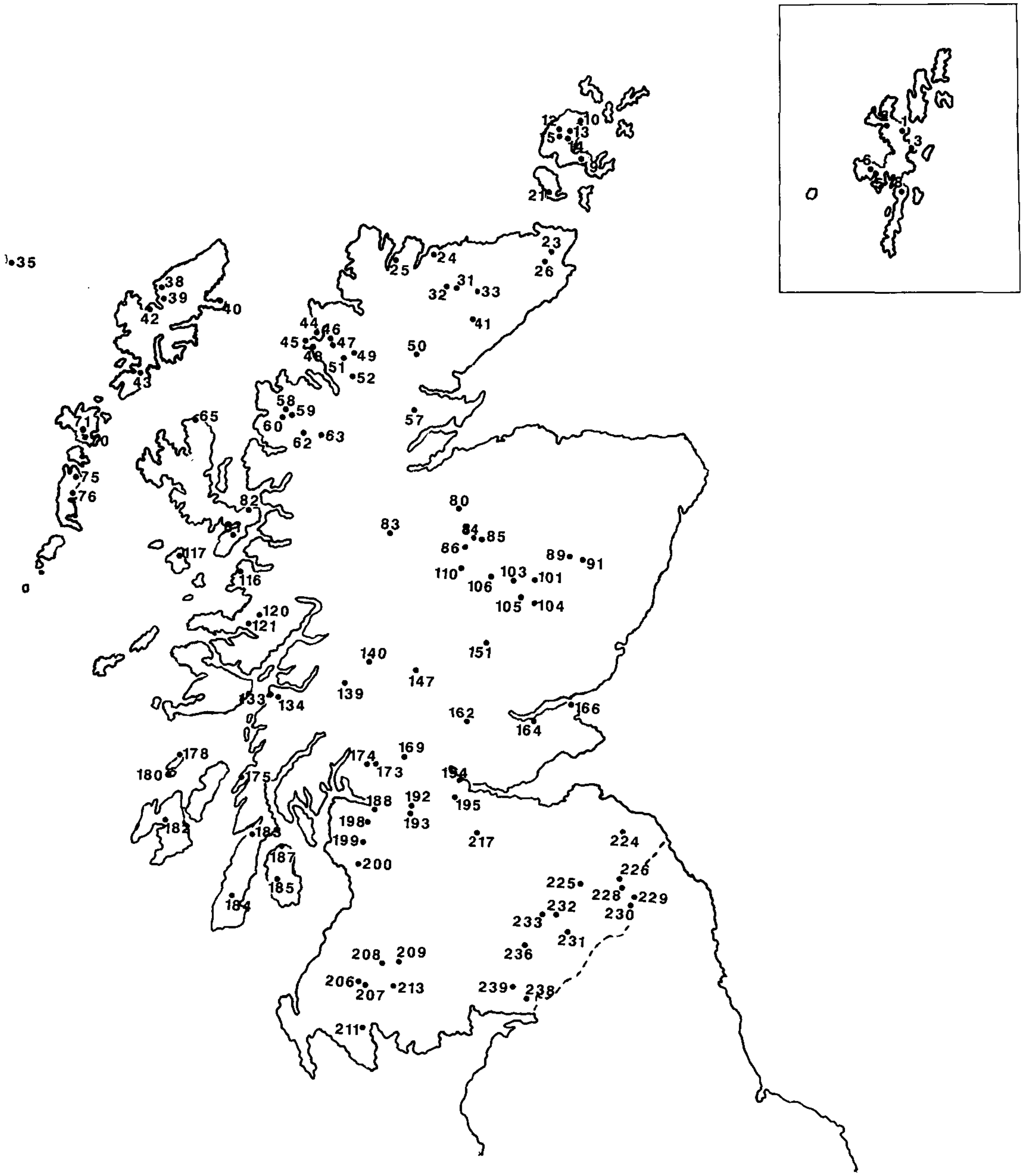
In attempting to synthesize data from a number of sites, secure chronologies are of the utmost importance. This is even more critical in discussing the timing of changes after 3000 BC, when the effects wrought by human impact are unpredictable in space and time. Until the full potential of new techniques such as tephrochronology (Dugmore 1989) are realized, radiocarbon dating will remain central to any analysis, and so critical that, as a first step in evaluating the database, sites that have no dating controls have to be rejected from further analysis. Illus 2a depicts those sites which do have some controls. Illus 2b continues this evaluation procedure further, in depicting those sites which have radiocarbon dating controls on sediments younger than c 3000 BC. This figure excludes those sites where anthropogenic activity was not of central, or even subsidiary interest, to the investigation. The sites depicted in illus 2b represent those which can, on this basis, be regarded as the fundamental database capable of analysis and interpretation. Clearly this is a very small percentage of the sites in illus 1, and this may seem a harsh evaluation, but the rigour in this process is necessary if we are to develop a site-network with secure temporal constraints.

Indeed, this evaluation exercise can be regarded as the bare minimum that should be applied. For example, illus 2c presents those few sites where radiocarbon dating controls have been applied to more than one depth-increment after 3000 BC. This figure, by accentuating those sites where some (although in most cases not all or most) anthropogenic clearance events have direct radiocarbon controls, or where interpolation to undated palynological features can be made with the least error induced by varying rates of sediment accumulation, emphasizes the paucity of reliable data from which to undertake this review. The evaluation could be extended to include other aspects of dating, but has not been. No consideration, for example, has been given to the temporal precision of radiocarbon dates. To be most precise, dates need to be obtained on thin slices of sediment, as these pertain most closely to the palynological event being dated – AMS radiocarbon dating offers exciting opportunities in this – but several sites in this review do not satisfy this requirement, and as a result the timing of changes in vegetation frequently remains poorly defined. Finally, no general assessment of the temporal resolution of pollen counts has been presented, although there are many sites where the number of analyses is less than desirable in fully understanding anthropogenic activities.

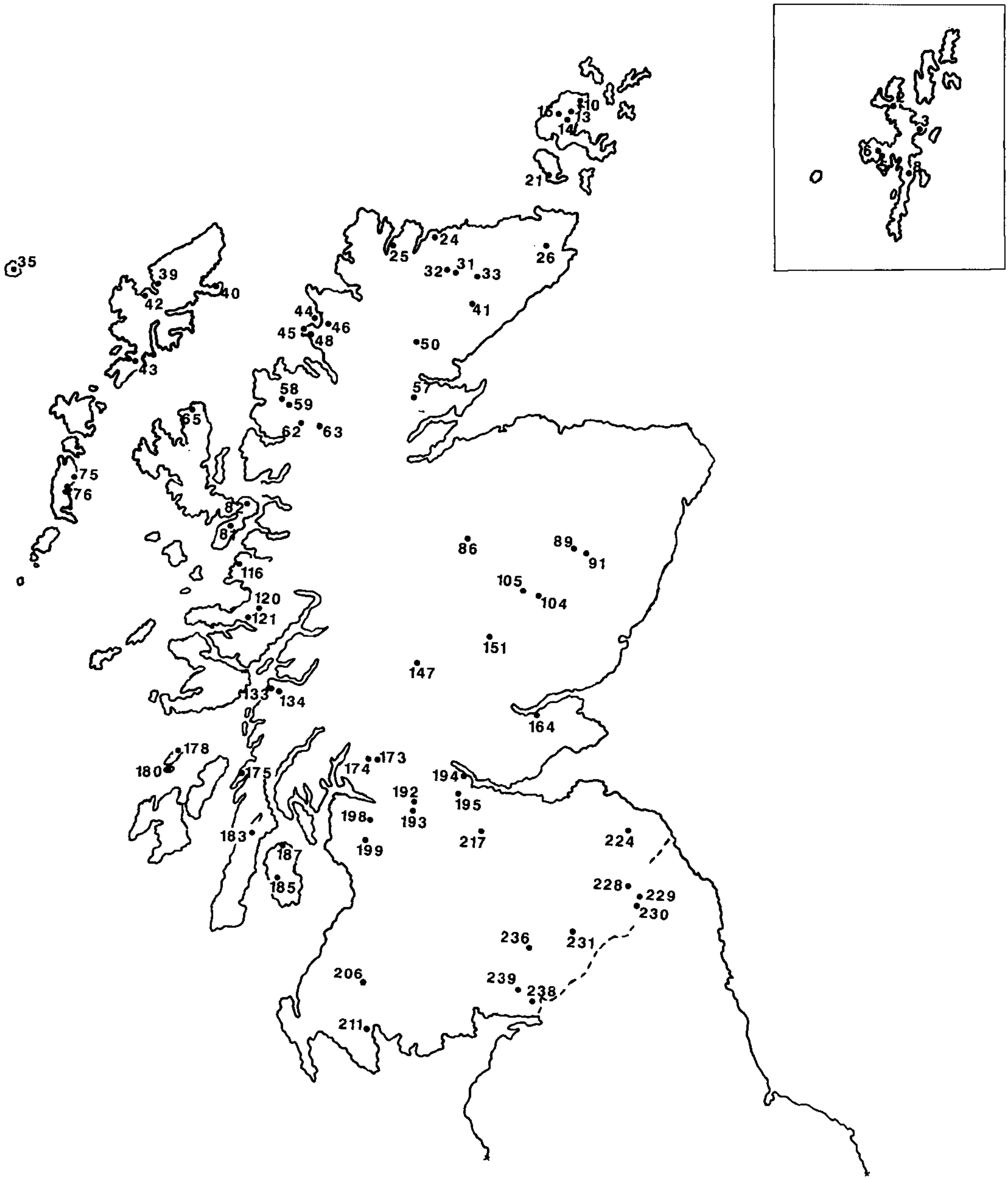
INTERPRETATIVE MODELS

Pollen analyses yield a deeply incisive yet distorted picture. There are many complicating factors in the interpretation of pollen assemblages that constrain a full reconstruction of plant communities and vegetation patterns (Birks & Birks 1980; Faegri & Iversen 1989; Moore, Webb & Collinson 1991). Factors such as contrasting pollination mechanisms, differential pollen production, dispersal and preservation, together with the complex pathways leading to pollen incorporation in suitable deposits, diagenesis, and the many biases in sampling and analysis, result in records of vegetation change that require skill and caution in interpretation.

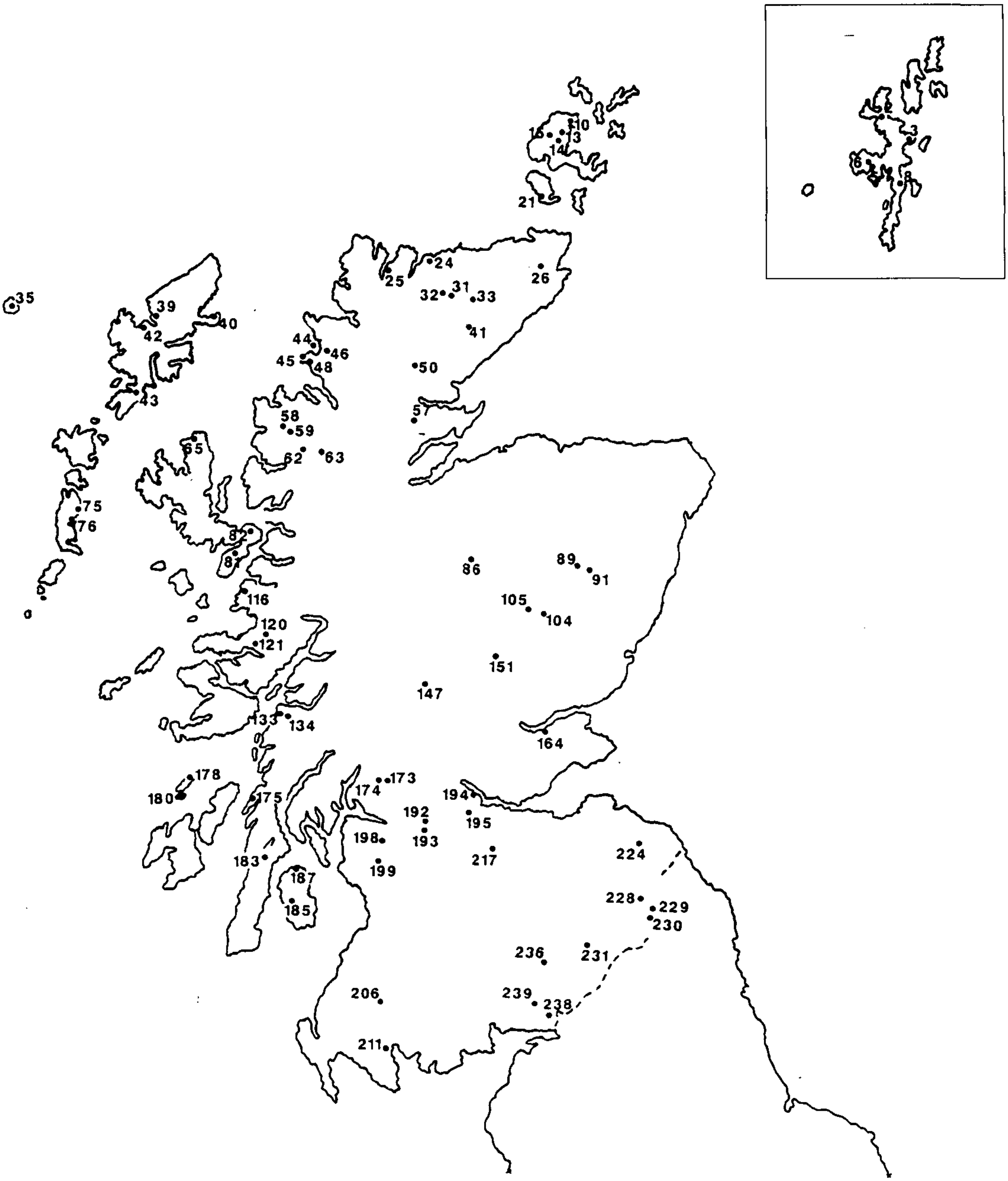
Beyond these difficulties, common to all palynological work, are complications specific to an understanding of anthropogenic impact on the landscape. In a timely review, Edwards (1993) has drawn attention to the more fundamental aspects of current interpretations, and has highlighted the difficulties that exist in many models for investigating the earliest agricultural inroads into natural woodland. Probably the most commonly applied interpretative tool is the 'expansion-



ILLUS 2 Map of Scotland depicting the sites that survive the processes of data-quality assessment: (a) sites with radiocarbon dating controls on Holocene sediments later than c 7000 ^{14}C BC



Illus 2 (b) sites which have radiocarbon dating controls on sediments younger than c 3000 ^{14}C bc



ILLUS 2 (c) sites which feature more than one radiocarbon date on sediments younger than 3000 ^{14}C BC regression' model, which is implicit in the earliest work on human effects (Iversen 1941) and which has been made explicit in Berglund's (1969; 1985; 1986) work in southern Scandinavia. In this model, agricultural expansion is marked by reductions in the proportions of woodland pollen taxa, as the landscape is cleared, and agricultural regression or woodland regeneration by increasing proportions of trees and associated shrubs. This approach is almost universally adopted in studies throughout the formerly forested areas of north-west Europe (eg, Behre 1986; Birks *et al* 1988; Frenzel 1993), and is used, consciously or unconsciously, in all investigations of Scottish sites.

There are, however, deficiencies in the model, and many uncertainties in the reconstruction of Scottish woodlands stem from its application. The model assumes that arboreal pollen frequencies roughly equate with the abundance of woodland, and there is some justification for this in studies of modern plant-pollen representation (eg, Maguire & Caseldine 1985). However, the model also seems to adopt the view that trees are in some way antagonistic to human activity, that they form monolithic blocks of unusable land that need to be removed. This leads to difficulties in interpretation and, in particular, results in rather unsubtle and unsophisticated reconstructions of landscape utilization, as will emerge.

