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Fine resolution pollen analysis of late Flandrian II peat at north Gill, north York moors

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FINE RESOLUTION POLLEN ANALYSIS OF LATE FLANDRIAN II PEAT AT NORTH GILL, NORTH YORK MOORS.

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ABSTRACT

Pollen and charcoal percentage and concentration analyses have been conducted upon several upland peat profiles of late Flandrian II and early Flandrian III age at North Gill, North York Moors, where earlier research had proven recurrent major pre Elm Decline woodland disturbance, supported in one profile by radiocarbon dating. Fine temporal resolution pollen analysis (FRPA) involving the use of contiguous millimetre sampling was applied to Flandrian II disturbance phases at five of the North Gill profiles. At North Gill 1A a further phase of disturbance near the end of Flandrian II was examined using FRPA to study evidence of pre Elm Decline agricultural activity, and at this profile both the horizontal and vertical resolution limits of the technique were tested by progressively finer sub-sampling.

The millimetre level FRPA analyses showed that each of the examined pre Elm Decline disturbance phases was an aggregate feature, composed of a number of smaller sub-phases, the ecological effects of which in terms of spatially-precise woodland successions and community structures were assessed and contrasted. Inter-profile spatial comparison of the ecology of woodland disturbances has been made at both FRPA and conventional scales of temporal resolution. FRPA study of the late Flandrian II disturbance phase at North Gill 1A showed that cereal cultivation had occurred prior to the Elm Decline as part of a multi-phase period of agricultural land-use activity.

The high resolution spatial and temporal data from North Gill have shown FRPA to be a most sensitive palaeoecological technique, and are discussed in relation to the effects of disturbance upon mire and woodland ecosystems, Mesolithic land-use, pre Elm Decline cereal cultivation and early Neolithic land-use.

DECLARATION

This thesis is the result of my own work and contains nothing which is the outcome of work done in collaboration. Data from other authors which are referred to in the thesis are credited to the authors in question at the appropriate points in the text.

STATEMENT OF COPYRIGHT

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CHAPTER ONE

INTRODUCTION

1.1 Research Background

Since its formulation and initial application as a research method for the reconstruction of vegetation history in the early part of this century, the technique of Quaternary pollen analysis has undergone progressive stages of development and refinement as a response to the continuing increase in both the diversity of research aims and the complexity of research designs which have required the collection and interpretation of palaeobotanical data. Its original application was to elucidate past climates by the study of changes in forest history at the broad scale (von Post 1916). It was apparent that climatic amelioration after the close of the glacial period would have allowed forest successions to take place until the mixed thermophilous forest or the boreal woodland which was regarded as the climax natural vegetation of central and northern Europe had come into being. Pollen studies on a continental basis suggested that gross changes in forest type were indeed governed by broadly contemporaneous climatic fluctuations and so, although differences in detail occurred through geographical factors, changes in tree pollen assemblages at the broad scale could be used as chronological markers. More regionally based investigations (e.g. Erdtman 1928, Godwin 1940) seemed only to reinforce this view, so that pollen-analytical research by vegetation historians provided workers in other disciplines with related interests in Quaternary history, such as geographers and archaeologists, with both a relative chronology and a climatic record.

The relative success of the pollen analysis technique encouraged its widespread application and the increase in the number of pollen diagrams available and also in the type of site location and range of sediment types from which they were prepared, meant that a greater variability in the pollen data became apparent, even from within quite restricted geographical areas. This increased availability of data, and the finer resolution study of vegetation history which became possible, showed that vegetation changes were likely to have been brought about at a variety of spatial and temporal scales, by a range of environmental factors. Over long periods of time and across long spatial distances, macro-climatic change remained a major regulator of vegetation character. With the increasing accumulation of evidence in recent decades, however, it has become accepted that more local influences such as edaphic factors, community structure, migration rates of taxa, hydrology, topography, altitude and micro-climate may determine the character and rate or direction of change in plant associations. In particular, the scale of the effects of man in modifying the vegetation had been consistently underestimated in vegetation history research. The cultural factor in vegetation change was largely dismissed as being of no significance before relatively recent times. Certainly prehistoric man, with his limited technology, had not been considered as a primary agent in bringing about changes in forest structure, and hence in the make-up of pollen assemblages. It was even less likely that early prehistoric man could have had any influence in the rate and direction of the assembly of the mixed woodland successional communities of the early and mid postglacial. Increasingly detailed pollen research, however, seemed to show that man's activities in forest clearance extended much further back in time, and with greater environmental impacts, than had been realised.

This change in perception occurred at the same time that the introduction of radiocarbon dating removed from pollen analysis the role of chronological indicator of anything but the most approximate kind. It became clear that, as pollen zone boundaries became radiocarbon dated at different sites, while climate governed the broad trends in vegetation development, the timing and character of individual stages in that development differed quite markedly from place to place as a result of a combination of more local factors, of which human impact was often the most major. Radiocarbon dating of major pollen zone boundaries has now shown them to be, to a greater or lesser degree, diachronous (Smith and Pilcher 1973) over even quite restricted geographical ranges (e.g. Boyd and Dickson 1986) with some age determinations well outside the usual range (e.g. Chambers and Price 1985, Turner and Hodgson 1981). This diachroneity in the time limits of pollen zone boundaries should not be unexpected, since the pollen changes used to define them (e.g. the rise of Alnus or the fall in Ulmus) are reflections of major biogeographical events which are explicable as the products of progressive postglacial environmental changes, including human actions. Variations in local ecological conditions consequent upon the range of factors listed above would, however, be decisive in deciding exactly when critical environmental thresholds would have been crossed to allow major events such as the Alnus rise (Smith 1984, Bush and Hall 1987) to take place. Within the postglacial there would have been the potential for a great many variations in the timing of transitions between successive forest types and in the character of the subsequent development of that ecosystem. Within regional and perhaps also local contexts therefore, large and small scale changes in the composition of vegetation communities were both time- and space-transgressive. It is thus impossible to use pollen zones alone as chronostratigraphical units in the postglacial (Birks 1982, Mangerud *et al*. 1982), for not only are they diachronous, but their taxa composition varies markedly from site to site (Bennett 1988).

With the acceptance of a multi-variable origin for pollen zone changes, an anthropogenic cause for several of the traditional pollen zone boundaries was postulated in turn, with varying degrees of acceptance. The *Ulmus* decline was attributed, at least in part, to a range of early Neolithic agricultural activities (Iversen 1941, Troels-Smith 1960) while the later *Tilia* decline has been seen as almost certainly resulting from the more intensive land use methods of later prehistoric man (Turner 1962). Earlier familiar features of pollen diagrams such as the rise of *Alnus* or the rise of *Corylus* have been suggested as perhaps linked to the use of fire by Mesolithic hunter-gatherer communities as a means of manipulating their forested environment (Simmons 1975a, 1975b, Smith 1970, 1984).

The factors described above have meant that the scale of emphasis in pollen analytical research has shifted markedly towards yielding much more refined and detailed data regarding the structure and processes within the vegetation community itself, and so the technique is used much more for palaeoecology than for vegetation history or relative dating. The degree of resolution required in both the collection of pollen data and in its interpretation has risen dramatically to reflect that change in emphasis. Of fundamental importance to the former has been the increase in the efficiency of pollen type identification, for precise ecological interpretations cannot be made without the most detailed possible knowledge of the taxonomic status of the pollen types present in the assemblage. This applies in particular to herb and shrub pollen identifications. It is now acknowledged that a modern pollen diagram is a most complex data set, for it reflects the very great complexities of structure, scale, distribution and duration which exist within plant communities. Modern developments in the pollen analytical technique have therefore concentrated upon:

a) defining and evaluating the factors which complicate the interpretation of pollen diagrams,

b) improving the spatial and temporal resolution of the pollen record itself.

Some of these will now be considered in more detail.