SCOTTISH WOODLANDS c 8000–3000 BC

This part draws on the full array of pollen sites (illus 1) in exploring the distribution of woodland types at their maximal development within Scotland. Woodlands are suggested as having their fullest development immediately prior to 3000 BC, in accord with earlier reconstructions (Birks, Deacon & Peglar 1975; Bennett 1989). By this time the tree types that migrated in the early- and mid-Holocene (Birks 1989) had become established over most of Scotland, although there are localities where extremes in latitude and/or altitude inhibited the appearance of late colonizers such as alder until after this time (Birks 1989; Bennett & Birks 1990; Birks 1993). In some areas of Scotland this date may not represent the fullest woodland development because earlier anthropogenic or natural disturbance may have permanently modified woodland composition and/or structure. The adoption of the date of 3000 BC allows sites with no dating controls to be synthesized since in nearly every diagram the well-known feature of the elm decline can be identified, assumed to date to c 3000 BC (Smith & Pilcher 1973; Huntley & Birks 1983; Groenman-van Waateringe 1983; Edwards 1985; see below).

TREE MIGRATION, COLONISATION AND CONSOLIDATION

It is most probable that no trees survived the climatic extremes at the end of the last glaciation to affect Scotland: the Loch Lomond Stadial (c 9000–8300 BC). Trees migrated from refugia in southern Britain and the Continent (Huntley & Birks 1983) in response to ameliorating climatic and soil conditions. The colonization of the British Isles by tree species was complex, and took several thousand years, but current models suggest that climatic warming sufficient to accommodate most tree species was rapid, certainly occupying less than 1000 years (Kutzbach & Guetter 1986; Atkinson, Briffa & Coope 1987), and was not the gradual amelioration over thousands of years so often assumed (Godwin 1975). So there was a time-lag between the conditions amenable to tree growth and the arrival of the trees themselves, a lag induced by different modes of seed dispersal, and also by distance from refugia (Huntley & Birks 1983; Birks 1989).

The pattern of colonization of the major tree taxa is readily established by radiocarbon-dated pollen diagrams (see Birks 1989 for the most recent review). The sequence of migration is remarkably similar across the country, though the timing differs through geographical and edaphic constraints, competitive interactions with already colonized trees (Bennett 1986) and stresses imposed through taxa approaching their latitudinal range-limits.

Birch is consistently found to have been the first tree to colonize following the Loch Lomond Stadial, at c 8000–7600 BC, and its near-synchronous appearance across the mainland indicates a virtual absence of stresses, climatic, edaphic or competitive. Hazel is the next migrant, at c 7500–7000 BC. Hazel cannot be separated from bog myrtle on palynological criteria (Edwards 1981), but it is very likely that hazel is represented (Godwin 1975). Because hazel colonized the British Isles before oak and elm in the Holocene, in contrast to earlier interglacials (West 1980), Smith (1970) suggested that it might have benefited from anthropogenic encouragement, perhaps through the use of fire, to which some species are preferentially resistant (but North American ones; Rackham 1980). Huntley (1993) endorsed this view, though considering natural fires at a time of greater aridity and fire frequency to have been the main agent. The climate probably was arid (Linnman 1981; Digerfeldt 1988), but there is no evidence from microscopic charcoal analyses in peats and lake sediments for increased fire frequency (Edwards 1990; Bennett, Simonson & Peglar 1990; Simmons 1993), and so no evidence for human interference with natural processes. Boyd & Dickson (1986) argued for the deliberate or inadvertent anthropogenic introduction of hazel to Arran much later than on the adjacent mainland (6600–6400 BC) when natural mechanisms were thought to have been hindered by the deep straits. Yet there are similar enclaves on the mainland which have consistently late dates (Turner & Hodgson 1979) and for which such a complex explanation would seem unnecessary.

Elm and oak arrived in Scotland between 6500 and 6000 BC. Elm often appears first, but the pattern is not consistent across the country, and edaphic controls may have determined which tree was first to be established in an area. The rate of migration for each was dramatically slowed as the Grampian Mountains were approached, and although routes up both the west and east coasts were available, climatic constraints on establishment might have existed. At the same time, the number of pine trees was expanding sufficiently in the north-west of the country to be identified in the regional pollen record. This group of trees has a distinct genetic character and may represent an isolated population that survived from the Late Devensian (Kinloch, Westfall & Forrest 1986), although pine pollen is not abundant in sediments this early. This colony may instead have come from Irish sources (Bennett 1984) and may have become established through lack of competition from oak and elm. Pine then expanded throughout the Highlands after c 5500–5000 BC, though it did not colonize the northernmost mainland until much later (c 2300 BC) under special edaphic and climatic conditions (below).

The concept of a major climatic deterioration at the 'Boreal-Atlantic Transition' (c 4500 BC) was based, to a large extent, on the apparent synchroneity of the appearance of alder, a tree of wetland habitats. With an increasing number of radiocarbon dates for its colonization has come a recognition that this event was clearly not synchronous everywhere (Chambers & Elliott 1989; Bennett & Birks 1990; Tallantire 1992). Nevertheless, alder is competitively inferior to most trees that had already colonized the country, but is an adventitious colonizer (Bennett 1986); climatic perturbations which disturbed the existing quasi-stable woodland would have encouraged its establishment. It is likely that small populations of alder colonized many areas considerably earlier than they are detected in regional pollen records (Chambers & Price 1985), but could not fully consolidate their position until some environmental disturbance. Mesolithic woodland interference is one valid mechanism for providing just such a niche (Smith 1984).

DISTRIBUTION OF MAJOR WOODLAND TYPES

Early attempts to reconstruct the different patterns of natural woodland were based on limited pollen analyses (Erdtman 1928) or on the present distribution of woodland and on place-name evidence (McVean & Ratcliffe 1962). Syntheses of the available palynological literature were explored in the 1970s (Birks *et al* 1975; Durno 1976; Birks 1977; Moore 1977); they have been developed further in the last 10 years (Birks 1988; Bennett 1989) and have tended to confirm in broad terms McVean & Ratcliffe's reconstruction.

Illustration 3 is an attempt to reconstruct, in crude terms, the distributions of the major 'dryland' woodland types in Scotland prior to the earliest agrarian modifications. It is inevitably close to earlier reconstructions, but incorporates more recent data. Each major woodland type would have contained a variety of subsidiary or more poorly represented trees and tall shrubs, such as poplar (whose pollen is strongly under-represented through being poorly preserved), rowan, willow, ash, hawthorn, holly, juniper, and bird cherry (Birks 1988). Lime reached its climatic tolerance in the southern English Lake District (Pigott & Huntley 1980), and did not grow in Scotland except perhaps on alkaline soils around the Cheviots (Tipping, in prep). The native status of yew is still an open question (Dickson 1993b). Alder is not included here, because although abundant in pollen diagrams, particularly from the south and east of the country (Bennett & Birks 1990), there is a bias in representation introduced by its preference for wetland habitats on or adjacent to most pollen sites.

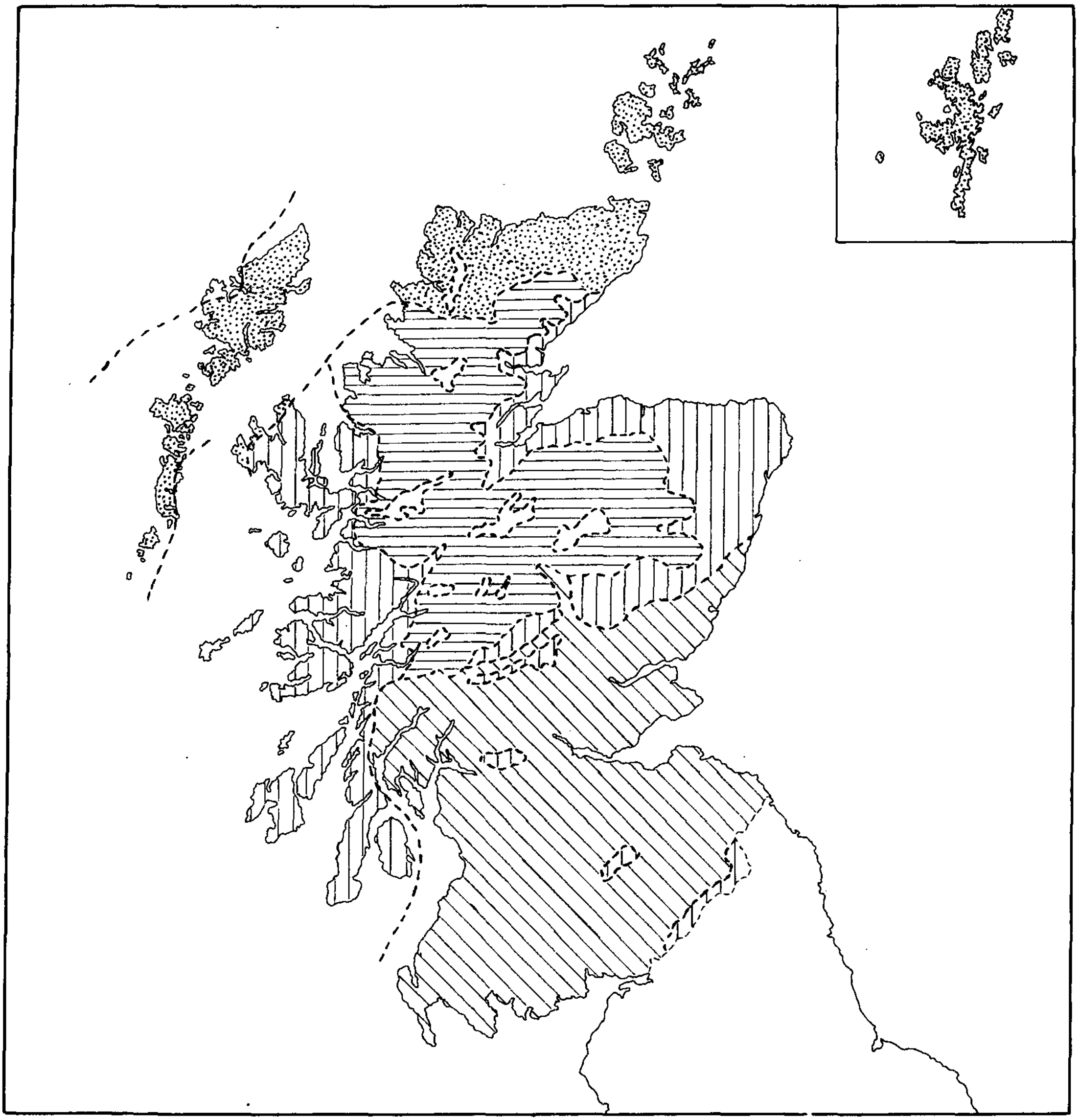
This 'broad-brush' reconstruction is simplistic. Considerable variation in woodland composition is demonstrated for areas subjected to detailed study, eg, Skye (Birks & Williams 1983), and by differences induced through aspect, altitude, soil type and quality, and microclimate. Kerslake (1982) detected a much greater species-diversity, and marked differences in the proportions of major trees, within small-diameter basins on presently wooded lochs in north-west Scotland than is apparent in pollen diagrams from large lochs in the same region (Pennington *et al* 1972), emphasizing the variety of native woodland when examined at appropriate spatial scales.

LATITUDINAL LIMITS TO WOODLAND

Birks' (1988) reconstruction placed the boundary of extensive woodland between Skye and the Outer Hebrides, and across northern Caithness. Pollen analyses from Little Loch Roag, on the extreme west coast of Lewis, suggested to Birks & Madsen (1979) that no trees colonized this region except sparse stands of birch and perhaps hazel, in support of the bulk of wood remains (Lewis 1906; 1907; Samuelsson 1910; Elton 1938; Ritchie 1966).

Wilkins (1984) provided indisputable evidence, in the form of radiocarbon-dated stumps, that pine also grew on blanket peat for a period between 2900 and 1900 BC. Fossitt has more recently (1990) argued that pine was widespread from 5500 BC. Bennett *et al* (1990) argued for the local presence of small stands of oak, elm, alder and, after 2450 BC, ash; to these Fossitt (1990) would add rowan and poplar. Areas of thin birch-hazel scrub may, then, have been restricted to a thin strip of land on the west coasts of the Western Isles (Birks & Madsen 1979; Bohncke 1988; Bennett 1989; Fossitt 1990), and on this most exposed edge, trees may have been few and far between (Fossitt 1990; Birks 1991). Further west still, Walker (1984b) regarded St. Kilda as being always treeless, with only scattered individuals, at most, of birch and alder.

Bennett *et al* (1992, 1993) adopted similar sampling strategies and arguments based on pollen analyses to sites on Shetland, also previously considered to be devoid of woodland save scattered birch, hazel, rowan and willow (Johansen 1975; Birnie 1981; Keith-Lucas 1986). Around Dallican Water, on the east coast of mainland Shetland, Bennett *et al* (1992) also envisaged a



ILLUS 3 Distribution of major woodland types in Scotland at c 3000 BC. Key: blank – unwooded areas; speckled – open birch/hazel woods; horizontal lines – pine & pine/birch woods; vertical lines – birch/hazel/oak woods; diagonal lines – oak/hazel/elm woods

natural cover of birch/hazel/juniper/rowan, but possibly accompanied by oak, alder, elm and ash, in a woodland that was at least locally diverse. As on the Western Isles, the local presence of some of these trees (willow, birch, juniper and alder) can be demonstrated by wood (Hawksworth 1970; Hoppe 1965; 1974; Birnie 1981), some radiocarbon dated (Bennett & Sharp 1993). On Orkney, Keatinge & Dickson (1979) considered that apart from birch, hazel and willow, trees were absent. Bunting (1993) has re-examined this reconstruction, and suggests that after disturbance of the birch/hazel/willow/?alder woodland after c 4550 BC, a greater diversity of taxa, including oak and pine, colonized the islands.

Two principal problems persist. First, the local presence of tree species on palynological criteria, but unsupported by wood remains, must remain conjectural. Interpretations rely on percentage-based pollen counts, and are essentially subjective assessments. Whilst some modern studies show these exposed islands to receive high amounts of wind-blown pollen from far afield (Tyldesley (1973) on Shetland), others (Randall, Andrew & West (1986) on the Monach Isles, west of the Uists) have demonstrated very few wind-blown components. The prevailing wind, its direction, frequency and strength, are critical in transporting pollen long distances, and it might be unwise to assume that low present-day wind-blown pollen deposition rates (Bennett *et al* 1990; 1992) have been thus in the past. In support of the argument for the tree taxa being wind-transported is the appreciation that, in the interpretation of pollen percentages of oak and elm as local to Dallican Water, Bennett *et al* (1992) have to countenance their growth on Shetland at c 7250 BC, astonishingly early and exceptional for regions as far south as southern Scotland (Birks 1989): such inconsistencies might imply that the pollen was transported long-distance (Birnie 1981).

The second problem relates to the nature of the woods present on these islands. It is probably wrong to assume that extensive areas of closed canopy woodland covered either the Northern or Western Isles. An open scrub woodland is more likely to have existed, although Bennett *et al* (1990) tentatively suggest that about half of the sheltered valleys of Beinn Mhor, on South Uist, might have been cloaked in trees. However, the importance of woodland should not be over-estimated. Despite the apparent abundance of pine stumps on Lewis and Harris (Wilkins 1984; Fossitt 1990), forests of pine have not been demonstrated, and Fossitt (1990) envisaged only scattered individuals or small stands at any one time, not woods capable of extensive utilization (Armit 1990).

ALTITUDINAL LIMITS TO WOODLAND

Present-day altitudinal tree-lines are in almost all cases unnatural, having been lowered through climate change, the growth of upland blanket peat, and by grazing pressures. The present-day altitudinal limit to pine at Creag Fhiaclach, on the western flanks of the Cairngorms, is thought to be the only surviving natural tree-line in Scotland (Watt & Jones 1948; Grace & Norton 1990). It lies at 648 m OD, but the present-day tree-line is probably sub-optimal. Ward, Haggart & Bridge (1987) estimated the optimal period for pine extension to have been c 4000 BC.