1.2 Pollen Data Interpretation

The validity of pollen analysis as a useful research tool in palaeoecology depends upon pollen data sets being capable of accurate interpretation in terms of the changing distributions of plant taxa and associations through time. The difficulty in relating pollen frequencies to past plant abundances and community composition is very great, however, because pollen data sets are the product of a taphonomic process influenced by a wide range of variable factors which differ in their importance from site to site. Each pollen assemblage is therefore a unique artifact derived from the complex inter-relationship of factors governed by the size and sediment type of the receptor site, the nature of the pollen catchment and the structure and type of the vegetation within it. The definition of pollen source areas is a major factor, for the pollen assemblage will contain a proportion of pollen originating from several different types of spatial location. Much of the pollen will have originated on or very close to the sampling site. This 'local' component is likely to dominate the pollen rain incorporated in the sediment, with over-representation of local taxa occurring relative to the wider vegetation. This is discussed further below. The dense foliage of local shrubs or tree vegetation can also cause the filtration of pollen from further away, preventing it reaching the site of deposition (Tauber 1965). Modern pollen studies (Turner 1964, Wright 1967, Tinsley and Smith 1974, Caseldine 1981) suggest that these maximum frequencies found at a highly productive local pollen source decline quite sharply, a matter of some tens of metres only, away from it. Pollen frequencies of a lower, but more stable, value form an 'extra-local' component (Janssen 1966) which reflects a more accurate and consistent measure of the pollen rain in the wider area of the pollen catchment around the deposition site. In a forested area this may be a few hundred metres in extent, but with the great majority of pollen derived from relatively close to the point of deposition. Within closed forest most pollen may travel less than 50 m from its source (Andersen 1970, Bradshaw 1981a). A more 'regional' component, derived from areas beyond the extra-local source, may also be recognised, providing a low but steady background to the assemblage. Oldfield (1970), in a discussion of the interpretation of scale in pollen data, emphasised the importance of distance from the sampling point, since a low pollen producer from an adjacent location may contribute as much pollen to the assemblage as a large producer further away. The spatial element is thus further complicated by the relative dispersal ability of individual taxa and their pollen productivity. Tauber (1965, 1967) considered that in a forested environment the transport and dispersal of the 'extra-local' component of the pollen rain is achieved through the 'trunk space'. The local component is derived from gravity fall (Jacobson and Bradshaw 1981), as most pollen produced by any taxon falls to the ground within several metres of it. The 'regional' component originates in above the tree canopy wind transfer and contributes the pollen of taxa such as Pinus which are adapted to an anemophilous mode of transport. While the regional pollen component may be most important in the centre of large pollen receiving areas, like lakes or major raised bogs, of up to a mile diameter, in small sediment basins within woodland it is only the local and extra-local components which are of real significance (Jacobson and Bradshaw 1981). The mode of pollen transport and deposition can be most important to an understanding of pollen accumulation (Krzywinski 1977). While Pinus is suited to wind transport its buoyant pollen grains may also be carried by water transport, which may introduce derived pollen loads to accumulation points (Peck 1973, Bonny 1978, Brown 1985), particularly of stream-side vegetation such as Alnus (Janssen 1959, Parsons et al. 1980). Taxa which are insect pollinated will tend to be under-represented in pollen diagrams and much more important in the vegetation than their pollen values would suggest. Tilia and Hedera are good examples. Many herbs which are ecological indicators are entomophilous and hardly represented within the pollen count unless growing close by (Berglund 1973). Such taxa do not need to produce abundant pollen, whereas taxa which use wind as a vector are heavy pollen producers such as Pinus, Alnus, Corylus/Myrica and Quercus. Several authors have attempted to calculate correction factors to allow for differential pollen productivity, primarily in arboreal taxa (e.g. Andersen 1967, 1970, 1973). Production of pollen can vary so greatly even within individual species like Corylus or Salix, depending upon ecological factors, that correction values do not exist, while even tree pollen correction values are open to question. Variable productivity remains a source of complexity in pollen data which can be only partly allowed for. Other processes such as the differential preservation of pollen during and after incorporation into the sediment also change the pollen spectra and affect their interpretation (Cushing 1967, Havinga 1964, 1967, Konigsson 1969) although deteriorated pollen can itself be a useful source of environmental inference (Lowe 1982).

Problems of scale, distance and space, however, need to be reconciled before pollen deposition can be related to pollen source areas, and the spatial interpretations of ecological change may be attempted (Edwards 1982). Modern workers have attempted to reconstruct plant (mainly tree) abundances from pollen percentages using quantitative techniques with some success (Bradshaw 1981a, 1981b, Prentice 1985, 1986, Prentice and Webb 1986, Webb _et_ _al_. 1981) especially in relation to depositional basins of limited size. An element of intuitive reasoning will always be necessary in this interpretive process, however, based upon a knowledge of the ecological regulators of vegetation change at varying levels of scale. This qualitative approach may be particularly necessary where small scale disturbance, perhaps of human manufacture, occurs within a woodland matrix (Smith 1982) for the ruderal pollen indicators which accompany such disturbance are poorly transported and represented in pollen diagrams and thus local in scale, although quantitative handling of anthropogenic indicators has been shown to be useful (Turner 1986). A further approach which promises to ease the problems associated with the interpretation of pollen data is to improve the quality of the empirical data itself, so as to remove some of the sources of confusion implicit within it and to increase the information upon which interpretation is based. An increase in resolution of as many aspects of the pollen data set as possible is therefore required and techniques for achieving this are considered below.

1.3 Fine Resolution Pollen Analysis

The aim of fine resolution pollen analysis (FRPA) is to reduce the sampling interval between counted pollen spectra so that the time interval between sampled levels is very low and observation of virtually continuous and detailed temporal changes in vegetation successions and plant community structure can be made. Previous pollen analytical research mainly has been at relatively wide sampling intervals, perhaps as much as several centimetres where general vegetation history has been the research aim. Palaeoecological studies have tended to increase the required level of precision so that sampling took place at a few centimetres, but sampling intervals of as little as one centimetre have been uncommon and of less than a centimetre very rare. The level of resolution attained by fine resolution work must be weighed against the time and effort required for the preparation of very large numbers of samples. It is one of the aims of this study to investigate whether or not the increased precision of ecological information gained warrants the time and effort required.

Previous applications of the technique have proved most promising. At Tregaron Bog, Wales, Turner (1964, 1965) analysed successive peat samples 6.25 mm thick through quite poorly humified Sphagnum peat at horizons which initial analyses had shown to contain evidence of forest clearance. The progressive effects of the clearance, shown by radiocarbon dating to be Bronze Age in date, could be followed in great detail at this finer sampling interval. A similar study conducted by Moore (1973) at Carneddau Hengwm, Wales, showed comparable results, with contiguous 5 mm samples from the base of amorphous blanket peat allowing the possible role of human activity in peat inception to be investigated. More recently Moore (1980) Garbett (1981) Sturludottir and Turner (1985) and Scaife (1988) have refined the technique further, using sampling intervals of 4 mm, 2 mm and even 1 mm to address ecological questions, in particular the Ulmus decline, from the point of view of human effects upon the environment. In all four cases the higher resolution data recovered provided ecological insights previously denied to the investigators. Moore studied the Elm Decline at Llyn Mire, Wales, at 2.5 mm intervals and was able to distinguish successive phases within it, some of which included cereal cultivation, which implied changes in the type and location of human activity.

Garbett used the technique to test his hypothesis that if elm disease were the major cause of the Ulmus decline, the likely increase in standing dead elm trees would encourage an increase in the amount of ivy growth in the woodland, to be reflected in the pollen spectra if sufficiently detailed pollen records could be analysed. This did not prove to be the case and Garbett suggested that alternative causes for the Ulmus decline were therefore more likely, although the poor pollen production and transport of Hedera pollen may have lessened his chances of success. Sturludottir and Turner used the technique to observe more closely the pollen changes in indicator taxa in the period leading up to the Ulmus decline and were able to discern evidence of deterioration of soils probably due to Mesolithic activity which they felt may have had a cumulative effect resulting in the decline of elm populations. Scaife (1988) used FRPA to look more closely at vegetational changes across the elm decline at a site in southern England, and found that 'close interval sampling revealed detail of agricultural practices which could not have been highlighted at a more usual sampling interval'. At North Gill, North York Moors, Simmons et al. (in press) have also applied fine resolution analysis to the study of pre Elm Decline forest clearance, and at 1 mm intervals have been able to detect a series of small sub-phases of deforestation within a larger phase, itself only a few centimetres in thickness, which appeared to be singular at the 1 cm sampling level. Most other FRPA analyses have been restricted to laminated lake sediments of modern age, although some studies in Europe, notably by Tolonen (1978) and van Geel _et al_ (1980), have been conducted upon mid-postglacial lake and bog deposits and have yielded high resolution data.

Green (1983) and Green and Dolman (1988) have considered the interpretation of fine resolution data sets such as those noted above, concluding that the extraction of highly detailed ecological information is possible as long as certain limiting factors are taken into account. It may be particularly suited to the observation of rapid ecological changes and their influences on plant communities, such as those which occur after fire. Such rapid changes are those which will have occurred after the spatially restricted and temporally short-lived forest clearance, probably involving the use of fire, which seems to have taken place during the Mesolithic cultural period, although late prehistoric land use should also be capable of productive investigation in this way. It may be that the increased data-yield will also allow the rarer, indicator type of pollen such as cereals to be recorded where conventional pollen analysis would be insufficiently detailed to do so. Therefore the potential of the method for use in forest ecology (Walker 1982) particularly through the study of fire-cycles of disturbance and stability (Swain 1973, Green 1982) may be most clearly realised in the study of the effects of early prehistoric land-use and particularly in those cases where forest clearance is a small scale event, the consequences of which may be so limited as to require a highly sensitive analytical technique. Moore (1980) also considered that the ecological effects of forest clearance could prove to be the most productive avenue of research for FRPA.

There are, however, a number of factors which are likely to limit the potential of the FRPA technique, and most of these concern the practicality of sediment sampling to the degree of precision required. Widely spaced conventional type samples are acknowledged to be composite, in that they contain a pollen assemblage comprising the pollen accumulation of many years, probably even a few decades. At a coarse temporal scale this does not matter, for there will be a relatively long time interval between sampled levels, probably of an order of magnitude greater than that covered by each sample itself. The object of FRPA, however, is to reduce the time interval between sampled levels to as little as possible and, with contiguous samples, to remove it altogether. When the sampling interval is reduced to as little as a millimetre, however, the temporal interval should be so small that the vegetation of a distinct time period of only a few years duration (Aaby and Tauber 1974) is being observed. At such a fine temporal scale, however, this will only be the case if the contiguous samples can be shown to have chronological integrity, with no admixture of pollen from earlier or later time periods. Such admixture may be caused by processes of bioturbation or reworking of sediment, although these factors may be of much less significance in peats than in other media, such as lake deposits. More crucial in this regard is the horizontal stratigraphy of the sampled sediment, for if the peat surface upon which pollen accumulated was not horizontal, then horizontal sampling will produce a temporally heterogeneous assemblage. Horizontal stratification is therefore a prerequisite for FRPA and the observation of coeval plant communities. This may be compensated for in part by the use of samples of small diameter, but the thinness of the sample makes it likely that up to two centimetres diameter of peat may in practice be required. There is also the possibility of the vertical movement of pollen within the peat profile, a factor likely to be of most significance during pollen accumulation and deposition in the surface layers of peats and the peat-forming vegetation. Clymo and Mackay (1987) have experimentally observed such vertical movement in the surface layers of fresh Sphagnum peat and calculate that it may represent median displacement of about 1.5 cm per year in the humified sediment of the peat body, the water-saturated catotelm where vertical water movement should not be significant. Field data are unavailable, however, and pollen movement will probably be much less in a peat forming medium with fewer water-bearing channels within it, such as slow forming amorphous basin or blanket peats.

A further constraining factor is thus the type of sediment analysed and in particular, the rate at which that sediment had accumulated. Sediment which accumulates quickly, such as fresh ombrogenous peat, has the advantage of incorporating fewer years' pollen output for each millimetre of sediment deposited. It therefore increases the level of resolution available with a millimetre comprising perhaps a single year's pollen input. Humification and autocompaction of sediment (Aaby and Tauber 1974) will affect this level post-depositionally, however, so that in fact an amorphous slow forming peat may not be as badly affected by compression of sediment and loss of resolution. A more serious problem is that sediment accumulation rates within peat can be very variable, so that the number of years' pollen represented by a millimetre of peat can be widely different in different parts of the peat profile. Fine resolution pollen spectra may therefore not be comparable as representing discrete time periods of vegetation. Green (1983) suggests that for interpretation of FRPA data, constant, and fairly rapid, sediment accumulation is a prime requirement, advocating varved lake sediments or the support of an independent chronology as the ideal. Given the problem of reworking of lake sediments, such conditions would rarely be met, and the degree of reworking of lake sediments cannot be measured. An estimate of varying sedimentation rates in peat deposits is obtainable, however, by the use of non-percentage 'absolute' pollen data, and the presentation of FRPA data as pollen accumulation rates (Green 1983) or pollen concentrations if an independent chronology is unavailable (Colinvaux 1982) is probably essential, even if only as an adjunct to traditional pollen percentage calculations. If pollen percentages are used, some form of calculating sum which reduces the inter-dependence of individual pollen curves is advantageous.

In view of the limiting factors discussed above, it remains to be seen what the resolution limits of FRPA are in practice, and these are probably different for each sediment type, even within individual profiles. It must be remembered that stochastic fluctuations occur within the pollen production of individual plants from year to year, and so there will be a background level of uncertainty for each pollen curve at this level of resolution which forms the limit of possible interpretation of pollen changes in terms of vegetation change, irrespective of problems caused by pollen taphonomy. Moore (1980) suggests that the best evidence that the limits of the technique have not been exceeded is if the pollen curves fluctuate in an orderly and sequential fashion, internal consistency being a good indication of non-random variation. Thus the presence of abrupt pollen changes should indicate the absence of post depositional mixing and smoothing of pollen curves, and should suggest a response to rapid vegetation change. If all curves change abruptly an hiatus could be implied, but a mixture of smooth and abrupt frequency changes should indicate a continuous period of accumulation during which some vegetation communities suffered sudden alteration while others did not. Internal evidence of this sort would indicate a dependable FRPA data set for ecological interpretation.

1.4 Pollen Concentration Analysis

The analysis of pollen concentrations as a source of ancillary environmental evidence has become employed increasingly in studies of pollen stratigraphic records, although as yet there have been no attempts to extend this analysis to the collection of fine resolution pollen concentration data. Pollen concentrations are likely to be most informative, however, because when calculated on a relative, percentage basis, the interdependency of the pollen frequencies of individual taxa has been recognised as a probable cause of unreliability in the presentation of the data, as at least some of the changes observed in pollen curves may be artifacts of the method of diagram construction. The disturbing, if temporary, influence of very local abundance of a particular taxon e.g. Alnus in its carr or streamside habitats (Janssen 1959) is a typical case. Abundance of one type of pollen in an assemblage will result in the depression of all other pollen types within the calculating sum. Pollen concentration analysis removes this difficulty, for each individual pollen type may be calculated as a finite number of grains per unit volume of sediment, and thus be expressed independently of one another upon a concentration diagram. As several authors have pointed out, however, low pollen concentrations may not reliably be equated with low rates of pollen input into the sediment, nor high pollen concentration with high rates of input, for variation in rates of sedimentation will complicate the process of pollen incorporation to an unknown degree. As Cundill and Whittington (1983) have stated, 'constant pollen output from plants coupled with variable rates of lacustrine sedimentation will lead to variations in pollen concentration, and variation in pollen output coupled with steady lacustrine rates could produce the same result'. If this may be acknowledged as a source of uncertainty in the analysis of lacustrine deposits which may often be presumed to have had rather even sedimentation rates (Bennett 1983b), a much greater degree of uncertainty must accompany such study of terrestrial peat deposits, in which greater variability of sediment accumulation rate may well have occurred. Unless the pollen analyst is able to work upon annually-laminated sediments (O'Sullivan 1983, Saarnisto 1986) this limitation of the pollen concentration method will need to be circumvented by the application of an independent dating technique, such as radiocarbon dating, to the profile to allow the construction of a pollen influx diagram (Bonny 1972, Craig 1978) or, more properly, a pollen accumulation rate diagram (Thompson 1980). This is difficult to achieve in peats, which may be characterised by extreme fluctuations in sedimentation rate over short intervals. This had led Colinvaux (1978) to suggest that pollen concentration analysis may be of little value in peat-based pollen studies. This need not be the case, however, for it is only during phases of rapid vegetation change that changes in pollen production among certain taxa may be sufficient to alter pollen concentration. In most cases concentrations will be affected primarily by sedimentation rate and thus can be used to provide a rough measure of it and thus as a basis for indirect dating (Middeldorp 1982). This is vital in FRPA so that some idea may be gained of the time period represented by fine resolution samples. In general it is reasonable to assume that only those concentration curve changes which go against the trend of the majority of the rest of the curves are caused by real vegetation changes or pollen production changes. Sedimentation rate changes should affect all taxa, while disturbance of vegetation in the catchment should affect only some, although disturbance itself may bring about hydrological changes likely to affect sedimentation rate (Wiltshire and Moore 1983,Moore et al. 1986, Moore 1988). For example, Innes (1981) recorded a general fall in pollen concentrations after the Ulmus decline at North Gill, North York Moors due very probably to an increased rate of sedimentation. The Calluna pollen concentration rose at this point, however, and presumably represented a real increase in the abundance of heather within the pollen catchment. In this thesis there are insufficient radiocarbon dates to allow the establishment of an independent chronological control, such as that employed by Aaby and Tauber (1974). The statistical limitations of radiocarbon dating may make its use with FRPA impractical at the present time in any case. Pollen concentrations are therefore used as a proxy record of relative changes in peat sedimentation rates. Available radiocarbon dates have been placed at the boundaries of phases of disturbance, where major concentration fluctuations are most likely to occur. Since pollen concentrations are to be used to reflect changes in sedimentation rate, the concentrations are calculated as grains per unit of volume of wet sediment, rather than as grains per unit of dry weight as preferred by Fletcher and Clapham (1974).

Several authors have found the measurement of pollen concentrations to be most effective as a supplement to percentage data in aiding ecological interpretation. With varying levels of radiocarbon support, concentration analysis has been widely applied to Late Glacial sediments (Pennington and Bonny 1970, Pennington 1973, Craig 1978, Birks 1981) and at these sites estimation of sediment accumulation rates between dated horizons has allowed measurement of pollen influx to be made. Hibbert (1978), Beckett (1979) and Beckett and Hibbert (1979) have successfully applied this method to peat profiles, including raised bog deposits, compensating for variation in peat deposition rate by the use of many radiocarbon analyses. Middeldorp (1982) used a similar approach, allied to macrofossil analysis to calculate peat growth changes, to produce from a peat bog profile detailed concentration data which seemed to be sensitive of ecological changes through time. All of the above authors working with Later Flandrian sediments found it possible to discern changes in pollen concentration and influx which could be attributed to the activity of man, and which clarified the evidence afforded by the percentage data. Donner _et al_. (1978), for example, were able to present concentration and influx data from adjacent lake and peat sites which, through multiple radiocarbon dates, could be related to the full cultural succession in southern Finland during Flandrian III.

It does seem, however, that even without an absolute dating framework, pollen concentration analysis is a valid technique for inferring past vegetational patterns and ecological change. In a Late Glacial context Caseldine (1981) found that concentration changes assisted the recognition of changes in local plant communities and Birks (1981) considered concentration data most useful in the interpretation of pollen percentages. Hyvarinen (1976), Mannion (1978), Hunt and Birks (1982) and Bennett (1983a) also stressed the value of concentration analysis, as it seemed capable of reflecting actual changes in plant abundances within the vegetation. In this thesis it is intended to use the independence of pollen concentration and its apparent sensitivity to changing vegetation patterns and abundances to check the reality of the pollen percentage data fluctuations. If these fluctuations are confirmed, pollen concentration should provide further ecological insights into the effects of disturbance on the local vegetation. Apart from the general recognition of late Flandrian fluctuations noted in studies such as those mentioned above, relatively few studies of pollen concentrations have been made with the aim of elucidating disturbance effects which may be the result of human activity. Fredskild (1975) used the technique to investigate the date and ecological context of a Mesolithic flint site in Denmark. Sims (1973, 1978) reported concentration figures together with percentage counts through Mesolithic (Flandrian II) and Ulmus decline levels at Hockham Mere, identifying a clear phase of Mesolithic age forest recession from both data. Simmons and Innes (1988b) have presented pollen concentration data from North Gill, North York Moors, which confirm pollen percentage evidence of substantial pre elm decline forest clearance. Robinson (1987) used pollen concentrations to supplement pollen percentage and charcoal evidence of Mesolithic age forest disturbance in Scotland. Pennington (1973, 1975) has used concentration evidence to study the vegetation changes associated with the Ulmus decline from a range of sites in north-west Britain. Innes and Frank (1988) have found that concentration evidence helped to identify probable Bronze Age forest clearance in the coastal area of Northumberland. The success of these studies in using concentration data to study post-clearance successions in plant communities promises that it may prove sensitive to the small scale ecological changes recorded by percentage FRPA.