The relative scarcity of suitable sediments for palaeoecological reconstruction at the highest altitudes, either for pollen analysis or for the preservation of wood remains, inhibits reconstruction of former tree-lines. In the Cairngorms (Pears 1970), in the west-central Grampians (Bridge *et al* 1990), and in northern Scotland (Gear 1989), pine limits have been defined, as greater than 780 m OD, 550–600 m OD, and 300 m OD, respectively. However, wood remains may not represent the maximal altitude attained by trees at any one time (Ward *et al* 1987; Bridge *et al* 1990). In particular, it is becoming increasingly clear that the presence of wood within peat is determined more by the conditions required for preservation than by the abundance of trees. On the Western Isles, radiocarbon dates for wood cluster between 6800–5800 BC and between 3300–1800 BC (Wilkins 1984; Fossitt 1990), and on Shetland also (Bennett & Sharp 1993); a similar, though more diffuse, pattern can be seen in Bridge *et al*'s (1990) compilation of 96 radiocarbon-dated pine stumps from Scotland. There may have been times when trees grew at higher altitudes but were not preserved, either prior to blanket peat formation (Dubois & Ferguson 1985) or during phases of very slow peat accumulation (Pears 1988; Bridge *et al* 1990).

Uncertainties over establishing the local presence of trees have handicapped the understanding of altitudinal tree-line limits from pollen data, as they have latitudinal limits (above). Very few high-altitude pollen sequences have been analysed and, until a few years ago, no single study had purposefully attempted to define altitudinal tree-lines. To the south of Scotland, Turner (1984) considered that the summit plateau of Cross Fell (893 m OD), in Cumbria, carried an open scrub at the maximum extent of forest cover, while Pennington (1970) suggested that trees extended above 760 m OD in the English Lake District. In Galloway, Birks (1972a) produced a rather conservative estimate of >457 m OD. On the Moffat Hills, at Rotten Bottom, wood remains and pollen frequencies suggest an open and diverse tree-cover up to 604 m OD of birch, hazel, willow, ash, elm and perhaps oak (Tipping, unpublished). There seems little reason to think that any unforested area need have existed south of the Forth/Clyde line at the maximum extent of woodland. Further north, Donner (1962) argued for a tree-cover at heights of 716 m OD on Beinn Lawers, supported by Tipping, Edmonds & Sheridan (1993) from the flanks of the same mountain at 750 m OD. In the eastern Grampians, Huntley (1981) proposed a birch/hazel tree-line at between 600 and 700 m OD. To the west, Birks (1988) furnished an estimate of c 457 m OD for Skye, and c 520 m OD for the north-west Highlands.

If reliably estimated, the maximal extent of tree-cover clearly declines to the north and west, and would appear to have been determined by climatic stresses. The northward fall in the limit means that progressively greater areas of land lay above the tree-line in mountains north of the Great Glen, possibly more than half the total altitudinal range in the north-west Highlands (Birks 1988).

WOODLAND MARGINS AND CLIMATE CHANGE

The earliest tree-line, altitudinal or latitudinal, was not the sole tree-line. At woodland margins, fluctuations through time in the abundance of tree pollen, and in wood remains, are observed in the early-mid Holocene. These can be interpreted in certain situations as the result of Mesolithic anthropogenic activity (below), but a number of studies have concluded that these oscillations in woodland density were natural, and were climatically controlled. The most detailed reconstructions are those on pine woodlands. Significant reductions in numbers of pine trees occurred in the mid-Holocene (Pears 1970; Birks 1975). Bridge *et al* (1990) proposed a correlation between the abundance of radiocarbon-dated pine macrofossils and wetter climatic phases suggested by deuterium/hydrogen (D/H) ratios measured from pine tree-rings (Dubois & Ferguson 1985). D/H ratios within tree-rings are thought by Dubois & Ferguson to be determined by precipitation levels and, from the patterns derived from 33 radiocarbon-dated data-points, they have inferred a series of three 'pluvial' episodes in the early and mid-Holocene, at and before c 5550 BC, 4300–3850 BC and at c 1350 BC (the first and third 'pluvials' are poorly defined through the scarcity of available macrofossils). Bridge *et al* (1990) then inferred that periods of high pine pollen frequencies might be correlated with drier climatic phases.

The 'pluvial' episodes of Dubois & Ferguson (1985) have yet to be demonstrated by independent means, and there are possible uncertainties in their sampling strategy (Pears 1988), replication of results and causal mechanisms in inducing changes in D/H ratios; other applications of D/H measurements, though on peats, have assumed a relationship with temperature, not precipitation (eg, Dupont & Brenninkmeier 1984; van Geel & Middeldorp 1988). Nevertheless, this work draws out the observation that the Holocene was characterized by significant climatic fluctuations, intense or prolonged enough to disrupt the natural vegetation cover. In the eastern Grampians, above Pitlochry, Tipping (1995a) has identified periods in the early- to mid-Holocene when the natural birch/hazel/elm tree cover was disrupted. Coincident with these are phases of intense soil erosion, seen at other sites in the region (Huntley 1981) and so likely to be climatic in origin. Some of these phases of soil erosion and woodland disturbance correlate with Dubois & Ferguson's (1985) 'pluvial' episodes. On the Western Isles, Fossitt (1990) recognized a period of severe woodland disturbance at c 5900 BC, broadly synchronous between four sites throughout Lewis, Harris and the Uists, which she too regarded as climatic, not anthropogenic, in origin. A comparable decline in birch/hazel woodland on Colonsay at c 7900 BC, sustained until c 4200 BC (Andrews *et al* 1987), is similarly not accorded an anthropogenic origin, but no cause has been put forward. These examples show the often tenuous hold that woodland had at its furthest extent.

BLANKET PEAT INCEPTION AND 'SPREAD'

So difficult is this topic that only the briefest consideration can be given in this paper. The intricate hypothesis involving blanket peat spread and apparent agricultural decline in Scotland (Piggott 1972) is far from resolved, although there are strong grounds for thinking Piggott's case overstated. But it is clear that in northern and western Scotland the growth of blanket peat across the landscape, through whatever cause, may have been as significant a factor, or more so, than direct human agency in limiting tree growth.

Clearly there is a difference between the onset of peat accumulation in basins and the spread of peat in topographically unconstrained situations. Very many of our earliest Holocene pollen records (pre-7500 BC) are from basin peats. But modelling and monitoring the spread of peat is exceedingly complex, and the factors involved (pedogenic change, climate decline, burning, tree-clearance) are diverse and insufficiently understood (Moore 1987; 1993). In a recent review of the phenomenon throughout the British Isles, Tallis (1991) could not draw on any Scottish examples, which might astonish the archaeological community in Scotland. Part of this deficiency comes from a dearth of studies that fully appreciate that peat spread cannot be dated from single points in the landscape (Barber & Brown 1984). Nor can it be assumed that blanket peat 'spreads' uniformly across and down slopes; thin peats appear to coalesce from foci in small depressions, and so merge in a strongly diachronous way. Attempts to date this process clearly require careful strategies (Edwards & Hirons 1982). Jones (1987), Charman (1992), and Tipping (1995a) have attempted to establish directly the range in basal ages of peats in different microtopographic situations. Pennington *et al* (1972), Bennett *et al* (1990) and Fossitt (1990) have chosen to measure the cumulative effects of peat 'spread' using proxy measures within lake sediments.

Peat inception by c 7600 BC is identified throughout the country. Blanket peat 'spread' can occur at any time after that, and it is difficult at present to establish any regional pattern. There is little point in making generalizations, indeed, it would be dangerous, since even to identify within a region a point in time for its 'spread' is not to suggest that peat grew then at any specific locality. In archaeological work in the Highlands, chronologies for blanket peat 'spread' must be generated from individual sites, not 'borrowed' even from adjacent areas. There is the strong likelihood that, for instance, peat 'spread' can be retarded by continuing agricultural practice (O'Connell 1990).

MESOLITHIC WOODLAND INTERFERENCE

This subject has been recently and comprehensively reviewed by Edwards & Ralston (1984) and Edwards (1989a). The identification of hunter/gatherer activities from pollen diagrams has, of necessity, always been rather tentative. There are no unambiguous indicators of human woodland modification or disturbance. Changing woodland structure and composition can have natural causes, including different rates of tree migration, climate change and pedogenesis. Openings in the woodland can be induced, at a small scale, by the death of trees and the creation of gaps, natural mechanisms necessary to maintain tree regeneration. At a larger scale, the potential impact of climatic deterioration (above), whether through increasing precipitation (Bridge *et al* 1990), declining temperature, or increased storminess (Walker 1984b), introduces complexities in interpretation (Smith 1970). Many Scottish woodlands were always naturally open, particularly at altitudinal and latitudinal extremes, but also on cliffs, ravines, or stream-sides, so that an anthropogenic interpretation for so-called 'clearance' herbs can be unwise. Analyses of microscopic charcoal (Patterson, Edwards & Maguire 1987), so much a corner-stone of recent interpretations (below), need to be interpreted with care since the fine dust on pollen slides can have widely differing sources (Clark 1988) and many different origins (Edwards & Ralston 1984; Edwards 1990).

The evidence for anthropogenic controls on the major features of tree migration have been dismissed in recent syntheses (above), as they were by Edwards & Ralston (1984). Descriptions of smaller-scale, purportedly anthropogenically influenced phases as 'interference' (Simmons & Innes 1981) or 'disturbance' (Simmons & Innes 1987), rather than as 'clearance', illustrate the very limited alteration of natural plant communities that palynologists are interpreting. Turner, Innes & Simmons (1993) have tried to define the spatial and temporal scales, and suggest that woodland management, through burning and the lopping of branches, was limited to areas of woodland only tens of metres in diameter, but which yet persisted for up to a few hundred years. To detect such modifications in pollen diagrams requires either luck or the sort of careful research strategy adopted for parts of the North York Moors by Simmons & Innes (1988). A comparable programme of research has not been undertaken in Scotland, except perhaps in association with Wickham-Jones' (1991) excavations on Rum (Hirons & Edwards 1990). So the comparative abundance of Mesolithic activity reported from pollen diagrams from Scotland (Edwards & Ralston 1984; below) can only indicate either an astonishingly high population or, more likely, that not unexpectedly we are confounding artificial with autogenic deflections of woodland processes.

POSSIBLE MESOLITHIC IMPACTS IN WESTERN AND NORTHERN SCOTLAND

On Rum, possible Mesolithic activity, sharp reductions in alder and hazel/bog myrtle and the expansion of grasses and bracken (*Pteridium*), possibly accompanied by increased burning, took place over c 250 years from c 4000 BC (Hirons & Edwards 1990). This phase does not coincide with archaeological evidence of Mesolithic occupation, which occurs substantially earlier (Wickham-Jones 1991), but the apparent absence of artefactual evidence should not constrain palynological interpretations, either on Rum, where Mesolithic settlement is at least known, or in other regions where until very recently Mesolithic artefacts were not known, as in Caithness and Orkney (Wickham-Jones 1990; Wickham-Jones & Firth 1990). Palynological interpretations should be sufficiently robust to stand alone.

Most recently, pollen analyses from open and scrubby woodlands in Shetland and South Uist, and from the northern Scottish mainland have produced the most exciting, and problematic, interpretations concerning Mesolithic human impact. At Lang Loch, on the east coast of South Uist, Bennett *et al* (1990) interpreted a nearly continuous microscopic charcoal curve from c 7000 BC as possibly implying a human presence on the islands. No other palynological evidence was presented in support of this. However, Bohncke (1988) saw Mesolithic disturbance as most likely to account for an abrupt decline in the birch scrub, increases in open ground herbs and in microscopic charcoal between c 6450 and 5700 BC close to Callanish, on Lewis. Edwards (1990) was more circumspect as to the cause in his correlation of high charcoal values and a fall in birch pollen at North Locheynort, South Uist, at c 5350 BC, merely pointing out the apparent association.

These tree pollen declines are, interestingly, approximately contemporary with that found by Fossitt (1990) throughout the Western Isles, where a Mesolithic presence was not felt to be necessary in order to explain these often dramatic changes in woodland cover (above).

Subsequently, on the east coast of mainland Shetland, Bennett *et al* (1992) presented a more adventurous thesis. They suggested that reductions in shrubs and tall herbs between c 5550 and 3450 BC, were related to new grazing pressures: tall-herb communities are particularly susceptible to grazing. However, there is no evidence that Shetland supported a wild mega-fauna capable of applying such pressures, and Bennett *et al* suppose that Mesolithic settlers (for which there is no artefactual evidence) purposefully introduced large animals, perhaps red deer, to a new, untouched and well-suited habitat. For c 2000 years these animals suppressed the natural vegetation and were hunted, until after 3450 BC they became extinct, either 'naturally' or through over-hunting, and the natural vegetation was fully regenerated. This complex interpretation is intriguing, but there are perhaps more parsimonious explanations for the losses of these plant taxa. Shrub and tall-herb percentages are reduced, but do not disappear, and tree pollen frequencies are unaltered. If both the fragile and open nature of these most northerly woods is accepted (eg, Fossitt 1990; Birks 1991), and the possibility that the maximal extent of woodland cover was delayed until c 5500 BC, the losses of shade-sensitive tall herbs and shrubs from the pollen record may be explicable in terms of a greater density of woodland cover – as Peglar (1979) thought for similar losses in tall-herb communities at this time around the Loch of Winless in north-east Caithness, and much further south on Arran (Robinson & Dickson 1988), and as Butler (1993) has argued for Kebister, close to Dallican Water on Shetland itself. Robinson (1987) reported a late expansion of birch/hazel woodland around Aukhorn, north of the Loch of Winless, at c 5600 BC.

Robinson (1987) did, however, implicate Mesolithic activity in blanket peat inception, by increased burning of the existing vegetation between 6250 and 5800 BC. Burning is thought to have two principal and possibly significant influences on heathland soils and peat formation: it increases nutrient losses in soils which are already leached and acid, and, by blocking pores in soils with charcoal, burning also reduces soil porosity (Mallik, Gimingham & Rahman 1984). Intense burning within pre-peat layers at Aukhorn is assumed by Robinson to have been anthropogenic in origin, despite acknowledging that there are no clear human indicators in the pollen record, no removal of trees and no losses of tall herbs through grazing pressures. Natural origins for these fires, such as lightning strikes, are dismissed as inefficient ignition sources. At c 5550 BC, within the 'flow country' at Cross Lochs, in Sutherland, Charman (1992) identified a brief but severe burn which is thought to have led to reductions in open birch woodland. This too was ascribed to human impact. Earlier episodes of burning, back to c 7220 BC, are less confidently assigned to human agency. What typifies these two studies is a reliance solely on the abundance of charcoal (despite some misgivings from Charman). Reference to the aphorism by Rackham (1986, 72) that 'British woodlands (except pine) burn like wet asbestos' is perhaps unwise, given the extreme contrasts in woodland types and structures that exist between, say, East Anglia and northern Scotland, and the probability that some periods of the Holocene were much drier than the present (Digerfeldt 1988; Magny 1992). Moreover, no consideration is provided of what might be gained by hunting communities from the deliberate firing of vegetation in such open woods. Recourse is made in Charman's work to the models of Mesolithic woodland management developed for the North York Moors by Mellars (1976), Simmons, Dimbleby & Grigson (1981) and Simmons & Innes (1987), wherein woodland clearance by fire is thought to have been purposefully applied to remove the tree canopy and to encourage a nutrient-rich grazing sward. But the North York Moors supported a completely different type of woodland, and it has yet to be explained why such activity should be necessary in already open and herb-rich woods in northern Scotland.