1.5 Numerical Analyses

As stated by Birks (1986) and Prentice (1980, 1986) numerical analyses provide an alternative way of subdividing pollen diagrams, which represent highly complex data sets which contain high degrees of internal variation. Large numbers of counted levels, many pollen taxa per level and widely variable counts for individual taxa make synoptic appraisal of the entire data set very difficult. It is to make the data manageable that the pollen diagram is subdivided into smaller units as a preliminary to description. The intuitive zonation of the North Gill diagrams on the basis of the *Quercus* curve as diagnostic of disturbance levels relies upon subjective criteria based upon ecological inference. An element of interpretation as well as description is therefore involved. Since this zonation will provide the foundation for between-site correlation of pollen curves, it is clearly important that the zonation criteria adopted must be as justifiable as possible. A range of numerical techniques exists which are of use in the analysis of multivariate data sets (Birks 1986, Prentice 1986) and two have been used in this study to provide an alternative means of examining some of the North Gill pollen data: Principal Components Analysis (PCA) and Detrended Correspondence Analysis (DCA). PCA is the method most used in recent years to address problems of handling palaeoecological data of various kinds, including pollen counts, and Prentice (1980) has considered the principles and applications of the method in relation to Quaternary palynology. It has the capacity to reduce the total variability contained in the original pollen data to a small number of new variables which are termed 'principal components'. The few most important of these principal components will then account for the great majority of the natural variation in the data set so that, being greatly summarised, the major patterns of variation in the data may be much more easily detected and interpreted.

PCA is capable of application to any pollen data set, whether spatially or stratigraphically distributed. Thus Gordon and Birks (1972) used it to zone individual pollen profiles, while other authors have employed it in the analysis of purely spatial pollen data, as in modern surface samples (O'Sullivan and Riley 1974, Caseldine and Gordon 1978). PCA has, however, been most widely used by recent authors as a means of analysing fossil pollen data sets which combine both spatial and biostratigraphical elements, i.e. for the comparison of pollen diagrams (Gordon and Birks 1974). Pennington and Sackin (1975) used the method to subdivide (zone objectively) two geographically distant profiles which were of broadly the same age (Late Devensian) but were difficult to correlate using conventionally defined pollen zones. At a regional scale, Turner and Hodgson (1979) have used PCA to compare Early Flandrian (Boreal) pollen spectra from over forty sites in the northern Pennines, discerning marked variability in woodland structure over quite short distances. At a national scale, a number of studies (Birks et al 1975, Birks and Saarnisto 1975, Birks and Berglund 1979) have applied the method to data from a large number of pollen diagrams and produced isopollen maps for selected periods during the Flandrian. Huntley and Birks (1983) have carried this line of enquiry to its logical conclusion and have produced fossil pollen maps for the continent of Europe which map vegetation distributions at intervals of one thousand years for the Late Devensian and Flandrian, as well as isopollen maps of modern pollen distributions.

The anthropogenic factor as a source of variation in fossil pollen data sets has not been overlooked in such studies, although generally it has been acknowledged only as the probable cause of regional scale changeovers to more open types of community during the more recent part of the Flandrian, which have been reflected in the upper pollen zones of individual sites (Birks and Berglund 1979, Birks and Madsen 1979). It has been unusual for PCA to be used to detect evidence of forest clearance in pollen diagrams and to categorise it, possibly because the recognition of cultural features in pollen spectra is very subjective. Birks and Berglund (1979) did, however, suggest that intra-regional variations within Flandrian III data detected by PCA could be due to variations in human land use type and intensity. This theme was extended to pre elm-decline human activity at the broad scale by Turner and Hodgson (1983) who attributed some numerically detected plant associations of unusual type to the possible modification of woodland by Mesolithic people through the use of fire, although again on the basis of multi-site analyses and on a sub-regional scale. Innes and Frank (1988) used PCA to isolate a phase of woodland instability which may have been due to Bronze Age forest clearance in a pollen diagram from Northumberland. Shennan and Innes (1986) have also used the method to distinguish cultural from natural effects within pollen spectra from a single locality. Firstly, Flandrian III pollen spectra in a peat bog profile were differentiated from Flandrian I and II spectra by PCA on the grounds of lower tree pollen levels and high frequencies of clearance indicator herb types. Secondly, pollen spectra from buried soils and other culturally related sediments from an adjacent archaeological monument were correlated with the pollen stratigraphy of the natural bog profile by PCA. Thirdly, PCA proved to be sensitive enough to detect clearly a single level which showed evidence of clearance type within otherwise undisturbed Flandrian II woodland, and which was thus attributed to the activities of Mesolithic man. Turner

(1986) has used PCA to examine the relationships of anthropogenic indicator taxa in pollen diagrams from a range of sites.

Numerical analysis has been used in this thesis in order to separate levels which contain evidence of local woodland disturbance from those which do not, to evaluate the type and degree of disturbance and to correlate disturbance evidence among closely adjacent profiles.

1.6 Multiple Profile Pollen Analysis

While improvements have been made in the temporal resolution of pollen data and the use of absolute pollen techniques, the spatial dimension in palaeoecology has not been greatly investigated, even though pollen analysis, by the nature of the taphonomic processes affecting pollen recruitment to sites of deposition, is essentially an exercise in spatial interpretation. A single pollen profile cannot be interpreted purely in terms of temporal change, for individual pollen spectra are composed of pollen assemblages derived from a large number of different source areas, so that the inevitable spatial variability in the distribution of plant communities will be reflected in the relative abundances, or perhaps in the presence or absence, of plant taxa in the pollen data set. The influence of factors of scale and source area on pollen catchment and assemblage composition is now accepted and taken into account in research design, particularly with regard to the selection of pollen sampling sites (Jacobson and Bradshaw 1981) of dimensions and sediment type sensitive to different spatial components of the pollen rain. Single profile studies have been the norm in past pollen analytical research, and probably still represent the majority of current pollen-based projects. Comparison of pollen profiles, and thus an assessment of inter-profile pollen variability, has been undertaken for many years, but usually by workers attempting a national or regional synthesis of major variations in vegetational history across large distances. The degree of both spatial and temporal resolution required to satisfy the aims of these comparative regional-scale studies (e.g. Birks 1977, Turner and Hodgson 1983, Bennett 1988, Boyd 1988) has not been high.

There has, however, been an increase in interest in the use of multi-profile pollen analysis for within-site, rather than inter-site, correlation and the reduction in the spatial scale involved has allowed the recovery of higher resolution, and therefore ecologically useful, data (Edwards 1983). Thus Donner et al. (1978) wee able to correlate records from adjacent lake and peat bog profiles and noted that certain taxa were represented differently within the two sediment types, illustrating variations in regional and local pollen rain. Edwards (1983) has cited several other studies of this kind in his review of the subject. Of more interest to the present study, however, are examples where a number of closely spaced profiles have been analysed from a single sediment type, particularly those based upon peat deposits. Perhaps the classic such three-dimensional interpretation of a series of pollen profiles has been the work of Turner (1964, 1965, 1970, 1975) who examined grass pollen frequencies at intervals from the margin towards the centre of a large raised bog, and interpreted differences and similarities in the pollen curves in terms of human farming activity in the vicinity. Although it is clear that cultural indicator pollens will be represented differently according to distance from their source (Janssen 1986), it has been suggested by Edwards (1982, 1983) that on such raised bog sites a pollen core may have to be situated on their very edge to avoid domination by regional components. Nevertheless, significant variation over quite short distances in particular pollen types has been reported, while overall vegetation trends have been quite consistent. For example Pilcher (1969) and Pilcher and Smith (1979) in Northern Ireland and Barber (1981) have used multi-profile correlations to detect localised pollen variability within a few tens of metres. Chambers (1982) and Housley (1988) are among those who have prepared major pollen diagrams from situations a few hundred metres apart and used them to reconstruct natural and human induced vegetation patterns in the landscape. Multiple profiles have perhaps been most useful where used to reconstruct vegetation changes along an environmental gradient. Thus Tooley (1978) used several diagrams at Downholland Moss, Lancashire to trace the spatial rearrangement of coastal plant communities due to sea-level fluctuation, while Maguire (1987) analysed basal blanket peat deposits on Dartmoor along a 200m transect at very close intervals demonstrating that peat initiation had occurred at different times over a relatively short distance. Solem (1986) employed a similar strategy to investigate the age and origin of blanket mire deposits in Norway.

A number of multi-profile studies on pre elm decline peats have been carried out with the aim of elucidating Mesolithic ecology, and thus are of direct relevance to the present work. Of these Smith and Cloutman (1988) may be of most interest, for not only was a three-dimensional approach taken to Welsh upland blanket peat with several profiles analysed at two main sites, but some thin sampling (0.25cm) and absolute pollen work was done. Clear evidence of a number of Mesolithic age episodes of interference with the vegetation was revealed, and the three dimensional approach used made an appraisal of the spatial distribution of the effects of clearance possible.

Localised clearings, and thus the creation of vegetation patches and a mosaic of contrasting vegetation types, could be discerned so that burning of woodland in Mesolithic times appeared to be controlled rather than random, perhaps the most convincing evidence that a human rather than natural agency could be postulated for the origin of the burns. A similarly successful three-dimensional study using several adjacent pollen profiles has been employed by Taylor et al. (1988) who were able to deduce, at least in broad terms, the location of individual Mesolithic age clearance events from the relative intensity of pollen indicator evidence in contemporaneous pollen spectra from shallow peats along a fossil lake shoreline in north Lancashire. Williams (1985) used duplicate pollen cores to confirm and investigate the character of late Mesolithic clearance of a most substantial nature in the central Pennines. Innes (1981) compared pollen data from four diagrams about eighty metres apart in upland basin peat at North Gill, North York Moors and noted differing manifestations of the effects of late Mesolithic forest disturbance of a kind comparable to those recorded using a similar research design by Smith and Cloutman (1988) in Wales.

The conclusions to be drawn from the above studies are that pollen evidence of a type different in kind from that available from single profile study may be recovered by multi-profile analysis. Whereas interpretation of single diagram data must primarily be in terms of vegetation history within a single pollen catchment, the spatial dimension attained by the comparison of coeval pollen spectra from multiple cores allows interpretation to be made in terms of ecological processes, for example vegetation patch dynamics, community structure and the patterning of successional changes.

For the potential of spatial pollen analysis to yield data of value for detailed reconstruction of ecological processes to be realised, two controlling requirements must be met. The first is fundamental in that before pollen spectra from two or more pollen stratigraphies may be interpreted spatially, a method is required which enables secure between-profile correlation of contemporaneous pollen spectra to be made. This may be achieved by an independent dating system or via the lithostratigraphy, but in many cases the biostratigraphic correlation of the pollen spectra themselves may be required, where a readily identifiable event, such as a distinctive phase of clearance or a major pollen zone boundary, may be recognised in several profiles. This is why most spatial correlation work has focussed upon sediments of Ulmus decline age or older. This has a bearing upon the second requirement, which concerns the selection of site type. It seems probable that an optimum site size for a multi-profile study requires an interval betwen profiles small enough to allow a discrete palaeoecological horizon to be identified and correlated between all pollen diagrams, yet large enough to allow significant spatial differences between the vegetation represented in that horizon at each profile to be observable. Jacobson and Bradshaw (1981) and Bradshaw (1981a, 1981b, 1988) would suggest that a small basin or a number of small hollows covering a maximum of a few hundred metres within diversified woodland might present such optimum conditions for the recovery of detailed ecological data. The work of Mitchell (1988) in Ireland would confirm that multi-profile study based upon sites of limited extent is ideally suited for the investigation of spatial successions and woodland dynamics.

1.7 Research Aims

Although relatively few research projects have been conducted using the range of research techniques discussed above, particularly regarding fine resolution pollen analysis and multiple-profile pollen studies, it is clear that these techniques are alike in promising greatly to increase the detail and thus the quality of pollen data sets and thus allow much clearer insights into the processes involved in palaeoecological changes in plant communities. Green and Dolman (1988) consider FRPA to be ideally suited to monitoring short-term dynamic successional changes and it has already been noted that multiple-profile studies can allow spatial patterning of vegetation to be reconstructed with a high degree of resolution. The limitations and complexities of the FRPA technique have not been closely defined, however, neither has the degree to which it is capable of integration with the other high resolution techniques discussed above. The great investment in time and labour involved in the processing of the large numbers of samples involved in FRPA mean that it will probably never be a technique for routine research use, but that it may be reserved for application to selected research problems. The major research aim of this thesis is therefore to test the capabilities, potential and limitations of the FRPA technique in elucidating a selected topic in palaeoecological research. More particular research aims may be defined as follows:

1) to explore the effective resolution limits of FRPA when applied to a particularly suitable sediment type.

2) to assess the relationship between increasingly close sampling intervals in FRPA and the increase in detail of ecological data obtained at each level of resolution.

3) to test the spatial replicability of FRPA data over varying distances.

4) to test to what degree pollen concentration analyses may be combined with FRPA.

5) to assess the degree to which FRPA in practice yields ecological insights which are beyond the scope of orthodox pollen analysis.

6) to compare the effect of slight variations in lithology upon the practical application of FRPA over short distances.

7) to test the feasibility of integrating the high resolution temporal and spatial information yielded by multiple profile FRPA to produce an understanding of spatial changes in local vegetation communities through time.

CHAPTER TWO

TECHNIQUES AND METHODOLOGY

2.1 Sediment Sampling

2.1.1 Field Collection

As all of the sites at North Gill which were selected for laboratory analysis were exposed peat faces, it was possible in each case to recover a suitable column of sediment by the use of aluminium monolith tins. Usual tin dimensions were 50 x 10 x 10 cm, but small tins (25 x 10 x 10 cm) were also used and wider tins (50 x 25 x 10 cm) were employed where the retrieval of a greater lateral extent of peat was required. Sections were cut back to vertical and, after cleaning and recording, tins were pressed into the peat face until filled with sediment. After appropriate labelling the tins were dug out, trimmed, immediately sealed in thick polythene sheeting and then removed to the laboratory for storage. Storage took place under refrigerated conditions at temperatures of between $0^{o}C$ and $4^{o}C$.

2.1.2 Laboratory Sampling

Sub-sampling methods differed according to the resolution of the sampling interval to be employed. At intervals of quarter, half or whole centimetres peat samples could be extracted with a spatula or scalpel blade in the conventional way, without reducing the level of accuracy available at that degree of resolution. At intervals of one millimetre or less, which in effect involved contiguous sampling, it was necessary to fine section the peat using a hand microtome and blade. A block of that part of the main peat column selected for fine resolution analysis was extracted from the monolith tin and cut into 2.5 cm vertical lengths, suitable for the chamber of the microtome. A column of peat was extracted from each of these lengths in turn, using a sharpened cork-borer of the same diameter (again 2.5 cm) as that of the microtome's chamber. This cylinder of sediment was deep frozen for at least 72 hours. It was found that if wrapped in thick polythene, which did not adhere to the peat, the sample did not dry out while frozen, and the polythene was very convenient for the secure labelling of the sample which was most important to avoid confusion in its orientation. A chalk mark upon the upper face of each sample is a further safeguard.

After inserting the peat cylinder within the chamber of the microtome so that the top of the peat was level with its surface, the peat was raised above the surface by screwing up the microtome piston. An adhesive tape printed with a millimetre scale was fixed to the rachet mechanism of the microtome, and each turn of the rachet raised the peat cylinder by the required amount. In this way consecutive millimetre slices of peat could be removed from the cylinder and lengths of as little as 0.5 millimetres proved to be feasible providing the consistency of the sediment was particularly amorphous and well humified. A very sharp rotary microtome knife was used to thin section the peat and had to be resharpened regularly to maintain cutting efficiency. Both the blade and the microtome surface were cleaned after each slice of peat was removed. Thin sectioning had to be carried out under refrigerated conditions, as close to $1^{o}C$ as possible, so that the peat remained frozen and would slice cleanly. At higher temperatures the peat became very difficult to slice without breaking up. Most difficulty was experienced with the lowest part of the peat cylinder, and the lowermost few millimetres were prone to breaking up unless the peat remained strongly frozen. It was necessary to insert a few small coins in the base of the microtome chamber and below the peat, so that the piston could raise the basal few millimetres beyond the microtome surface. These coins had to have been kept at freezing temperatures also, so that their contact did not cause the basal peat samples to thaw. After slicing, the millimetre thick discs of peat were sealed in labelled glass vials and stored under refrigeration.

The method of thin sectioning peat is virtually the same as that employed by Garbett (1981) and Sturludottir and Turner (1985), adapted slightly to be used on monolith tin columns rather than on cores from a Russian-type borer. The technique proved to be very reliable in suitable, amorphous sediments, although was much more prone to failure where a significant macrofossil or inorganic fraction occurred in the peat. Too high a proportion of sandy material rendered the method impractical, for the sediment would then not slice without crumbling. As noted above, sites with very discrete sand lenses had therefore to be avoided for the purpose of thin sectioning. The bulk sampling method of monolith tins meant that, where accidental loss of sample or failure to section successfully occurred, sufficient material remained for the thin sectioning process to be begun again so that gaps in the fine resolution pollen record could be avoided. Although the method requires meticulous sampling, the regular dimensions of the peat cylinders produced to fit the microtome chamber by the cork-borer, and the removal of contiguous millimetre thick samples, meant that it yielded slices of sediment of a consistent 0.5 cm^3 volume. Such known volumes allow the calculation of pollen concentrations and aid in interpretation of the relative pollen data, as recommended for fine resolution data sets by Colinvaux (1982) and adapted by Cloutman (1987). For this reason the thin section technique employed in this thesis has been adopted in preference to other methods (Wiltshire 1988) which yield fine resolution samples.