POSSIBLE MESOLITHIC IMPACTS IN SOUTHERN SCOTLAND

Away from the exposed west Scottish coast, the northern mainland, and the Northern and Western Isles, woodlands were both more diverse and probably more dense, with closed canopy cover; woodland interference might be seen as more valuable, and its recognition might be more reliable in plant communities not so prone to exposure and other natural disturbances. In these closed-canopy woodlands the occurrence of particular open-ground herbs probably represent openings in the tree cover. In the central Southern Uplands, Innes & Shennan (1991) record several short-lived episodes prior to 3000 BC, but only one, at c 6550 BC, is regarded as probably anthropogenic. Innes & Shennan draw parallels with other inland and upland southern Scottish sites, such as Birks' (1972a) sites of Coire Bog and Cooran Lane in the Galloway Hills of Kirkcudbrightshire. At both these sites, clearance herbs and indications of burning (charcoal and herbs that respond to fire, such as cow-wheat (*Melampyrum*)) appear as percentages of tree decline, at c 5000 BC and 5500 BC respectively. Birks preferred to see these palynological changes as the result of natural lightning strikes, but her interpretation was influenced by the lack of archaeological evidence for settlement (Edwards & Ralston 1984): this absence of evidence has now been redressed (eg, Affleck *et al* 1988). Again, these sites suggest how readily these short-lived disturbance phases can be interpreted in terms other than anthropogenic, and reveal the inherent ambiguities of the palynological evidence.

Other pollen diagrams from southern and central Scotland, most of which were reviewed by Edwards & Ralston (1984), report Mesolithic activity from similar lines of evidence, involving reductions in arboreal pollen frequencies, the appearance of several herbs usually suppressed by the canopy cover, and frequently the increased representation of charcoal. Innes & Shennan (1991) have suggested a degree of synchroneity in these phases within southern Scotland, but this is not entirely borne out by the data. Little advance can be gained from reviewing these site by site in the limited space available here; Edwards & Ralston (1984) effectively undertook such a review. The ambiguities in the evidence remain, and the repetition of these lines of evidence at site after site may merely compound initial and incorrect assumptions of human involvement. More definitive and diagnostic criteria – not merely more sites – are urgently needed. A useful approach might be to pay more attention to the duration of these apparent anthropogenic disturbances, in the way that Simmons & Innes have done, if one concern is to distinguish between natural and random events – such as tree-falls, storm wind-throws or lightning strikes – which can be anticipated to be very short-lived, and purposeful attempts by hunting communities to maintain an altered or partly cleared semi-natural woodland. This would require a more conscientious analysis of these phases, with contiguous and fine-resolution pollen counts to distinguish their longevity, supported by high-quality radiocarbon dating. This would also be a useful procedure at sites where archaeological evidence might suggest woodland clearance, but where, perhaps through too poor a sampling resolution, it has not been discerned (eg, Andrews *et al* 1987). The identification of the overwhelming majority of apparent Mesolithic disturbance phases in Scotland has been essentially serendipitous, and it behoves us to examine such phases with more earnestness, and to establish more assured ground rules for interpretation.

THE MESOLITHIC/NEOLITHIC TRANSITION

THE ELM DECLINE

For many years the elm decline has held a central role in hypotheses for the archaeological changes between the Mesolithic and Neolithic periods in the British Isles. Over the last 10 or so years this position has been overthrown. From being the key marker in the introduction of farming, the elm decline has been relegated to a subsidiary position, most commonly thought of as lying within and not at the beginning of, the early Neolithic. How was this long-standing paradigm (Godwin 1975) challenged?

In his thoughtful review of environmental change in the Neolithic period, Smith (1981) raised the possibility that some woodland clearances, pre-elm decline and so purportedly late Mesolithic, might instead be Neolithic. The one diagnostic palynological feature of clearance for agriculture is, of course, the occurrence of cereal pollen grains. Being mostly self-pollinating and having very limited pollen production and dispersal capabilities away from the parent plant (Hall 1989), cereal pollen can be difficult to find in pollen diagrams, particularly from periods when, over most of the British Isles, woodland was dominant, and where the pollen site may not have been close to the source of cereal pollen (Edwards 1982). But Groenman-van Waateringe (1983) and Edwards & Hirons (1984) independently produced syntheses of pollen diagrams, from Ireland and from the British Isles respectively, which showed that pollen grains which could be ascribed to cereal-type lay stratigraphically below the level of the elm decline.

SCOTTISH FINDS OF CEREAL-TYPE POLLEN GRAINS IN PRE-ELM (*ULMUS*) DECLINE CONTEXTS

In 1988, Edwards could identify 12 sites in Britain and Ireland where cereal-type pollen is claimed to occur prior to the elm decline (irrespective, at this stage, of the absolute age of this event; see below); a year later, 22 sites were reported (Edwards 1989b). Three sites were identified in Scotland – Rhoin Farm, Aros Moss on the Kintyre peninsula (Edwards & McIntosh 1988), North Mains in Strathallan (Hulme & Shirriffs 1985) and Machrie Moor on Arran (Robinson & Dickson 1988) – a small proportion, but sufficient from which to assess some of the problems and implications in this new paradigm.

Aros Moss was first analysed by Nichols (1967), and although undated, the pollen diagram exhibits a number of possible anthropogenic disturbance phases prior to the elm decline, though no cereal-type pollen grains (cf Edwards & Ralston 1984). Because of the difficulties in identifying cereal pollen when present in very low amounts, and because even the presence rather than abundance of cereal pollen must represent agricultural activity, techniques for optimizing cereal identification can be justified (Edwards, McIntosh & Robinson 1986; Edwards & McIntosh 1988; Bowler & Hall 1989). Optimizing procedures at Aros Moss included selecting a site near the moss-edge (rather than the centre (Nichols 1967)), and this new core, called Rhoin Farm, produced three cereal-type grains, the earliest radiocarbon dated to 3690 BC (Edwards & McIntosh 1988). Similar techniques were employed by Edwards and McIntosh at Robinson & Dickson's site on Machrie Moor, and this core (Moorlands) produced five such grains in pre-elm decline contexts. However, identifying cereal-type grains is not synonymous with identifying cereal pollen (Beug 1961; Andersen 1979; Dickson 1988), as is widely acknowledged (Groenman-van Waateringe 1983; Edwards & Hirons 1984; Edwards & McIntosh 1988; Edwards 1989b). The majority of cereal-type grain identified at both sites is of a type (*Hordeum* or barley type; Andersen 1979) that includes wild grass species. Many of these wild grasses occupy maritime environments (Gimingham 1964), and one disconcerting aspect of the Rhoin Farm analyses is the location of the site on a coastal isthmus close to (present-day) sand dunes.

That on occasions wild grasses can produce pollen of a size comparable to cereals seems the inevitable conclusion from O'Connell's (1987) identification of cereal-type (wheat or *Triticum* type) pollen at a site in western Ireland dated to c 5550 BC, from Bush & Flenley's (1987) identification of similar-sized grains pre-dating c 6350 BC in Yorkshire, or from early Mesolithic contexts at Oakhanger in southern England (Rankine, Rankine & Dimbleby 1960). O'Sullivan (1976) published a pollen diagram from Loch Pityoulish in the Cairngorms showing two cereal-type pollen grains dated to c 6450 BC and 4650 BC. These are not discussed by him, and Edwards (1989b) dismisses them as unreliable. Such cautionary tales have a clear message, and should remind us further that the same ambiguous criteria are used to determine cereal-type pollen finds from post-elm decline deposits also.

The North Mains pollen sequence (Hulme & Shirriffs 1985) is potentially of great significance, given its close proximity to clear evidence for early, but loosely dated, cultivation (Barclay 1983). However, the interpretation of the pollen diagram is somewhat difficult. Hulme & Shirriffs argue for pre-elm decline cereal-type pollen, while accepting that the elm decline itself is a poorly defined feature. Observation of their pollen stratigraphy would appear to show that cereal-type pollen is recorded after the initial and gradual fall in elm pollen percentages. This is an important distinction, and one that also appears to affect the interpretation of Robinson & Dickson's (1988) pre-elm decline cereal-type pollen also, where the single grain occurs during a prolonged and gradual decline but prior to a well-marked abrupt fall. Smith (1981) recognized both components, the gradual decline and abrupt reduction in elm pollen percentages, as part of the 'classic' elm decline. These considerations as to where the elm decline starts are not merely semantic, but critical. On these criteria, it is suggested that neither North Mains nor the original Machrie Moor analyses (Robinson & Dickson 1988) present sound stratigraphic evidence for pre-elm decline agriculture.

CONTEMPORANEOUS HUNTERS AND FARMERS?

The 'demotion' (Groenman-van Waateringe 1983) in status of the elm decline, and the suggestion that radiocarbon dates allow an overlap between 'Mesolithic' and 'Neolithic' activities (Williams 1989; Kenney 1993), provide new opportunities to explore the nature of the transition between the two, and pollen analyses can most usefully be adopted in this. Within the Howe of Cromar, on upper Deeside, Edwards & Ralston (1984; see also Edwards 1989a) have speculated that the earliest anthropogenic clearances, stratigraphically post elm-decline and dating to c 3350 BC, may have been created by hunter/gatherers broadly contemporaneous with the earliest arable cultivation at nearby Balbridie (Fairweather & Ralston 1993). The argument is partly derived from pollen analyses at Braeroddach Loch (Edwards 1978; 1979), which show no evidence for cereals within these clearings when crops of emmer, barley and, perhaps, bread-wheat were being raised at Balbridie. If exclusively pastoral in nature, these clearances are certainly undiagnostic with regard to who made them. But as discussed above, the axiom concerning 'evidence of absence' is of immense pertinence when dealing with cereal-type pollen. Kenney (1993) found no evidence for Mesolithic or early Neolithic flint-working around Braeroddach Loch, and suggested that the clearings may, after all, be Neolithic and associated with the need to make long cairns visible in the woodland.

However, strikingly similar reconstructions of contemporaneity between 'hunter/gatherer' and 'farmer' have been made from pollen work in the Cheviot Hills (Tipping, in press). Here, woodland clearances within and on the periphery of the Cheviots that have the character of late Mesolithic activity (small-scale; short-lived; pastoral) overlap in time with securely dated finds of cereal-type pollen at Din Moss (Hibbert & Switsur 1976), 4 km towards The Merse. These cereal-type finds are still stratigraphically post-elm decline, but have radiocarbon dates of c 3400 BC.

THE ELM DECLINE OR DECLINES?

It has long been recognized (Oldfield 1963) that there is more than one elm decline. Oldfield defined a 'primary' elm decline, and secondary events post-dating this and separated by phases of apparent elm regeneration; increasingly high sampling resolutions across the elm decline show this pattern to be widespread in the British Isles (Oldfield 1963; Nichols 1967; Edwards 1978; Beckett & Hibbert 1979; Hirons & Edwards 1986; Robinson & Dickson 1988; Bonsall *et al* 1989; Smith & Cloutman 1988; Steven & Dickson 1991; Whittington, Edwards & Caseldine 1991; Whittington, Edwards & Cundill 1991; Tipping 1995b) and in north-west Europe (Aaby 1986; Andersen & Rasmussen 1993), involving two or multiple elm declines.

One implication of this is that events in this period are more complex than had been appreciated. From sites which receive pollen from large distances it is easy to assume that changes in vegetation, such as the elm decline, are of regional importance, and a natural corollary of this is to assume that multiple elm declines represent regeneration and reduction within the same wood. This has led to suggestions that, for instance, causal effects that probably occurred only once, such as soil or climatic deterioration (see below), can be dismissed as factors in the elm decline (Hirons & Edwards 1986; Bonsall *et al* 1986; Tipping 1995b). However, Turner *et al* (1993) have introduced a much-needed insight into the spatial diversity and temporal variability of the elm decline from the North York Moors, where they found that even over distances of a few hundred metres, radiocarbon dates on the 'primary', and only, elm decline there vary from c 3650 to c 1550 BC. It is possible that multiple elm declines are, in fact, successive attacks on different areas of the elm population.

A second implication is that it cannot be assumed that the cause or causes of one decline explains all such declines in the same sequence. Thirdly, the 'primary' elm decline may not always be the 'classic' decline (Andersen & Rasmussen 1993). For instance, a reduction in elm pollen values at Valley Bog, in Teesdale in northern England, was radiocarbon dated to c 3950 BC (Chambers 1978), but more significance was placed on a subsequent decline which was correlated more closely with the radiocarbon age of the 'classic' decline at 3250–3000 BC (Smith & Pilcher 1973). One effect of such manipulations is to reinforce the apparent synchroneity of the 'primary' event (cf Baillie 1991). Fourthly, with the insight that comparatively high sampling resolutions provide, uncertainties arise as to the correct depiction of the elm decline in earlier, less well resolved analyses, and thus with the precision of attendant radiocarbon dates (see below).

THE TIMING OF THE 'PRIMARY' ELM DECLINE

Radiocarbon assays on the elm decline are not applied consistently to the same feature, and dates can relate to the beginning, middle or end of the 'primary' fall, or, in poorly resolved sequences, can span all stages of the decline. This complicates discussion. There are suggestions (Hirons & Edwards 1986; Andersen & Rasmussen 1993) that radiocarbon dates from lake sediments contain a systematic error that makes them older, perhaps in some cases significantly so, than dates from peats. It is, of course, necessary to assume that the 'primary' decline is that first detected in the diagram, and that pre-'primary' declines have not been missed through inadequate sampling resolutions.

No date list for the 'primary' elm decline has been compiled for this review. The majority of dates appear to lie between c 3300-2850 BC in accord with expectations. Attention is drawn, however, to three localities within the native oak/hazel/elm woods (illus 3) where dates suggest significant diachroneity in this event over comparatively small distances. The first of these is the Howe of Cromar (Edwards 1978), where the elm decline at Braeroddach Loch appears to be some 270 radiocarbon years prior to that at Loch Davan. On the west coast, Williams (*in* Birks 1980) gives a date of 2955 BC for a site close to Oban, whereas an interpolated age close to c 4000 BC can be gained from analyses at Gallanach Beg on the southern outskirts of the town (Rhodes, Rumsby & Macklin 1992). At the foot of the Cheviots, a very securely dated elm decline at Din Moss

(Hibbert & Switsur 1976) at c 3390 BC can be compared with one of 2740 BC at nearby Yetholm Loch (Tipping 1992). These tend to suggest that the elm decline was far from synchronous. A spread of about a millennium in the timing of this event has been argued for across the British Isles (Bonsall *et al* 1989; Kenney 1993).

Hirons & Edwards (1986) raised the possibility that the second elm decline, at sites where this is a significant feature, might also be broadly synchronous at c 2300–2100 BC, as seems to be the case in northern Ireland. This is not entirely supported by more recent studies (Whittington *et al* 1991b; Bonsall *et al* 1989; Tipping 1995b).

CURRENT VIEWS ON THE CAUSES OF THE 'PRIMARY' ELM DECLINE

It is probably fair to say that discussion of the elm decline has suffered from a neglect of the scientific axiom that the specific case needs to be explained before moving to the general. Thus, the 'intoxication' of the tenet of general synchroneity has greatly influenced not only causal hypotheses but also the evaluation of individual sites. Sturlodottir & Turner's (1986) plea for the elm decline to be evaluated site by site should be well heeded.

It is also probably true that of the four principal arguments generated to explain the decline in elm pollen values within the early Neolithic (climate change, soil deterioration, disease, anthropogenic activity; Smith 1981), none has so far been disproved. Some are thought more credible, but each has, either singly or in combination, been proposed anew within the last decade or so. It is beyond the scope of this paper to analyse each in turn. However, an increasingly common line of interpretation is to suggest that more than one cause might be responsible. For instance, Sturlodottir & Turner's (1986) interpretation of this event at Pawlaw Mire in County Durham places emphasis on soil deterioration, aggravated and accelerated by preceding late Mesolithic woodland disturbance. Disease (Watts 1961) is increasingly seen as influential since the occurrence of Dutch Elm Disease this century. Links between it and increases in anthropogenic activity are argued for, either through human populations moving into open disease-ravaged woods (Rackham 1980) or through anthropogenic activity facilitating the spread of disease (Robinson & Dickson 1988).

TEMPORAL AND SPATIAL PATTERNS IN LATER PREHISTORIC CLEARANCE

GENERAL CONSIDERATIONS

This paper is concerned with the chronology of woodland destruction in Scotland. It is beyond the scope of this work to extend discussion further, to concern itself, for instance, with patterns of settlement reflected in archaeological analyses. Such an enormous task is outwith the competence of this contributor. Indeed, this is probably not feasible with the existing palaeoecological database, since so much of the data does not have human effects as a prime concern.