2.1.3 Sediment Description

The lithology of the sedimentary successions was recorded in the field in boreholes and free-face excavation, and in detail from the bulk samples removed in tins to the laboratory, using the system devised by Troels-Smith (1955) for the characterisation of unconsolidated sediments, modified as recommended by Aaby and Berglund (1986). This scheme employs a range of descriptive symbols corresponding to lithological elements, which are used in the stratigraphic and pollen diagrams, and these are illustrated and interpreted on fig. 1. The scheme characterises sediments in terms of the relative proportions of the lithological elements of which the sediment is composed. Five main element groups are recognised: Turfa, being roots, rhizomes and stumps of plants and moss remains accumulated in situ; Detritus, being larger fragments of plant material such as stems and leaves transported to their point of deposition; Limus, being homogeneous detrital material comprising very fine particles such as lake mud; Argilla, being the finer size range of inorganic particles, clay and silt; Grana, being the larger range of inorganic particles, sand and gravel. A further category, Substantia humosa, is used to describe amorphous organic material which cannot easily be otherwise defined. These component elements are explained in greater detail in appendix 1.

The stratigraphic succession at each profile is described in a standard form. Each stratum identified is numbered from the base of the profile and it is accompanied by a formula in which the component elements are described using Troels-Smith's standardised notation. The proportion of the elements is estimated on a five point scale (0 - 4), where 0 represents complete absence, 1 represents 25%, 2 represents 50%, 3 represents 75% and 4 represents maximum presence, forming 100% of the sediment. Trace amounts of any element, being less than 25% of the total, are represented by a plus symbol, each plus corresponding to roughly 5% of the total, additional to the major sediment components. The notation formulae are accompanied by a conventional description of the nature of the deposit.

The physical properties of sediments are also described on a five point scale as follows: Nigror (nig.), the degree of darkness in colour; Stratificatio (strf.), the degree of stratification; Elasticitas (elas.), the degree of elasticity; Siccitas (sicc.), the degree of dryness. The degree of humification is indicated by the addition of a superscript number (0 - 4) to the component elements of organic origin, 4 indicating maximum humification. It has been shown (Aaby and Tauber 1974, Heathwaite and Ross 1987) that degree of humification may more accurately be measured by chemical means, and may then be a more reliable way of classifying peat deposits than the Troels-Smith scheme. It appears, however, that only raised bog peats may be securely assessed by chemical humification analysis and that the method may not be of value in basin or blanket deposits such as are the subject of the present work. No attempt has been made to use chemical methods for this purpose therefore, and the Troels-Smith scheme's assessment of humification is considered to be sufficiently precise for the purposes of this thesis.

2.2 Charcoal Analysis

Measurement of the micro- and macrofossil charcoal content of peat deposits can allow an assessment to be made of the intensity and frequency of past fire occurrences. Since fire is a major force in bringing about changes in vegetation (Wright & Bailey 1982), knowledge of fire history is most important for the interpretation of other ecological data, such as detailed pollen analyses, which are sensitive to changes in the composition and structure of past vegetation communities (Swain 1973, Heinselman 1981). The role of fire as a disturbance mechanism in ecosystem successions (Koslowski & Ahlgren 1974, Tolonen 1983) and the recognition of its use in environmental manipulation by recent low technology forager and horticulturalist societies (Mellars 1976, Myers and Peroni 1983) has suggested that high charcoal frequencies in sediments can be correlated with high levels of past human activity. Iversen (1941) suggested that charcoal layers could be related to prehistoric human impact, a view adopted by later authors (Jacobi et al.1976, Huttunen 1980, Simmons & Innes 1981, Tolonen 1978, 1985). A detailed review of the literature is not appropriate here and relevant studies are referred to below during the interpretation of the evidence from North Gill. A discussion of microscopic charcoal as a fossil indicator of fire has, however, been undertaken by Patterson et al. (1986).

The techniques and criteria employed by palaeoecologists for the recording of fossil charcoal content have varied markedly and have been reviewed by Robinson (1984) and Tolonen (1986). An estimation of the relative abundance of charcoal fragments based upon visual scanning of a consistent number of traverses of microscope slides has been used (Birks 1975, Sturludottir & Turner 1985), plotted on a numerical scale of 1:5.

Similar visual estimation methods of charcoal retained in sieve washings during the pollen preparation process may also yield good results for the larger size class of charcoal material. More quantitative methods have been used, most particularly the point count estimation method for microscopic samples described in detail by Clark (1982, 1983) and also used by Iversen (1941) and Singh et al. (1981). An assessment of total area on spaced traverses on slides prepared for absolute pollen counts has also given satisfactory results (Maher 1972, Swain 1978). Innes (1981) and Simmons & Innes (1981) estimated the volume of charcoal per unit of wet sediment from an upland blanket peat site in the North York Moors by disaggregating peat with water in a gridded petri dish. At a magnification of x60 the percentage of each square occupied by charcoal was estimated and calculated as a proportion of the total area of the grid. Chemical methods have also been tried. Innes (1981) tested the chromic acid reduction method developed by Schollenberger (1927) and described by Allison (1935) but this was found to be unreliable in highly organic sediments. Tallis (1975) used a technique involving hot nitric acid to remove all organic material except elemental carbon (charcoal) followed by high temperature combustion of the residue, allowing the calculation of charcoal percentage. This nitric acid and ignition technique has been developed further by Winkler (1985) with apparently satisfactory results.

Robinson (1984) has tested the three main methods; visual estimation from sieve washings, microscopic counting and chemical, on peat profiles from Arran, Scotland. Of these the chemical method failed to produce reliable results. The other two methods were more successful, providing broadly comparable results. Visual estimation of the sieve washings, however, failed to record the microscopic charcoal particles (<180 microns) which passed through the sieve, while microscopic counting was able to provide a good account of the smaller particles, and was sensitive to changes even at lower abundance levels.

On this basis, therefore, both the visual estimation from sieve washings and the microscopic counting methods have been used in this thesis. The microscopic counting method is that based upon Maher (1972) and Swain (1978), and refined by Robinson (1984), which enables both relative abundance and charcoal concentration to be estimated. The abundance of charcoal particles relative to the tree pollen sum was estimated by recording the number of charcoal particles encountered during the standard tree pollen count. These were weighted for size, with pieces 0-30 microns counted as 1, 30-60 microns as 2, 60-90 microns as 3, 90-120 microns as 4, 120-150 microns as 5, and 150-180 microns as 6. In practice most charcoal fragments fell within the lower part of this range. This scale forms an extension of the size-class system of Mehringer *et al.* (1977). These individual size-class counts were aggregated to produce a total figure which could then be compared with the tree pollen count as a ratio of charcoal to tree pollen, or with the total pollen count as a ratio of charcoal to total pollen. These relative microscopic charcoal figures are shown upon charcoal diagrams (where they are termed micro-charcoal), calculated as percentages of tree pollen, and provide a charcoal/pollen ratio of the kind advocated by Swain (1973). Separate curves of the different microscopic size-classes are not calculated, since fragmentation of the particles during the pollen preparation process has probably occurred (Clark 1984).

Since the size of the basic individual charcoal unit counted (value 1) is comparable to that of individual grains of the exotic spore *Lycopodium* clavatum, the charcoal counts can also provide a measure of microscopic charcoal concentration. This is expressed, in the same way as the pollen concentration data, as numbers per unit volume (cm^3) of wet sediment.

Charcoal which failed to pass through the 180 micron sieve was regarded as macroscopic and estimated subjectively on a five point scale of relative abundance (0-4) as follows: 0 = Absent, 1 = Rare, 2 = Occasional, 3 = Common, 4 = Rich. 'Large' macroscopic charcoal pieces of more than about 3 mm size were visible in the peat matrix prior to pollen preparation and are retained as a separate category upon the charcoal diagrams of wider sampling intervals. 'Small' macroscopic charcoal fragments of between 180 microns and c. 3 mm was estimated from examination of the sieve washings during preparation. Only the small category could be estimated for the finer resolution sampling intervals. The terms 'microscopic charcoal' or 'micro-charcoal' are used in this thesis for carbonised particles of <180 microns, rather than referring to them as 'soot' (Tallis 1975, Simmons & Innes 1981), as the latter term is more properly reserved for carbonaceous particles derived from the recent combustion of fossil fuels (Renberg & Wik 1983, 1984, Tolonen 1986). The division of the charcoal record by size measurement technique also assists its interpretation, for it would appear that the taphonomy of charcoal fragments is size-determined(Clark 1988). Macrofossil charcoal pieces are probably derived from a nearby source area and so provide a record of local fire events. Indeed, Tolonen (1983) argues that only very local fires leave detectable macro-charcoal layers in peat profiles. The transport mechanism of larger charcoal pieces is predominantly fluvial, so that burning within the catchment will have been responsible for discrete macro-charcoal bands as recorded at North Gill. The micro-charcoal record will contain some of local provenance, but most will be the result of wind transport of finely comminuted charcoal particles, which may be derived from fires much further away (Robinson 1984, Tolonen 1986). It follows that the microscopic charcoal curves shown on the diagrams from North Gill reflect the regional fire history much more than the macrofossil curve which imparts site-relevant information.

2.3 Other microfossil analysis

Van Geel (1978, 1986) has identified a range of microfossils, particularly fungal spores and algal remains, from which ecological inferences may be drawn and which may be used to supplement the pollen and charcoal data. A number of these have been recognised from the sediments at North Gill, and those which may be diagnostic of post-fire conditions have been included upon the charcoal diagrams. Of these, *Neurospora* ascospores are held to indicate the incidence of local fire, perhaps on the mire itself or at its margins. *Gelasinospora reticulata* and *Gelasinospora spp*. ascospores also reflect very dry local conditions and are probably indicative of carbonised material (Van Geel 1978, Boyd 1986). Other microfossil types are indicators of local mire hydrology and are referred to only in the text. These include testaceous rhizopods *Amphitrema flavum* and *Assulina sp*., and zygospores of *Zygnema* and *Mougeotia*. Other, rarer types also occur.