There is litle doubt that studies into the 'cultural landscape' (Birks *et al* 1988) require approaches to the temporal and spatial resolution of events which, if not at total variance to that adopted for reconstructions of the 'natural landscape', are sufficiently different to imply that the same methodologies cannot apply to both. One concern is that sites chosen to depict woodland history, such as lake basins, are not those best served to illustrate human impacts. The latter tend, particularly in the prehistoric period, to be (or rather appear to be) very small-scale depredations into the woodland, and it is not at all clear whether many of the lake basins from which pollen analyses have been obtained are sufficiently sensitive to reflect such spatially restricted activities.

THE OPEN BIRCH/HAZEL WOODS OF NORTHERNMOST SCOTLAND

Trees probably had a tenuous hold on the outermost parts of Scotland throughout the early and middle Holocene (above; Fossitt 1990; Birks 1991). The 'flow country' and the northern mainland in general, and the Western and Northern Isles, probably supported open birch/hazel woods for the most part, accompanied by a variety of other subsidiary tree species. Closed canopy woods probably did not exist at all in the most exposed areas, and in more sheltered locations trees may have become sufficiently dense to cast effective shade only within the mid-Holocene.

The often uncertain survival of trees may have meant that small-scale changes in the landscape effectively inhibited regeneration. Given this sensitivity, human effects may either have had little impact on woodland maintenance, or conversely, an impact disproportionately large to the scale of attack. Combined with this problem is the difficulty (some might argue, impossibility) of unambiguously identifying anthropogenic influences on vegetation that was nearly always open and herb-dominated. Fossitt (1990), for example, has argued that no palynological signals in the Western Isles are uniquely anthropogenic. 'Cultural' indicator herbs (Behre 1981) and wild grasses which produce cereal-sized pollen grains occur naturally in many plant communities (Birks & Madsen 1979; Fossitt 1990). *Plantago lanceolata* (ribwort plantain) and cereal-type pollen appear at one site, Loch Bualaval Beag on Lewis, during a phase of woodland decline dated to c 6000 BC (Fossitt 1990), when agriculture can effectively be dismissed. Fossitt argued for short-lived climatic extremes to explain the woodland demise, from which at this site it never recovered. The complexities of landscape development are such as to preclude any simple correlation of woodland decline with human activity. Climatic fluctuations such as increased storminess (Walker 1984b; Keatinge & Dickson 1979; Birks 1991), changes in precipitation (Fossitt 1990), sea-level change (Birks & Madsen 1979; Whittington & Ritchie 1988) and associated machair formation (Ritchie 1979), natural soil acidification and blanket peat formation, all had a deleterious effect on woodland survival.

On the Outer Hebrides, anthropogenic clearance is inferred at some sites, such as after c 1950 BC at Little Loch Roag (Birks & Madsen 1979), after 1750 BC at Sheshader on the east coast of Lewis (Newell 1988), and after c 2350 BC at Loch Lang on South Uist (Bennett *et al* 1990). Woodland decline has generally been regarded as gradual, with few suggestions that woodland, once disturbed, could successfully regenerate. Because of this, and because of the methodology developed to interpret anthropogenic activity on pollen diagrams from forested areas – the expansion-regression model (above) – it has proved exceedingly difficult to identify successive phases of human impact in what were, by c 3000 BC, predominantly treeless regions (Davidson, Jones & Renfrew 1976; Robinson 1987).

Nevertheless, Bohncke (1988) was able to deduce a complex series of fluctuations in the birch woodland at Tob nan Leobag, close to Callanish, all ascribed to human interference. Purported Mesolithic activity (see above) is followed between c 3000 and 2850 BC by a short-lived clearance of the birch woodland. Unlike others working in the Western Isles (Birks & Madsen 1979; Fossitt 1990), Bohncke equated without question finds of cereal-type and plantain (*Plantago lanceolata*) pollen with agricultural activity. Using these in conjunction with fluctuations in proportions of tree pollen, he was able to identify woodland regeneration after c 2850 BC, renewed clearance between 2250 and 1450 BC, and again after c 500 BC. The difference in interpretation between this and most other studies is intriguing. Fossitt (1990) described successive phases of woodland destruction and recovery on Harris that coincide with the first and final phases at Callanish, but human activity was not thought necessary to explain these. Tob nan Leobag may be a 'sensitive' site, or Bohncke may have been overly concerned to identify anthropogenic activities adjacent to the Callanish stone circle complex (although he was careful not to associate any one 'clearance' with its construction). The work by Newell (1988) and by Mills (*in* Crone 1993) on blanket peats from the Outer Isles do not reveal such complex fluctuations.

On Orkney, a widespread phase of woodland removal close to 3000 BC was ascribed a complex origin by Keatinge & Dickson (1979) in order to explain a lag of a few hundred years between clearance and the introduction of 'cultural' indicator herbs. Increased storminess was thought responsible for woodland decline and changes in coastal configuration. A similar delay between clearance and pastoral farming was identified by Pilcher *et al* (1971) in northern Ireland, but the intervening period was argued not to have been devoid of human activity, but to have been dominated by cereal cultivation. It is possible that this phase went unidentified at Keatinge & Dickson's sites through limited cereal-type pollen transport. Most recently, however, Bunting (1993) has found no significant time-lags between woodland decline at 3000 BC and the introduction of agriculture. Short-lived phases of apparent scrub regeneration were recorded by Davidson *et al* (1976) at Lesliedale Moss after c 1450 BC, but the early Neolithic clearance is generally seen as being so effective as to inhibit regeneration, and it is possible that most of Orkney was treeless after about 3000 BC.

Farther north, on Shetland, there is very good agreement in the dating of the first agricultural activity at Murraster (Johansen 1978), Scord of Brouster (Keith-Lucas 1986) and Kebister (Butler 1993), at c 2750 BC, slightly delayed (c. 2450 BC) at Dallican Water (Bennett *et al* 1992). No climate-induced deforestation at c 3000 BC (cf Keatinge & Dickson 1979) has been detected. Initial clearance is sustained, and intensified, at Kebister until c 2000 BC, whereas at Scord of Brouster the earliest agricultural activity is very short-lived, over a century or so, before scrub regeneration and renewed clearance at 2250 BC. Considerable synchroneity is found in the next major agricultural expansion. Close to c 1150–950 BC extensive clearance of remaining woodland occurred at Kebister, Dallican Water and Gunnister Water (Bennett *et al* 1993) – the Scord of Brouster record ceases prior to this – and this seems to represent the final phase of woodland destruction on Shetland.

Very few diagrams exist on the northern mainland which have archaeological concerns foremost. It is accordingly very unclear how and when the woodlands in this region declined, and whether anthropogenic impacts were as significant as natural effects. At An Druim on the north-west coast (Birks 1993a), for example, anthropogenic clearance is inferred to have started at c 3000 BC, comparable to the Northern and Western Isles, but apart from an apparent agricultural intensification at c 500 BC, the decline in tree cover is seen as gradual and uninterrupted by major phases of recovery. It is possible to interpret this as the product of, for instance, persistent but low-intensity grazing pressures, perhaps signifying a constant but small human population. But it is also possible that a combination of the choice of a lake site, with its inevitable smoothing of any small-scale signal, analyses undertaken at too low a temporal resolution, and human impact not being of prime interest in the investigation, has resulted in an imperfect understanding of the chronology and intensity of anthropogenic activity around this site. This problem affects interpretation at sites such as Loch Assynt (Birks 1980), where no significant anthropogenic activity is recorded, and Loch of Winless in eastern Caithness (Peglar 1979), where strong clearance phases are largely absent until c 500 BC, or in Strathnaver, where Gear (1989) reported a dearth of indisputable human impact on the vegetation. Robinson (1987) and Charman (1990; 1994) found it difficult to define any other than the vaguest indications of modifications at their sites. Are these true reflections of minimal prehistoric human activities, or are they constructs of particular palynological methodologies? Or are they the inevitable result of applying palynological models of clearance/regeneration (cf Berglund 1986) to environments unsuited to such interpretations? Is it only at localities where woodland survived more-or-less intact into the later stages of the prehistoric period that we can identify more than the most generalized impression of human activities? But if so, are these localities typical?

THE NATIVE PINE WOODLANDS

The boundary between birch/hazel (*Betula/Corylus*) and pine/birch (*Pinus/Betula*) woods (illus 3) appears clear-cut, but this is largely due to the scarcity of pollen sites at this boundary. Nevertheless, at c 3000 BC a broad division can be seen between the flatter and more low-lying 'flow country', supporting increasingly open birch/hazel woods, and in some areas no or very few trees, and the hills to the east and south of Ben Klibreck in central Sutherland, where pine/birch woodlands, with some oak and elm, were well established. Factors such as aspect, altitude and soil cover governed the distribution of woodland types (Pennington *et al* 1972; Kerslake 1982). This boundary or ecotone was not fixed in time. After 3000 BC, pine trees, probably colonizing the already extensive blanket peat (Charman 1992), extended their range to the north coast (Gear 1989; Gear & Huntley 1991) before, c 2000–1800 BC, disappearing almost entirely from areas north of the Great Glen (below).

At Suisgill, in Helmsdale (Andrews *et al.* 1985), the proportions of trees decline at c 2850 BC in the face of small-scale but seemingly sustained clearance; cultivation is suggested. Regeneration of the open woodland is not seen until c 1650 BC, sustained except for a brief pulse of woodland removal at c 650 BC until c AD 200, when a final but gradual woodland decline started. Above the Dornoch Firth, Birks (1975) detected early Neolithic impacts at c 3000 BC, but sampling resolutions are too low to understand whether clearance was interrupted by phases of regeneration.

Near Lairg, much more detailed analyses by Smith (unpublished) show contrasting patterns of activity. Little unambiguous human impact can be seen until c 1650 BC, when grazing and some cereal cultivation induced soil to wash across the peat, but seemingly there was little change in woodland structure. Notwithstanding this, woodland regeneration at c 1450 BC is clear, the preceding disturbance appearing to allow the stronger establishment of oak and elm in the absence by then of pine. Much more intensive clearance of the woodlands is seen between c 700 and 200 BC, comparable in time but not in intensity to that near Suisgill. Final clearance of the birch/hazel/oak woodland in Achany Glen was not until the medieval period.

Within the birch/pine woods of the north-west coast a number of pollen sites suggest very low prehistoric human populations, in that no or very little human impact can be recognized. Pollen diagrams from sediments in Loch Clair (Pennington *et al* 1972) and Loch Maree (Birks 1972b) provide virtually no information on anthropogenic activity. At Loch Craggie (Pennington *et al* 1972) some evidence for pasture and cereals at c 2750 BC is seen but not associated with woodland decline. Very slight woodland disturbance is recorded at Loch Maree at c 2250 BC (Birks 1993b), but its origin could lie in climatic stresses. Similarly, a more significant woodland 'collapse' around Loch Sionascaig at c 1300 BC is thought to have either a climatic or human cause (Kerslake 1982). Kerslake saw no single factor as being dominant in woodland destruction. Only Johansen's analyses (in Pennington *et al* 1972) from blanket peat near Loch Sionascaig is thought to yield an interpretable anthropogenic signal, with strong but localized clearance for pasture at c 1500 BC, close to the time of Kerslake's 'collapse' of woodland in the same locality. No subsequent woodland regeneration is recorded in the studies by Pennington *et al* (1972) or by Kerslake (1982), the landscape becoming by continued minor setbacks the blanket peat-dominated landscape of the present.

This pattern recalls the difficulties in interpretation on the Outer Isles and the northernmost mainland. It also contrasts with the interpretations of Andrews *et al* (1985) and Smith (unpublished) nearer to the east coast, and suggests a strong west/east climatic gradient in woodland density, which to some extent exists today in pine woods to the south of the Great Glen (Steven & Carlisle 1959).

Below the Great Glen, the more closed pine woods of the Cairngorms show a complex history of clearance. Birks (1970; 1975) noted that the initial human impacts varied greatly in timing, and this was confirmed by O'Sullivan (1974a; 1976). Around Loch a'Chnuic, deep within the Cairngorms, much forest survived until the last few hundred years, and prehistoric land use in the remoter parts of the forest may have been limited to rough grazing and the very gradual conversion of forest to heath through low-density grazing. Similar low-intensity grazing is suggested for the head of the Dee Valley near Braemar (Huntley 1976). In contrast, the earliest evidence for clearance near the River Spey, at Loch Garten, may have occurred as early as 3000 BC, and a series of small-scale and temporary incursions are recorded until c 1700 BC, when a widespread clearance was initiated; this was gradual but perhaps representative of permanent colonization (O'Sullivan 1974a; 1974b). Around Loch Einich (Birks 1975) the spread of heathland and significant anthropogenic clearance are not seen until a time estimated here at c 500 BC. At nearby Loch Pityoulish (O'Sullivan 1976), temporary disturbance is recorded at c 1450 BC, and more permanent clearance, possibly inducing some soil erosion, is seen later than at Loch Garten, after c 1000 BC. But at Loch Pityoulish this phase was terminated by an apparent woodland regeneration, uncertainly dated but occurring after c AD 300. Re-colonization by farming communities, which grew crops, occurred only in the last 1000 years. Nevertheless, much pine woodland survived, and continued to be managed into the late historic period, as it is today (O'Sullivan 1973).

The density of pollen sites within the south-western native pine woods, around Rannoch Moor, is high (illus 1), but data are very few from which to understand the impact of farming communities. Nevertheless, there is no evidence for any clearly discernible agrarian activities (Haggart, pers comm), and the almost complete cover of blanket bog and rare birch copses appears to have developed without obvious human interference, in much the same way as more northerly landscapes.

THE PINE DECLINE AND HUMAN IMPACT

After c 2850–2450 BC, pine advanced northward from its former range-limit in the hills to the south of the 'flow country' (above), to the coast of Caithness (Birks 1975; Gear 1989; Charman 1990), to Lewis (Wilkins 1984; although Fossitt sees it colonizing earlier; above) and to eastern Skye (Williams 1977) and Rum (Durno 1967; Birks 1975). Pine trees at these extremes grew on blanket peat, in which its barely rotted stumps can be seen in many areas today. Probably less than 1000 years later, c 2000–1800 BC, there was a dramatic collapse in the extent of the native pine population throughout Scotland (Birks 1975; Bennett 1984; Bridge *et al* 1990; Gear & Huntley 1991), as well as in isolated outposts in England (Bennett 1984) and in western Ireland (Bradshaw & Browne 1987). Only in the core areas of Speyside and the Cairngorms was natural pine woodland able to survive, albeit increasingly open through human incursions and the spread of heather moorland (Birks 1970; O'Sullivan 1974a; 1976; above).

This phenomenon has attracted much palaeoecological interest, in the way that the elm decline has, since major readjustments in the range of a major forest-forming species over such a wide area, seemingly involving only one taxon and apparently very rapidly (Bennett 1984), are unusual and immensely informative. The possibility of prehistoric human impact in the pine decline has been raised by Pennington *et al* (1972) at Loch Sionascaig, where a contemporaneous peak in charcoal was recorded, and in more general terms by Birks & Williams (1983) and Bennett (1984), who pointed out the sensitivity of pines to anthropogenic clearance by fire. However, the majority of investigations have rejected this possibility on the absence of palynological evidence for such impacts at the time of the pine decline (eg, Birks 1975; Kerslake 1982; Gear 1989; Bridge *et al* 1990), and on the scale and synchroneity of the changes (Gear & Huntley 1991). Climatic controls have been favoured, and in particular a substantial increase in precipitation over the British Isles (Birks 1975; Dubois & Ferguson 1985; Bridge *et al* 1990). Gear & Huntley (1991) have argued for major changes in regional atmospheric circulation systems to account for both the northward extension and the subsequent crash in the pine population.