2.4 Radiocarbon Analyses

Sediment samples from critical horizons in the pollen stratigraphy were selected for radiocarbon dating in an effort to provide a measure of chronostratigraphic control to the biostratigraphic zonation scheme. Only four dates were obtained and were used at the North Gill 5B profile, providing a consistent series of age determinations for this central location. Five previously obtained radiocarbon dates from other North Gill profiles are used to supplement the new ones and assist correlation between profiles. Material for dating was extracted from the monolith tins, bulk sampling allowing this to be concentrated at the selected level. Macrofossil material, especially rootlets which may have penetrated from above, which may have been extraneous to the sample was removed before the sample was sealed in thick polythene bags and labelled. Not all the deposit was removed from any one horizon, in case further samples were required. Radiocarbon dating was carried out at Harwell Isotope Measurements Laboratory, Oxford. Small samples (2g. weight) were submitted to Harwell for accelerator dating in 1985, but unfortunately the results of these have not been made available up to the date of submission of this thesis, and so could not be included. All new and previous dates from North Gill are listed in appendix 2. Dates are quoted in the text using uncalibrated dates in radiocarbon years BP (before present).

2.5 Macrofossil Analysis

In general, plant macrofossil remains in peat sediments are derived from locally growing vegetation and are thus useful indicators of local vegetation conditions, particularly regarding mire communities. With detrital deposits some degree of transportation of macrofossils will be involved, but in an upland, small catchment peat basin it is unlikely that many will have travelled far. The streamside locations of the sites in this thesis are very suitable for the introduction of seeds and other macrofossils from the local surrounding catchment and these may provide valuable information about ecological changes. The fine resolution pollen work has proved to be so time-consuming, however, that it has not been possible to undertake any systematic macrofossil work, although this is desirable in future research. Occasional identifications made were done using Katz et al. (1965). Some wood identifications were made of both detrital and in situ wood in an effort to separate local from extra-local taxa, using Schweingruber (1978), but many wood fragments proved to be too small or deteriorated to allow identification.

2.6 Pollen Analysis

Although differences in detail and emphasis exist in the methodology of pollen analysis employed by various workers, in essence the techniques employed are established ones and have been described in several standard texts and manuals (Kummel and Raup 1965, Faegri and Iversen 1975, Barber 1976, Moore and Webb 1978, Jones and Cundill 1978, Berglund and Ralska-Jasiewiczowa 1986).

2.6.1 Laboratory preparation

Laboratory preparation of samples for pollen analysis was achieved using the standard techniques, and the detailed laboratory schedule is shown in appendix 3. Sediment samples of known volume were used in the preparations, either measured by water displacement or provided by the thin sectioning method for obtaining fine resolution samples. In most cases samples of 0.5 cc were used. Stages in the extraction and concentration of microfossils included maceration and alkali digestion to remove colloidal material and acetolysis to remove cellulose. Those samples containing silicate mineral particles were subjected to hot hydrofluoric acid treatment. No samples were found to be sufficiently clay rich or high in lignin content to warrant treatment with sodium pyrophosphate for deflocculation or sodium chlorate for oxidation. Samples were dehydrated with tertiary butyl alcohol. The resulting pollen material was stored in silicone oil ready for mounting on slides, having been stained with safranin. Silicone oil was chosen as the mounting medium because it has a low refractive index relative to the refractive index of pollen grains, aiding microscopy, does not cause swelling of grains and, as it forms a fluid suspension, enables individual grains to be manoeuvred under the coverslip so that diagnostic features perhaps critical to identification can be observed from all angles (Andersen 1960). Although less permanent than alternatives such as glycerol jelly, slides several years old show no sign of deterioration, and all slides and pollen vials have been retained as a research archive.

The use of known sample volumes of sediment enable pollen concentrations to be measured, the method chosen being that of Benninghof (1962) in which a known volume of an 'exotic' pollen type was introduced to each sample at the beginning of the laboratory preparation, so that the concentration of each fossil pollen type could be calculated relative to that of the exotic marker. Other methods exist, such as the 'volumetric' method (Davis 1965, 1966) in which aliquots of material are removed from a sample of known volume, and the 'weight' method (Jorgensen 1967) in which a sub-sample of known weight is counted and extrapolated to find the number of grains in the original sample. The three main methods have been compared by Peck (1974) and reviewed by Mannion (1980). Both the volumetric and weight methods involve the counting of all grains in the final preparation and so they are prone to error and too time consuming for the present study which requires the analysis of very high numbers of pollen spectra. The exotic method, however, requires only that counting proceed to a convenient pollen sum of fossil grains and exotics, after which the concentrations may be calculated by a simple formula, calculated automatically in this thesis by computer as part of the pollen diagram plotting program. As accurate ratios of fossil to exotic pollen are all that is required then once the exotic marker is homogeneously mixed into the pollen preparation total pollen counts may vary between spectra as sub-samples of different sizes are counted without invalidating the method. Even loss of part of the sample during preparation would not matter, once homogeneous mixing was achieved and for that reason the exotic marker grains were introduced into the peat samples before the laboratory preparation began, a procedure recommended by Tipping (1985) for maximising the reliability of the method. Lycopodium clavatum spores have been used as the exotic marker, introduced in tablet form following the simplified procedure described by Stockmarr (1971). With both the sediment volume and number of Lycopodium spores known, the total number of fossil pollen grains and spores may be calculated by dividing the product of the number of fossil grains counted and the total exotics introduced by the number of exotics counted. Since this research is concerned with mid postglacial forested environments, the presence of fossil Lycopodium spores confusing the exotic Lycopodium spore count is considered most unlikely.

Some initial difficulties were encountered with the 'clumping' of pollen material during preparation, with large amounts of organic material sticking together, preventing the pollen grains being in free suspension and making their accurate counting on microscope slides almost impossible. Although a number of reasons for this may exist, the chemical properties of the Lycopodium tablets have been implicated as a cause (Francis and Hall 1985). Clumping was avoided by allowing the Lycopodium tablets to dissolve overnight in distilled water in the boiling tubes to be used for pollen analysis. This water was then decanted after thorough centrifuging to retain all the Lycopodium spores and the peat sample added. Checks on the decanted water showed there to be negligible loss of exotic spores in this procedure. A reduction in the number of tablets used, and an appropriate reduction in sample volume also helped to prevent 'clumping' problems.

2.6.2 Pollen Counting and Identification

Counting and identification of microfossils was carried out using a Zeiss 'Standard WL' microscope at routine magnification of x250, and closer inspection of grains at x400. Detailed observation of critical features was achieved using an oil-immersion objective at x1000 magnification. Phase contrast was used to assist observation of the surface sculpturing patterns of cereal type grains. Pollen counting involved repeated traversing of the slide, and identification and recording of all types encountered. Mechanical counters were used to record the totals of more abundant types. An interval of at least a field width was maintained between traverses to avoid duplicate counting as grains mounted in silicone fluid are potentially mobile and may be set in motion when individual grains are turned to assist identification. All parts of the slide were included within traverses, since the distribution of pollen grains on microscope slides is not random (Brookes and Thomas 1967, Peck 1974), with lighter grains perhaps differentially transported to the edges of the coverslip and concentrated there.

Pollen identifications were made with reference to standard pollen keys, Moore and Webb (1978) being the main source used, but with Faegri and Iversen (1975), Erdtman et al. (1963), Hyde and Adams (1958) and Andrew (1984) also consulted. Identifications were checked by comparison with the Department of Geography's modern pollen type-slide reference collection. Identifications were made to the lowest taxonomic level possible, plant nomenclature following Clapham et al. (1962) except where terminological groupings have been used in pollen keys which have no direct counterpart in

Flora of the British Isles, such as Tubuliflorae and Liguliflorae. As recommended by Birks (1973) and Berglund and Ralska-Jasiewiczowa (1986), the standard of certainty of the pollen identifications is indicated on the pollen diagrams, with taxa shown at family, generic or specific level accordingly. Where two taxa are equally likely to be represented by a fossil pollen type, both alternatives are shown, e.g. Plantago major/media. Thus Corylus and Myrica, which cannot be confidently separated morphologically (Edwards 1981) are shown as a combined Corylus/Myrica curve. Where one fossil type may represent more than two alternatives, a common taxon is used as representative of the type, as selected in the pollen keys, e.g. Erica-type (abbreviated to Erica-t). Where some members of a family can be taken to closer identification and some cannot, the undifferentiated family curve does not include the taxa shown at generic or specific level, e.g. 'Rosaceae' includes only those types incapable of finer resolution and excludes taxa which are, such as Crataegus-t, or Potentilla-t. In this way the term 'Filicales' is used to include all undifferentiated pteridophyte spores, although most are probably Dryopteris or Blechnum type. Special keys were used to identify critical taxa more securely. Large grains of Gramineae were regarded as cereal type (Cerealia-t) following the criteria of Andersen (1979), supported by Faegri and Iversen (1975) and Dickson (1988). These cereal type grains were examined by phase-contrast optics for diagnostic surface sculpturing and were measured for maximum diameter and annulus diameter to separate the major cereal groups. The results are shown in appendix 4. Further differentiation within the Gramineae, e.g. into Phragmites type, was considered impractical and not attempted. Similarly the occasional grain which could be referred to *Carex* type was not separated from the Cyperaceae curve.