Most recently, Blackford *et al* (1992) have suggested a link between the pine decline and Icelandic volcanic activity (an eruption of Hekla), either through direct fallout of tephra or through volcanically induced climatic deterioration. This correlation would be more convincing had pine pollen been represented at their sites, near Altnabreac in Caithness, in proportions clearly signifying local presence (eg, >20–30 % terrestrial pollen; cf Huntley & Birks 1983; Bennett 1984; Ward *et al* 1987; Gear & Huntley 1991), and it may be that the pine decline in this region occurred some time prior to the start of their pollen sequence at c 1900 BC, and therefore the Hekla eruption at c 1800 BC. Hall, Pilcher & McCormac (1994) have rejected a correlation between Hekla-4 tephra and the pine decline at sites in northern Ireland.

THE BIRCH/HAZEL/OAK WOODS OF THE WEST COAST

On the west coast to the south of Loch Maree, pine appears never to have been abundant (Birks 1977, 1980; Bennett 1984, 1989). Oak replaces pine. To the west and south-west, however, on the exposed coasts and islands of the northern Inner Hebrides, oak did not gain as strong a foothold as on the mainland, and elm is rarely considered to have been locally present. Birks & Williams (1983) considered northern Skye to have been dominated by birch and hazel, but the suggested greater significance of oak in sheltered parts of South Uist (Bennett *et al* 1990; above) might imply that oak may have been more important on Skye (Durno 1967; Vasari & Vasari 1968). Detailed palynological investigations employing several sites within one island, such as on Skye (Williams 1977; Birks & Williams 1983), Mull (Walker & Lowe 1985; 1987; Lowe & Walker 1986) and Oronsay & Colonay (Andrews *et al* 1987) have shown the complex mosaic of woodland types that could develop in sheltered localities. On the mainland of Argyll, from Ardnamurchan to Lorn, Cowal and down the Kintyre peninsula, proportions of oak pollen increase sufficiently for it to be regarded as of equal dominance with hazel (Andrews *et al* 1987), but individual sites show subtle differences in arboreal proportions and occasionally the virtual absence of oak (eg, Walker & Lowe 1981; Steven & Dickson 1991).

To maintain a certain geographical unity, this section includes data on both the birch/hazel woods of the Inner Hebrides and the oak-rich west coast. The detailed work of Dickson and colleagues on Arran is also included here. Boyd & Dickson (1986) suggest Arran to be more isolated from the mainland, palaeoecologically, than it might first appear, and Robinson & Dickson (1988) make the point that the island is as exposed as areas of the west coast, and more so than the mainland.

The view that the earliest detectable human-induced disturbance in this region occurred after 2000 BC (Walker & Lowe 1986; 1987; Andrews *et al* 1987) may be valid on individual islands (eg, on Colonsay; Andrews *et al* 1987), but at most dated sites can be questioned. On Skye, sustained clearance from c 2200 BC is seen at Loch Cleat in Trotternish (Williams 1977), leading to a mainly treeless landscape by 600 BC, but initial woodland disturbances, probably anthropogenic in origin, are recorded from c 3250 BC. In eastern Skye, initial Neolithic clearances between 3250 and 2250 BC are the only clearly discernible prehistoric impacts. The attractions of Trotternish's greater soil fertility would seem to account best for these marked differences in woodland survival (Williams 1977; Birks & Williams 1983). Hirons & Edwards' (1990) work on the east coast of Rum revealed similarly early agricultural impacts, from c 2950 BC, which led without apparent regeneration to an increasingly intense phase of land use, possibly including cereal cultivation, after c 2000 BC, which was most intense after c AD 450, set within a treeless landscape.

To the east, one site near Mallaig, Lochan Doilead, shows possible pre-elm decline woodland disturbance at c 3650 BC, but then no further impact for approximately 1000 years. Between 2600 and 1600 BC a series of small-scale intakes are recorded, and sustained clearance only after this, until perhaps 500 BC (Williams 1977). Around Loch Shiel, Moore (1977) recorded a series of short-lived interference phases post-3000 BC, before major and sustained deforestation, unfortunately undated. Within the sediments of Loch Shiel itself, Thompson & Wain-Hobson (1979) reproduced this same pattern, and the observation that some of their radiocarbon dates are affected by erosion into the loch of old organic matter in soils, probably after 300 BC, might be good evidence that this period marks the first major clearance event in this part of Ardnamurchan. This would suggest that while parts of the peninsula were opened up, nearby localities such as around Mallaig were at least partly abandoned, and that no regionally synchronous pattern of clearance is recognizable. Indeed such a contrast can be seen on a small scale on Oronsay and Colonsay (Andrews *et al* 1987). Increasingly widespread clearance from c 2150 BC around Loch Cholla on Colonsay is curtailed at c 650 BC by the growth of birch scrub over former pasture and arable, but at the same time the neighbouring isle of Oronsay was becoming treeless through renewed grazing pressures.

If some degree of regional synchroneity in clearance is looked for, the period c 2600–2500 BC can be suggested as one in which the majority of sites show some anthropogenic activity. This is so even at sites which failed to attract the attention of agricultural communities at other times, such as Loch Ashik in eastern Skye (Williams 1977). Farther south, in western Islay, Andrews (1989) suggested that while the elm decline was accompanied by clearance, the first major impact was delayed until c 2500 BC. Strikingly similar patterns are seen on the mainland opposite Jura, at Loch Cill an Aonghais (Peglar *in* Birks 1980; Birks 1993c), although the clearance at c 2600 BC is only the first of a number of short-lived incursions, and here the landscape may have remained substantially wooded until much later, post-AD 600 .

Arran seems both to confirm and contradict these interpretations. Throughout the island, anthropogenic impacts are seen significantly before 2600 BC (Boyd & Dickson 1987; Robinson & Dickson 1988; Steven & Dickson 1991). In the south, sustained late Mesolithic disturbance might have helped maintain an anomalously open woodland (Robinson 1983; Robinson & Dickson 1988). But above this initial agricultural phase, differences emerge between the north and south of the island which might reflect contrasts in the region as a whole. Around Loch a' Mhuillin in the north, a succession of small-scale clearances for grazing throughout the later prehistoric period, accompanied by the spread of heathland, appears to have had a gradual but compound and lasting effect on woodland survival (Boyd & Dickson 1987). A similar pattern is seen at nearby Glen Diomhan (Steven & Dickson 1991) until c 1500 BC, when a still gradual but more intense phase of clearance was instigated, with nearby cereal cultivation. On Machrie Moor in the south, a very different pattern develops, with comparatively intense bursts of agricultural activity, both arable and pastoral, being separated by phases of apparent woodland regeneration and agricultural decline. Early clearance is curtailed at c 2350 BC, only to resume to a limited extent after c 1950

BC, greatly intensified between 1550 and 800 BC. A lowered 'commitment' to farming is seen after this, and Robinson & Dickson (1988) suggest some depopulation of the island in the face of blanket peat spread and climatic deterioration.

THE BIRCH/HAZEL/OAK WOODLANDS OF NORTH-EAST SCOTLAND

A woodland dominated by birch and hazel, with seemingly only a small proportion of oak and even less elm, is recognized by most of those engaged in research along the eastern and north-eastern seaboard north of the Firth of Tay (Gunson 1975; Durno 1976; Birks 1988), although not by Bennett (1989). These do not appear comparable with the open birch/hazel woods of northern Scotland, which they seem to approach above the Moray Firth; totals of arboreal pollen at the few sites within this region suggest closed tree canopies. Proportions of oak and elm may decline with latitude as they approach their range-limits (Gunson 1975). With increasing altitude, similar effects are seen, and both oak and elm appear to have been excluded from the deepest recesses of The Mounth (Huntley 1981); both were rare farther south, above Glen Shee (Caseldine 1979), and oak was absent from the upper slopes of the central and eastern Grampians (Donner 1962; Tipping *et al* 1993; Tipping 1995a), although the base-rich Dalradian rocks did allow elm to extend its altitudinal range to accompany birch and hazel.

This region is very poorly researched, and much of our understanding comes from Durno's (1956; 1957; 1959; 1970) early investigations. Only within the Howe of Cromar in upper Deeside have radiocarbon-dated pollen analyses been undertaken on lowland sites (Edwards 1978; 1979; 1989a; Edwards & Rowntree 1980; Whittington & Edwards 1993). Lying very close to the ecotone with pine/birch woodland (illus 3), it remains to be seen how typical of the region these very detailed analyses are; but these analyses, from Braeroddach Loch and Loch Davan, are closely concerned with elucidation of the archaeological record (Edwards 1975)

At Braeroddach Loch, small-scale clearance(s) at the elm decline, c 3350 BC, persisted for about 600 years before woodland at least partially regenerated. But at c 2450 BC a 400-year 'cycle' of more temporary incursions led eventually to sustained regeneration. After c 1850 BC the clearance phases appear to be fewer but more prolonged; they presage a sustained phase of activity between 1100 and 300 BC, featuring the earliest evidence for cereal cultivation, in which severe soil erosion affected the lake sediment (Edwards & Rowntree 1980) and distorted the high-resolution radiocarbon chronology by introducing old organic matter (Edwards 1979). Partial regeneration of birch scrub occurred at c 300 BC, according to Edwards (1979), and renewed clearance was delayed until very late in the historic period. Loch Davan is 3.5 km west of Braeroddach Loch. Equally careful radiocarbon dating at this site allowed an independent chronology of clearance to be constructed (Edwards 1978). Encouragingly, many clearance events appear synchronous within the resolution of radiocarbon dating; but even when they are apparently non-synchronous, as when woodland regeneration in the very late Iron Age seems to have occurred some 200–300 years after the same phase at Braeroddach Loch, site-specific and general uncertainties in the radiocarbon chronology allow considerable flexibility in interpretation.

Only in the uplands south of Deeside, over Caenlochan and The Mounth, are there pollen diagrams that can illustrate anthropogenic activities. Caseldine's (1979) sites above Glen Shee are undated, though they show that the earliest clearance closely followed or accompanied the elm decline. This association is endorsed at Creag na Caillich, above Loch Tay (Edmonds, Sheridan & Tipping 1992; Tipping, Edmonds & Sheridan 1993), and at Carn Dubh, above Pitlochry (Tipping 1995a), where grazing pressures on the upland woods are apparent. But later prehistoric activities in the hills are small in scale, limited to grazing, possibly transhumant, as they are farther east within the Caenlochan glens (Huntley 1981). Nevertheless, low-intensity grazing pressures, sustained over long periods, seem to have gradually but effectively removed the woodlands. In only one brief phase, c 1250–1000 BC, are anthropogenic uses of the uplands around Carn Dubh intensified and crops grown (Tipping 1995a).

THE OAK/HAZEL/ELM WOODS OF SOUTHERN SCOTLAND

Over large areas of southern Scotland the primary woodland was dominated by oak, elm and hazel. Birch was present but subsidiary, possibly shaded out by the canopy cover. There were altitudinal and edaphic contrasts here as in other parts of the country. In the Campsie Fells, for example, neither oak nor elm is thought to have colonized the base-poor soils (Dickson 1981), and in the higher parts of the Southern Uplands the acid Silurian rocks discouraged elm from colonizing (Erdtman 1928; Tight 1987; Innes & Shennan 1991; Tipping, unpublished). Nevertheless, between the Highland Boundary and Southern Upland faults, and on the eastern seaboard of Angus and Aberdeenshire, the great expanse of low-lying ground allowed the fullest expression of oak/elm/hazel forest. Suggestions that pine played a significant role in these central/southern woods (Fraser & Godwin 1955) have been comprehensively challenged by Dickson (1988), although it is also clear that pine did extend southward onto blanket peats, as it did northward (Gear & Huntley 1991; above), perhaps most concertedly at around the same time as in the north, c 3000–2000 BC (Stewart 1980; Dickson 1993a). In the Galloway Hills, however, pine colonized dry blanket peat earlier, c 5400–4000 BC, and was locally abundant (Birks 1972a; 1975; Jones, Stevenson & Battarbee 1989).

For ease of discussion prehistoric disturbance to this woodland type is considered in two parts: north and south of the Forth/Clyde line.

THE NORTHERLY OAK/HAZEL/ELM WOODS

Within this region the earliest agricultural clearances appear to coincide closely with the elm decline, at Dubh Lochan, adjacent to Loch Lomond (Stewart, Walker & Dickson 1984), and in Fife at Black Loch (Whittington *et al* 1990) and Pickletillem (Whittington *et al* 1991a). The North Mains analyses (Hulme & Shirriffs 1985) were discussed earlier. The pollen record at Loch Lomond (Dickson *et al* 1978) is poorly resolved and cannot be analysed closely, and at Flanders Moss, Turner (1965) argued that the apparent absence of prehistoric clearance was the consequence of selecting a pollen site insensitive to small and temporary clearances.

At the majority of these few dated sites the record is poorly defined, possibly because early clearances were of very limited extent and very brief. The detail of the record at Black Loch stands out, even when compared to nearby Pickletillem, and it is difficult to know whether this is because Black Loch has an exceptional history, is especially 'sensitive' to disturbance, or has been particularly well-researched. Whittington *et al* (1990) show anthropogenic activity, probably involving cereal cultivation, to be associated with all three elm declines at Black Loch, between c 3150 and 2500 BC. At both Black Loch and Pickletillem this activity was greatly reduced after c 2500 BC, but whereas at Pickletillem seemingly little change occurred prior to the early years AD, the woodland around Black Loch underwent renewed and major clearance at c 1950 BC, again with crops grown, and a further intensification/expansion to a substantially open landscape after c 1000 BC. A substantial but short-lived agricultural expansion is seen at this time around Loch Lomond (Stewart *et al* 1984), before apparent woodland regeneration and very low levels of human activity within the Iron Age.

The thriving agricultural economy in north-east Fife, around Black Loch, appears to have suffered a recession, and pronounced woodland regeneration, in the first century AD, thought significant by Whittington & Edwards (1993) with regard to the Roman advance into Scotland. Dickson (1993a) has briefly reported apparent pre-Roman clearance at Methven Moss in Strathallan. Farther west, Turner (1965), Dickson *et al* (1978) and Stewart *et al* (1984) all record clearance phases, large-scale around Flanders Moss, only slight to the east of Loch Lomond, in (as far as can be established) the early centuries AD: c AD 100–300. The reasons for agricultural expansion, and the role of Roman forces, are, however, not discussed (see below).

THE SOUTHERLY OAK/HAZEL/ELM WOODS

The number of reasonably well-dated records from areas south of the Forth/Clyde line allow an appreciation of landscape changes at scales greater than that in other regions. There are several areas within southern Scotland where the elm decline itself seems not to be associated with anthropogenic activity, such as in north Ayrshire (Bloak Moss: Turner 1965; 1970; 1975) and the central Southern Uplands (Tight 1987; Tipping & Boyd, unpublished). On the Solway Firth, Squires' (1978) analyses at Burnswark Hill suggest that both elm declines there may feature contemporaneous woodland clearance, whereas a few kilometres to the east, Tipping (1995b) found evidence for clearance only at the second of two elm declines. The foothills of the Cheviots show much evidence for early Neolithic agriculture (Hibbert & Switsur 1976; Tipping, in press), and also deep within these Border hills (*contra* Burgess 1984). Later Neolithic activity at some sites is identified by short-lived clearances, but at a few – Swindon Hill in the Cheviots (Tipping, in press) and Kingside Loch near Hawick (Tight 1987) – more enduring, semi-permanent openings for both pasture and crops were established by c 2800 BC. In apparent contrast, many sites around the Solway Firth suggest at least partial woodland regeneration after c 2500 BC (Tipping 1995b).

Considerable evidence exists throughout the region for near-synchronous increases in the scale of clearance at c 2000–1850 BC. This occurs in lowland and upland contexts. This might represent in many areas the first comparatively intense interest in the uplands (Davies & Turner 1979; Tipping 1992), and there are suggestions from well-dated sites that the clearings were maintained for hundreds, rather than tens, of years, and might suggest a more determined settlement than implied by temporary clearances (Turner 1965; Davies & Turner 1979). Nevertheless, the apparent small extent of these forest openings does not imply widespread colonization, and clearings may at this time have remained discrete around still-isolated farmsteads (Tipping, unpublished). It is equally clear that the lowlands were not abandoned at this time. All pollen sites in the region show some evidence of human impact after c 2000 BC, but the intensity and duration of this varies from site to site; the significance of these different patterns remains to be explored. In addition, some sites show clear evidence for cereal cultivation while others suggest the economy to be exclusively pastoral. Of course, the absence of cereal-type pollen is not necessarily evidence for the absence of cereals.

There are particular sites which seem to suggest the partial or total abandonment of agricultural land after c 800 BC, but the suggestion of a significant decline in activity (Burgess 1985) is by no means justified by the palynological evidence (Tipping, unpublished). While some sites seem to indicate a gradual, perhaps piecemeal, process of clearance in the early/mid Iron Age (Tight 1987; Dumayne 1992), perhaps the majority show no significant intensification in the extent of clearance until c 500 BC. But in the centuries following this, a large number of sites quite clearly depict a major clearance episode, the first clearance of any great spatial extent. Indeed, this can be said to be of truly regional significance, although the available radiocarbon dates suggest that no synchroneity can be demonstrated. Individual pollen 'catchments' were systematically cleared, often very abruptly, and often with the near-complete removal of trees, occasionally inducing quite severe soil erosion. This pattern is equally clearly seen throughout northern England as in southern Scotland (Roberts, Turner & Ward 1973; Bartley, Chambers & Hart-Jones 1976; Donaldson & Turner 1977; Turner 1979; Barber 1981; Dumayne 1992, 1993b; Tipping 1992, 1995b; Innes, unpublished; Ramsay, unpublished). There is no evidence that clearances show any significant spatial patterning, such as suggested by Turner (1979; 1981) who, from a limited data-set, suggested that clearances were significantly later north of northern England. There are suggestions that this 'wholesale' woodland destruction is of a slightly later date at sites close to Hadrian's Wall, possibly of Roman or Romano-British origin (Davies & Turner 1979; Dumayne 1992; 1993a; Dumayne & Barber 1994; Tipping 1995b; Innes, unpublished), but at the overwhelming majority of sites north and south of the Wall the clearances are clearly of late Iron Age date (Wilson 1981; Fenton-Thomas 1992; van der Veen 1992; Dickson 1993a; Dumayne 1993b; Fleming, A pers comm). The most dramatic and rapid clearances were not necessarily the most sustained (Dumayne 1992), and one product of this is that at some localities, woodland regeneration had occurred prior to the Roman advance into Scotland (Dumayne 1993b). But there seems little doubt that this widespread clearance, almost certainly undertaken to provide vastly increased areas for both crops and grazing (but see Dumayne 1993a and Dumayne & Barber 1994), left substantial areas of southern Scotland almost treeless at the time of the Roman advance (Breeze 1992; Dickson 1993a; Tipping, unpublished).

SPECIFIC THEMES IN LATER PREHISTORIC DEFORESTATION

The sketched impressions of prehistoric woodland removal, presented above, serve to illustrate the nature of the pollen records in different parts of the country. Although at times rather simplistic syntheses have been proposed, no broader reconstructions have been attempted. What follows are brief summaries of some of the outstanding features insofar as they are currently understood.

THE 'CONSTANCY' OF EARLY NEOLITHIC ACTIVITY

It is particularly striking how abundant is the identification of early/mid Neolithic impact throughout Scotland, particularly when later periods are far less obviously consistent in the registration of anthropogenic activities. Precisely what these early agricultural clearances represent is very difficult to determine (see Edwards 1993), but their commonness does raise questions concerning, at one level, the size of the population, or perhaps more likely, the mobility of the population (Thomas 1988).

A MID-NEOLITHIC AGRICULTURAL RECESSION?

In the late 1970s both Bradley (1978) and Whittle (1978) saw in an apparently synchronous woodland regeneration phase across the British Isles, at c 2400–1750 BC, grounds for suggesting a serious agricultural 'recession' in the mid-Neolithic. This phase is recognized farther afield, in southern Scandinavia (Berglund 1969). A number of people have drawn attention to such a phase at particular Scottish sites, such as Robinson & Dickson (1988) at Machrie Moor on Arran, Tipping (1995b) on the Solway Firth, and perhaps unsurprisingly, Keith-Lucas (1986) at the Scord of Brouster. It is possible to see comparable regeneration phases at approximately the same time at other sites (Callanish, on Lewis: Bohncke 1988; Loch Cleat: Williams 1977; Black Loch in Fife: Whittington *et al* 1990), but it is equally apparent that neighbouring sites show no such features. Regional synchroneity cannot be argued for from the present data-set. Nor can the distribution of the few sites listed here permit the argument that these are marginal environments. At the moment it appears safest to assume that these sites reflect local and regionally insignificant fluctuations in land use.

EARLY BRONZE AGE AGRICULTURAL EXPANSION AND CLIMATIC DETERIORATION

It is possible that the presumed synchroneity of the preceding 'regeneration' phase was greatly emphasized by the degree of synchroneity seen in its end. A recurring pattern throughout the country is renewed clearance or the intensification of existing agricultural pursuits in the centuries c 2000–1800 BC. There are exceptions, of course, but it does seem likely that the Early Bronze Age was a period of real agricultural expansion. Conventional interpretations of this widespread phenomenon tend to stress climatic amelioration, but there is increasing palaeoenvironmental evidence for exactly the opposite trend, for profound increases in precipitation and, less certainly, a decline in temperature, throughout north-west Europe. This climate shift is identified as causal in the collapse of the pine population (above), through waterlogging of the peats that previously (but briefly) supported the trees, and is increasingly seen as one of the major Holocene climate shifts (Birks 1991; Barber, K E, pers comm). These new data present an intriguing twist to the long-standing observation of early Bronze Age population growth, and the precise relationship between climate and population over this turbulent period needs to be explored.

PALAEOECOLOGICAL CHANGE AT THE BRONZE AGE/IRON AGE TRANSITION

Evidence for further climatic deterioration at the end of the Bronze Age, c 800 BC, is summarized by Turner (1981). The reality of this shift in climate is not in doubt, but the widespread dereliction of marginal land postulated by Burgess (1985) has not been confirmed for the 'type area' of the Cheviots (Tipping, unpublished). It is not currently possible to identify land abandonment at around this time elsewhere in Scotland, and in fact there are a significant number of sites which seem to show increases in the amount of land cleared.

A LATE IRON AGE AGRICULTURAL REVOLUTION

Data for southern Scotland show an intensification of agricultural activity after 500 BC (above). Individual sites in other regions similarly show this period to be one of major woodland clearance, but there seems not to be the regional response so clear to the south of the Forth/Clyde line. What this extraordinary episode signifies in archaeological terms is far from clear.

THE IMPRINT OF ROMAN INVASION

Dumayne (1992; 1993a; 1994; Barber, Dumayne & Stoneman 1993; Dumayne & Barber 1994) has argued that the extensive woodland clearance seen in southernmost Scotland at the end of the Iron Age has a Roman and not native origin, and a military, rather than agricultural, function, in the construction of the installations on and accompanying Hadrian's Wall. Radiocarbon dates cannot allow so precise a correlation with historical events, and the chronology of events requires much higher resolution. But in the observation that these clearances compare in all respects (particularly the sharp increases in agricultural indicator taxa) with earlier and demonstrably Iron Age clearances, there would seem to be few grounds for considering woodland removal to have had a different purpose.

There are no grounds at present to think that the Roman occupation had any distinctive effect on native farming in the Borders, although this is a major field of inquiry for which the current dataset in this region is, for the first time, capable of further interrogation. Farther north, in north-east Fife and eastern Aberdeenshire, Whittington & Edwards (1993) have suggested that the Roman invasion might have had deleterious effects on the native population in initiating depopulation and widespread woodland regeneration. One must look forward to increasingly spatially and temporally resolved pollen analyses being capable of testing these intriguing hypotheses.

THE FUTURE

TEMPORAL PRECISION

Of central concern in future investigations must be the careful and rigorous application of dating controls. Radiocarbon dating is essential at all sites, and it is not enough to provide one or two dates only through a profile. The uncertainties in interpolation between dated points are profound, and there is a strong case for dating all major human interference phases within a pollen diagram (see, for instance, Edwards 1979). The circularities in assuming synchroneity of such phases between sites are self-evident, and correlations can be made only by independent and 'absolute' dating controls (above; Hall, Pilcher & McCormac 1993).

Notwithstanding this point, the limitations in radiocarbon dating need to be appreciated. It may well prove impossible to demonstrate precise synchroneity between events, although developments in high-precision dating and 'wiggle-matching' against the tree-ring chronology (Clymo *et al* 1990; Pilcher 1991) allow the error to be narrowed around a mean radiocarbon date. Increasingly critical is the need to be able to test our radiocarbon chronologies. This can be done in broad terms in lake sediments through correlation with the Holocene palaeomagnetic record (Dickson *et al* 1978; Thompson & Wain-Hobson 1979). Increasing the numbers of radiocarbon-dated points in a profile does provide some internal checks, since they should lie in a conformable sequence, and in lake sediments again, the effects of soil erosion in introducing old carbon can in some cases be detected (O'Sullivan 1976; Edwards 1979; Thompson & Wain-Hobson 1979). In peats the introduction of reworked sediment is probably less likely (though can be demonstrated; Huntley 1981; Edwards, Hirons & Newell 1992; Tipping 1995a). But hiatuses in peat accumulation, either climatic (Gear & Huntley 1991) or anthropogenic, through peat-cutting (Innes & Shennan 1991) or burning (Birks 1975), are probably far more common than is recognized, and are by no means readily distinguished in either sediment or pollen stratigraphies. In the late historic period, radiocarbon dates can be tested against other radiometric techniques (Pennington *et al* 1976), but this is not possible for earlier periods. This is one area where the development of tephrochronology (Dugmore 1989) will be so important in the future (Pilcher & Hall 1992).

Firm chronologies, thoughtfully applied and rigorously tested, lead inevitably on to the posing of more challenging questions concerning rates of change in the cultural landscape. How rapid or gradual is woodland clearance at particular sites ? How long did clearances last ? We can already appreciate that Turner's (1965) 'temporary' clearances can persist for much longer than the c 50 years she postulated (Pilcher *et al* 1971; Edwards 1978), although Buckland & Edwards

(1984) suggested that the maintenance of open spaces need not have been through direct human intervention. To answer these and similar questions we need to improve the sampling and temporal resolution of our pollen diagrams. Pollen diagrams are constructed from the counting of individual slices of sediment, lake mud or peat. Two simple but highly critical aspects of pollen diagram construction are deeply embedded in this simple statement; how thick should individual sediment slices be, and how widely spaced should they be ? Thought needs to go into the appropriate resolution of individual sediment slices (Simmons, Turner & Innes 1989), and into the frequency of analyses. Most usefully, temporal resolution should be viewed in terms of human time-scales, such as human generations, and not simply in terms of depth-increments. Sampling resolutions of, say, one 0.5 cm thick slice every 4.0 cm can then be understood in their true light, as representing, for example, the combined pollen record of c 10 years, examined every c 80 years. This approach would inevitably throw new and much-needed emphasis on dating controls (above). As bemoaned in the opening comments, the current database is surprisingly inadequate in this respect.

THE ABSOLUTE EXTENT AND SCALE OF CLEARANCE

Turner (1965) defined three types of clearance: temporary, major and extensive. Throughout this paper I have used these terms freely, as the original researchers have. However, what these terms mean with regard to the actual extent of land farmed cannot be determined at present. Pollen sites are point sources, and do not depict area at all successfully. Coupled with this limitation is the immense complexity of pollen recruitment to a site. While some objective and quantitative approaches to the identification of intensity of human impact have recently been proposed (Birks, Line & Persson 1988), the results are still only relative measures. Three-dimensional pollen 'diagrams', the product of cross-correlating three or more individual diagrams (Turner 1975; Smith & Cloutman 1988; Turner, Innes & Simmons 1993), have proved capable of quite powerful reconstructions over limited areas of a few hundred square metres, but given good chronological controls (above) should be capable of spatial resolution at much larger scales (Berglund 1988). At the moment such analyses can be attempted only for limited time periods and in specific regions such as those to the south of the Forth/Clyde line, where the density of securely dated pollen profiles is high.

MECHANISMS OF CLEARANCE

Despite the readily observable fact that trees have been cleared from the Scottish landscape over a very long time-period, extending to before the introduction of agriculture (above; Tipping 1993), little evidence is forthcoming concerning the processes of deforestation. Sustained grazing pressures might seem sufficient to explain the slow, gradual and often apparently unidirectional (ie, without apparent regeneration) decline in the tree cover over large parts of upland and northern Scotland in later prehistory. But this process is coupled with natural reductions in tree populations, through soil deterioration, climate change and the spread of blanket peat, and grazing densities need not have been prodigiously high, merely constant. However, much of the evidence from northern Scotland comes from quite poorly resolved analyses, and where deforestation has been examined with higher temporal resolution, the gradual decline is interrupted by abrupt reductions in arboreal pollen, readily comparable to clearance events farther south.

These abrupt anthropogenic events are unlikely to have been brought about by grazing pressures alone. Clearance by either felling or burning, or a combination of these, is most reasonable. At some localities the combined analysis of microscopic charcoal and pollen can allow some discrimination, and clearances where fire frequency is not elevated can imply that fire was not employed in clearance. However, where high levels of charcoal coincide with woodland removal, it does not imply that fire was used in clearance. There are many anthropogenic sources of charcoal, such as settlements, and it is reasonable to infer that, for example, increasing amounts of charcoal from an increasing number of settlements would coincide in time with an increasing need for agricultural land and woodland clearance.

THE UBIQUITY OF 'MIXED' FARMING

It is unsurprising to find that at the majority of sites both arable and pastoral elements are represented. Agriculture at the subsistence level would probably require the maintenance of both. Phases with only pastoral indicator species (Behre 1981) might represent simply the difficulties of identifying crop-growing from palynological analyses. It is very likely that cereal cultivation is under-estimated in the pollen record, and even more so if one of the key 'pastoral' indicator herbs, ribwort plantain (*Plantago lanceolata*), can in some situations be an arable weed (Groenman-van Waateringe 1986). Clearance events seeming to be characterized by only cereal-type pollen are non-existent. This might suggest that agricultural specialization is a characteristic only of the late historic period, even in the most intensly farmed areas of southern Scotland.

Within this mix of arable and pasture, it is very difficult to determine the balance of the two components. Ratio measures using particular indicator species (Turner 1964; Maguire 1983) present severe interpretative problems, not simply because the assumption that a particular species can be assigned to a clearly defined niche is not justified (Behre 1981), but also because the differential representation of pollen from such species will inevitably distort the results.

Pollen analysis may never approach the detailed reconstruction of crop-growing techniques that plant macro-subfossil analysis can (Hillman 1981; van der Veen 1992). However, in recent years renewed interest in the character and purpose of anthropogenic grasslands has led to the tentative recognition of subtle differences in pasture types. Perhaps most successful has been work on identifying the effect of different grazing intensities on pollen from pasture (Groenman-van Waateringe 1986), and recognizing different forms of meadow using indicator species (Greig 1984; 1988). These are based on so-called 'modern analogues', present-day agricultural environments presumed typical of those in the past. There are, of course, problems in comparing the present with the past, but parts of Scotland seem to have had, until comparatively recently, 'traditional' forms of land management (eg, Fenton 1978), and this represents one as yet untapped resource for comparison. Increasing use of multivariate statistics in pollen analysis is allowing entire 'modern analogue' pollen assemblages to be compared directly to subfossil assemblages, rather than individual indicator taxa (Gaillard *et al* 1992), and this approach needs to be investigated further.

WOODLAND REGRESSION OR WOODLAND MANAGEMENT?

The depiction of agricultural practices from pollen analyses lacks a certain finesse. The interpretation of increases in arboreal pollen as representing agricultural regression and woodland regeneration is even less sophisticated. It is an inevitable consequence of the widely adopted 'expansion-regression' model (Berglund 1985; 1986), but this interpretation is in a number of instances almost certainly incorrect. Woodland management through coppicing is argued in southern Britain to have been practised as early as the Neolithic (Coles & Coles 1986). The control of woodland resources would have become increasingly necessary into the later prehistoric period (Hanson & MacInnes 1980). Boyd (1988) has presented macro-subfossil evidence to suggest that Late Iron Age woods in upper Eskdale, southern Scotland, were coppiced. Yet palynologists do not appear able to distinguish such features. Stevenson & Harrison (1992) have very recently identified woodland management from pollen analyses, using multivariate statistics on 'modern analogue' environments, but in south-west Spain.

There are, throughout the Scottish palynological literature, 'regeneration' phases characterized by the continued representation of agricultural indicator taxa. Edwards (1979, 32) referred to their 'enigmatic' nature, and the majority of those engaged in research would see these as representing 'partial' regeneration (whatever that means). Might these not represent instead the management of an integral agricultural resource? Equally, there are apparent regeneration phases which persist for some time, for hundreds of years, and in which there is only a single dominant tree type, for example, birch, hazel or alder. These make very curious 'regeneration' phases: there appear to be no successional processes typical of abandoned woodland, and no reappearance of more sluggish but ultimately competitively superior trees such as oak. What these represent is unclear, but protected woodland must be a likely candidate.

SCOTTISH WOODLANDS AT THE END OF THE PREHISTORIC PERIOD

By the early centuries AD it would seem most likely that much of Scotland had been subject to considerable deforestation. In northernmost Scotland and the Northern and Western Isles this was probably not achieved exclusively through human agency, but was a consequence of the combined effects of climate change, soil deterioration, blanket peat growth and human depredation. Farther south the efficacy of natural mechanisms may have been somewhat diminished. It may have been that in some areas of southern Scotland little woodland persisted, and that areas remaining to be cleared represented re-growth from earlier prehistoric clearance. But in central and north-central Scotland some remnants of the original woods survived, nibbled by grazing animals, but still to an extent intact.

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APPENDIX

A directory of published and unpublished works from which can be gained some understanding of regional-scale mid-late Holocene vegetation history (see illus 1):

1	Garths Voe, Shetland	Birnie *in* Gordon & Sutherland (1993)
2	Gunnister Water	Bennett *et al* (1993)
3	Dallican Water, Catta Ness	Bennett *et al* (1992); Bennett & Sharp (1993)
4	Grunna Water, Nesting	Edwards *et al* (1993)
5	Murraster	Johansen (1975, 1978, 1985); Bennett (1993)
6	Scord of Brouster	Keith-Lucas (1986)
7	Loch of Brunatwatt	Edwards & Moss (1993)
8	Kebister	Butler (1993)
9	Foula	Hawksworth (1969)
10	Loch of Knitchen, Rousay	Bunting (1993)
11	The Loons	Moar (1969 a)
12	Glims Moss	Keatinge & Dickson (1979)
13	Mid Hill	Keatinge & Dickson (1979)
14	Braes of Aglath	Keatinge & Dickson (1979)
15	Burn of Rusht	Keatinge & Dickson (1979)
16	Qoyloo Meadow, Mainland Orkney	Bunting (1993)
17	Loch of Skaill	Keatinge & Dickson (1979)
18	Crudale Meadow, Yesnaby	Bunting (1993)
19	Lesliedale Moss	Davidson *et al* (1976)
20	Wideford Hill	Renfrew (1979)
21	Loch of Torness, Hoy	Bunting (1993)
22	Quintfall	Durno (1958)
23	Aukhorn	Robinson (1987)
24	Loch Mer, Strathnaver	Gear (1989)
25	Lochan an Druim, Eriboll	Birks (1993a)
26	Loch of Winless	Peglar (1979)
27	Cnoc a' Bhroillich	Durno (1958)
28	Braehour	Durno (1958)
30	Flows of Leanas	Durno (1958)
31	Cross Lochs	Charman (1990, 1992, 1994)
32	Lochstrathy	Gear (1989); Gear & Huntley (1991)
33	Altnabreac	Dugmore (1989); Blackford *et al* (1992)
34	Lochan by Rosail, Strathnaver	Gear (1989)
35	St Kilda	Poore & Robertson (1949); Walker (1984b)
36	Loch na Moine	Durno (1958)
37	Duartbeg	Moar (1969b)
38	Loch Bualaval Beag, Lewis	Fossitt (1990)
39	Callanish	Bohncke (1988)
40	Sheshader, Lewis	Newell (1988)
41	Suisgill	Andrews *et al* (1985)
42	Little Loch Roag	Birks & Madsen (1979)
43	Loch Horsaclett, Harris	Fossitt (1990)
44	Eilean Mor	Kerslake (1982)
45	Lochan Dubha	Kerslake (1982)
46	Loch Sionascaig	Pennington *et al* (1972)
47	Druim Bad a' Ghaill	Pennington *et al* (1972)
48	Badentarbet	Pennington *et al* (1972)
49	Strath Oykell	Pennington *et al* (1972)
50	Achany Glen	Smith, M (unpubl.)
51	Loch Borralan	Pennington *et al* (1972)
52	Loch Craggie	Pennington *et al* (1972)
53	Coire Bog	Durno (1967)
54	Edderton	Durno (1967)
55	Aultnamain	Durno (1967)
56	Loch nan Clach	Durno (1967)
57	Coire Bog	Birks (1975)
58	Eilean Dubh na Sroine	Kerslake (1982)
59	Eilean Subhainn Lochan	Kerslake (1982)

60	Loch Maree	Birks (1972)
61	Beinn Eighe	Durno & McVean (1959)
62	Coille na Glas Leitire	Kerslake (1982)
63	Loch Clair	Pennington *et al* (1972)
64	Ben Wyvis	Durno (1967)
65	Loch Cleat	Williams (1977); Birks & Williams (1983)
66	Strichen Moss	Fraser & Godwin (1955); Durno (1957)
67	St Fergus Moss	Durno (1956)
68	Rora Moss	Durno (1957)
69	Kingsteps Quarry	Knox (1954)
70	Bharpa Carinish	Mills (1993)
71	Loch Reallasger, N Uist	Fossitt (1990)
72	Loch Cuithir	Vasari & Vasari (1968)
73	Loch Fada	Vasari & Vasari (1968)
74	Stonebridge, S Uist	Heslop-Harrison & Blackburn (1946)
75	Loch a' Phuinnd, S Uist	Fossitt (1990)
76	Loch Lang	Bennett *et al* (1990)
77	Barra	Blackburn (1940)
78	Leonach Burn	Durno (1957)
79	Burreldale	Durno (1957)
80	Allt na Feithe Sheilich	Birks (1975)
81	Loch Meodal	Williams (1977); Birks & Williams (1983)
82	Loch Ashik	Williams (1977); Birks & Williams (1983)
83	Loch Tarff	Pennington *et al* (1972)
84	Abernethy Forest	Vasari & Vasari (1968); Birks 1970, (1975)
85	Loch Garten	O'Sullivan (1974a, b, 1975)
86	Loch Pityoulish	O'Sullivan (1975, 1976)
87	Loch a' Chnuic	O'Sullivan (1974a, b, 1975)
88	Inchrory	Preece *et al* (1984)
89	Loch Davan	Edwards (1978, 1989, 1990); Whittington & Edwards (1993)
90	Loch Kinord	Vasari & Vasari (1968)
91	Braeroddach Loch	Edwards (1978, 1979, 1989); Edwards & Rowntree (1980); Whittington & Edwards (1993)
92	Nethermills Farm, Banchory	Ewan (1981)
93	Skene	Durno (1957)
94	Candyglirach	Durno (1957)
95	Maud Moss	Durno (1957, 1961)
96	Aberdeen buried peats	Durno (1970)
97	Loch of Park	Vasari & Vasari (1968)
98	Netherley Moss	Durno (1956, 1961)
99	Goyle Hill	Durno (1959, 1961)
100	Allachy Moss	Durno (1959)
101	NE Corrie, Lochnagar	Rapson (1981, 1985)
102	Monelpie Moss	Durno (1959)
103	Morrone Birkwoods	Huntley (1976)
104	Coire Fee	Huntley (1981)
105	Caenlochan Glen	Huntley (1981)
106	Coire nan Lochan Uaine	Rapson (1981, 1985)
107	Cam Mor	Pears (1968)
108	Coire an Lochain	Rapson (1981, 1985)
109	Eidart	Pears (1968)
110	Loch Einich	Birks (1975)
111	Drumochter	Walker (1975)
112	Feagour Channel	MacPherson (1978)
113	Roy-Spey col	MacPherson (1978)
114	Gloy-Turret col	Lowe & Cairns (1991)
115	An Dubh Lochan, Loch Treig	MacPherson (1978)
116	Lochan Doilead	Williams (1977)
117	Kinloch, Rum	Hirons & Edwards (1990)
118	Canna	Flenley & Pearson (1967)
119	Claish Moss	Moore (1977)
120	Loch Shiel	Thompson & Wain-Hobson (1979)

121	By Salen	Williams (1977)
122	Lairigmor 1	Walker & Lowe (1981)
123	Lairigmor 2	Walker & Lowe (1981)
124	Mishnish	Lowe & Walker (1986)
125	Beinn Rheudle	Lowe & Walker (1986)
126	Gribun	Walker & Lowe (1987)
127	Iona Loch	Scaife & Dimbleby (1990)
128	Lochan Mor, Iona	Bohncke (1981)
129	Loch an t' Suidhe	Lowe & Walker (1986)
130	Fhuaran	Walker & Lowe (1985)
131	Coire Clachach	Walker & Lowe (1985)
132	Torness	Walker & Lowe (1985)
133	Gallanach Beg	Rhodes *et al* (1992)
134	Oban 1	Donner (1957); Williams *in* Birks (1980)
135	Oban 2	Donner (1957)
136	Oban 3	Donner (1957)
137	Oban 4	Donner (1957)
138	Tyndrum	Lowe & Walker (1981)
139	Clashgour	Walker & Lowe (1981); Bridge *et al* (1990)
140	Coire Seilich	Bridge *et al* (1990)
141	Kingshouse 2	Walker & Lowe (1977)
142	Kingshouse 1	Walker & Lowe (1977)
143	Kingshouse 3	Walker & Lowe (1977)
144	Corrour 2	Walker & Lowe (1979)
145	Rannoch Station 1	Walker & Lowe (1979)
146	Rannoch Station 2	Walker & Lowe (1979)
147	Creag na Caillich	Edmonds *et al* (1992); Tipping *et al* (1993)
148	Lochan nan Cat	Donner (1962)
149	Loch Creagh	Donner (1962)
150	Dalnaglar	Stewart (1962); Durno (1965)
151	Carn Dubh	Tipping (1995a)
152	Corrydon	Walker (1977)
153	Loch Mharaich	Caseldine (1979)
154	Heatheryhaugh	Caseldine (1979)
155	Stormont Loch	Caseldine (1980, 1993)
156	Laidwhinley	Durno (1959)
157	Tynaspirit	Lowe (1982)
158	Cambusbeg	Lowe (1982)
159	Mollands	Lowe (1982)
160	Loch Mahaick	Donner (1962)
161	Methven Moss	Erdtman (1928); Durno (1976)
162	North Mains, Strathallan	Hulme & Shirriffs (1985)
163	Forgandenny	Erdtman (1928); Godwin (1943)
164	Black Loch	Whittington *et al* (1990, 1991b); Whittington & Edwards (1993)
165	Pitbladdo	Donald (1981)
166	Pickletillem	Whittington *et al* (1991a)
167	Auchtertyre Moss	Erdtman (1928; Godwin 1943)
168	Flanders East Moss	Durno (1956)
169	West Flanders Moss	Turner (1965)
170	Woodend Farm 2	Brooks (1976)
171	Gartmore	Donner (1957)
172	Drymen	Donner (1957); Vasari & Vasari (1968)
173	Dubh Lochan	Stewart *et al* (1984)
174	Loch Lomond	Dickson *et al* (1978)
175	Lochan Taynish	Rymer (1974)
176	Lealt Bay	Durno *in* Mercer (1967)
177	Bird Loch	Durno *in* Mercer (1967)
178	An t' Aoradh	Andrews *et al* (1987)
179	The Strand	Andrews *et al* (1987)
180	Loch Cholla	Andrews *et al* (1987)
181	Loch a' Bhogaidh, Islay	Agnew *et al* (1987)
182	Newton, Islay	Andrews (1989)

183	Loch Cill an Aonghais	Peglar *in* Birks (1980)
184	Aros Moss	Nichols (1967); Edwards (1990); Edwards & McIntosh (1988)
185	Machrie Moor	Robinson (1981,1983); Robinson & Dickson (1988); Edwards & MacIntosh (1988)
186	Glen Diomhan	Steven & Dickson (1991)
187	Loch a' Mhuillin	Boyd & Dickson (1987)
188	Linwood Moss	Boyd (1986)
189	Craigbarnet Muir	Stewart (1983)
190	Campsie Fells	Eydt (1958)
191	Auld Wives' Lifts	Dickson (1981)
192	Lenzie Moss	Ramsay, S (unpubl.)
193	Lochend Loch Bog	Ramsay, S (unpubl.)
194	Letham Moss	Dumayne (1992, 1993b)
195	Fannyside Muir	Dumayne (1992, 1993b)
196	Darnrig Moss	Durno (1956)
197	Drumbow Moss	Dickson (1988)
198	Walls Hill Bog	Ramsay, S (unpubl.)
199	Bloak Moss	Turner (1965, 1970, 1975)
200	Shewalton Moss	Boyd (1982)
201	Peel Hill	Coles & Scott (1962); Durno (1965)
202	Airds Moss	Durno (1956)
203	Girvan	Boyd (1982)
204	Loch Doon	Carter (1986); Edwards (1989, 1990)
205	Snibe Bog	Birks (1972)
206	Round Loch of Glenhead	Jones (1987); Jones *et al* (1989)
207	Loch Dee	Edwards *et al* (1991)
208	Loch Dungeon	Birks (1972)
209	Cooran Lane	Birks (1975)
210	Little Lochans	Moar (1969c)
211	Carsegowan Moss	Dumayne (1992, 1993b)
212	Moss of Cree	Erdtman (1928); Moar (1969c)
213	Clatteringshaws Loch	Birks (1975); Durno *in* Condry & Ansell (1978; Edwards (1989)
214	Moss Raploch	Carter (1986); Edwards (1989)
216	Racks Moss	Erdtman (1928); Nichols (1967)
217	Cranley Moss	Dumayne (1992, 1993b)
218	Carnwath Moss	Fraser & Godwin (1955)
219	Kitchen Moss	Newey (1967)
220	Upper Eddleston Valley	Newey (1967)
221	Side Moss	Newey (1967)
222	Fala Moss	Durno (1976)
223	Threepwood Moss	Durno (1976); Mannion (1980)
224	Dogden Moss	Dumayne (1992, 1993b)
225	Blackpool Moss	Butler *in* Rideout & Owen (1992)
226	Din Moss	Hibbert & Switsur (1976)
227	Linton Loch	Mannion (1978, 1982)
228	Yetholm Loch	Tipping (1992)
229	Sourhope	Tipping, R (unpub.)
230	Swindon Hill	Tipping, R (unpub.)
231	The Dod	Shennan & Innes (1986); Innes & Shennan (1991)
232	Wester Branxholme Loch	Tight (1987)
233	Kingside Loch	Tight (1987)
234	Loch Skene	Erdtman (1928)
235	Rotten Bottom	Tipping, R (unpub.)
236	Over Rig	Tipping, R & Boyd, WE (unpub.)
237	Bigholm Burn	Moar (1969c)
238	Burnfoothill Moss	Tipping (1995b)
239	Burnswark Hill	Squires (1978)