Since pollen preservation was generally very good, very few grains were unidentifiable and so a separate curve for unidentified grains is not included on the diagrams. Similarly, too few grains could be regarded as deteriorated to warrant their systematic categorisation in the way prescribed by Cushing (1967) and Lowe (1982). Where corroded grains were observed, they have been noted in the text. All pollen and spore counts are tabulated in appendix 7.

2.6.3 The Pollen Sum

As stated by Berglund and Ralska-Jasiewiczowa (1986) it is important to choose a pollen sum which is appropriate to the ecological conditions under study, as long as the total number of grains counted was high enough to ensure an adequate statistical representation of the major types. As this research is concerned with variation within mid postglacial forested environments, a pollen sum based upon tree pollen has been used. *Alnus* was excluded from the tree pollen sum because the pollen sites have a stream-side location where alder may well at times have dominated the local vegetation and contributed unrepresentatively heavily to the pollen rain. Superabundance of alder pollen occurred in many levels and alder wood was present in the stratigraphy at a number of sites. Janssen (1959, 1973, 1986) has investigated the role of alder and other superabundant local pollen types in distorting pollen representation and advocates their exclusion from pollen sums, particularly in relative diagrams where massive percentages for one taxon will, as a statistical artifact, suppress all other pollen values, making their interpretation impossible. Several other studies (e.g. Simmons and Cundill 1974, Innes 1981, Scaife 1988) have successfully handled high alder counts in this way. Alnus was therefore excluded from the tree pollen sum, and counting proceeded until 150 grains of the other tree types was reached. In almost every case this meant that the count of all pollen types (excluding aquatics and spores) exceeded 500, and often attained 1000 or more. These high pollen counts, permitted by the exclusion of Alnus from the tree sum, meant that identifications of rarer, but often most diagnostic, pollen types was achieved. The use of a total land pollen sum from which local (i.e. mire) types were excluded (Barber 1981) was rejected because of the great difficulty in separating mire and non-mire types in the context of a small basin mire within closed woodland subject to localised clearance. Many taxa could not be thus categorised, and the source areas of their pollen would vary greatly both spatially and temporally through the pollen stratigraphy.

2.6.4 Pollen Diagrams

Results of the pollen analyses are presented in the form of pollen diagrams of standardised construction, intended to be consistent with the recommendations of Berglund and Ralska-Jasiewiczowa (1986) for pollen diagrams from sites in temperate forest regions. Conventions observed include; a vertical axis representing depth, a horizontal axis representing the abundances of the recorded pollen and spore types according to the scale upon the diagram, and a stratigraphic column at the left hand side to assist in interpretation of the pollen curves. Abbreviations used upon the pollen diagrams are listed in appendix 5. 'Bar histogram' diagrams have been used as this method illustrates fine detail of frequency changes very well and avoids unjustified assumptions of pollen frequency between sampled levels, although at the millimetre interval level of resolution, pollen spectra are contiguous. Relative pollen diagrams have been used, with values for every pollen and spore type identified shown as percentages of the diagram calculating sum for each site. This calculating sum is formed by the total tree pollen count plus the total count for an appropriate ecological group. Ecological groupings have been added to allow the pollen counts for individual taxa to be more directly comparable with taxa of similar, and thus more likely competitive, life form. This 'life form' concept is of value in assisting the interpretation of the changing spatial distributions of taxa in successional communities, (e.g. Tooley 1978, Scaife 1988), as changes in the relative abundances of individual taxa within particular ecological groups are most likely to affect other member taxa of that group. This calculation method has the added benefits of preventing the percentage frequency of individual taxa from rising above 100%, and of preventing the superabundance of one taxon (e.g. *Alnus*) from statistically depressing the percentages of other non-tree taxa which may not be in direct competition with it in the plant community (e.g. *Calluna* or Gramineae). Nine ecological groupings are recognised: Trees, *Alnus*, *Corylus/Myrica*, Other Shrubs, Dwarf Shrubs, Gramineae, Other Herbs, Pteridophytes, and Bryophytes. Thus, for example, the frequency of *Calluna* pollen is expressed as a percentage of tree pollen plus total dwarf shrub pollen; the frequency of *Corylus/Myrica* pollen as a percentage of tree pollen plus *Corylus/Myrica*, and so on. Two relative 'tree pollen plus group' diagrams are presented for each pollen data set, the first showing the woody taxa groups, Trees to Dwarf Shrubs, the second showing groups from Gramineae to Bryophytes. Summary curves are shown on each diagram to show total pollen changes of that diagram's groupings relative to tree pollen. The taxa included within the composite ecological groupings are listed in appendix 6.

Many authors have attempted to assemble pollen types into exclusive groups indicative of distinctive plant communities associated with particular forms of anthropogenic activity or ecological conditions (e.g. Moore 1973, Behre 1981, 1986). These have not been used, since they are not appropriate to pre elm-decline forested landscapes and because no real degree of agreement has been established between various authors. For the same reason correction factors which transform the pollen counts to allow for different pollen production and dispersal (e.g. Andersen 1973) have not been applied to the data.

Pollen concentration diagrams are presented for each site, and these express the frequency of the pollen types as numbers per unit volume of wet sediment (N x 10^3 grains cm^{-3}). Again, selected taxa and broad taxa categories are used. Due to the probability of fluctuating sedimentation rates in peat and the lack of a comprehensive series of radiocarbon dates, it was not possible to produce pollen influx diagrams. All of the pollen diagrams were drawn using a FORTRAN program, NEWPLOT10, devised by Dr. Ian Shennan of the Department of Geography, University of Durham.

2.7 Diagram Zonation and Correlation

2.7.1 Introduction

It has become established practice for the pollen stratigraphic record to be subdivided into smaller pollen stratigraphic units to assist firstly in the description of the pollen data, and thereafter in their interpretation and possible correlation with other pollen diagrams. Since the first application of pollen analysis was in describing gross changes in forest history caused by postglacial environmental changes at the national or even larger scale, it was possible for Godwin (1940) to devise a pollen zonation scheme for Britain closely comparable with the climatic periods of

Blytt and Sernander (Sernander 1908), so closely in fact that the two schemes came to be used almost interchangeably. Since climatic changes were responsible for the major tree pollen changes which Godwin's scheme described, his pollen zones acquired climatic and chronological connotations, the latter becoming so strong as to even associate them with particular cultural periods.

It has become increasingly clear, however, as the degree of detail in which pollen diagrams have been prepared has greatly increased, that this traditional way of ordering pollen data is not adequate to describe vegetation history at other than the very broadest scale, and even then is unable to cope with the kind of forest communities recorded in regions away from southern Britain, where it originated. Smith and Pilcher (1973) have shown that the major pollen zone boundaries are not synchronous. Even the Elm Decline which marks the end of zone VIIa, which is one of the less diachronous, varies within half a millennium around its mean of about 5000 BP, while another major feature of Flandrian pollen diagrams, the rise of Alnus, can vary up to two millennia around its mean age of about 7000 BP (Chambers and Price 1985, Turner and Hodgson 1981) according to geographical factors. Different regions may have vegetation histories (Birks 1973, Bennett 1988) radically different from the southern English model, and some, and indeed perhaps all, of even the major changes which mark pollen zone boundaries may be anthropogenically rather than climatically determined (Turner 1962, Smith 1984). Ecological and cultural assumptions based upon biostratigraphic (pollen zone) changes are therefore likely to be at least uncertain, and probably unfounded.

This has led to the modern usage of the local pollen assemblage zone (Cushing 1963) as the basic unit for the descriptive subdivision of pollen stratigraphic data. It may be defined as a biostratigraphical unit (Hedberg 1976) characterised by a particular pollen assemblage and this having internal uniformity, which distinguishes it from sub and superjacent pollen spectra. Local pollen assemblage zones (LPAZ) have, in themselves, relevance only to the pollen diagram of which they form part and, being defined only by their internal pollen content, carry no ecological or chronological implications. The construction of such a sequence of independant biostratigraphic units at the site scale has been recommended by West (1970) as a necessary prelude to any attempt to correlate the pollen record with standard chronostratigraphic units of purported regional significance, such as those at Red Moss (Hibbert et al. 1971) or Din Moss (Hibbert and Switsur 1976). Once local pollen assemblage zones are defined they are labelled either by the names of their major taxa or, as suggested by Berglund and Ralska-Jasiewiczowa (1986), by the use of a code for the site name followed by a number in sequence from the base upwards. The latter course is followed in this thesis. Zone boundaries are indicated upon pollen diagrams by drawing lines across the diagram at the appropriate level.

While the adoption of the local pollen assemblage zone has become standard practice, the choice of criteria adopted for their definition has been standardised in the same way. Since pollen assemblages can be viewed as independent but highly complex multivariate data sets, the use of objective numerical methods of comparing pollen spectra and delimiting pollen zones have found favour (Gordon and Birks 1972, Birks 1974, 1986). Although these computer-based methods are most useful in handling highly complex bodies of data such as represented by a pollen diagram, their virtue of objectivity is also a failing in that no account is taken of the ecological significance of individual pollen types so that features such as the Ulmus decline which are believed by virtually all pollen analysts to be of great significance in vegetation history may not be recognised at all. Also the relative importance of regional and local changes in the pollen rain will not be apparent in a purely mathematical analysis. Thus, just as the 'intuitive' definition of pollen zone boundaries is usually based upon a few major, usually tree, pollen types so the restriction of the numerical database to only those contributors to the pollen sum which attain more than a certain abundance may be necessary, rather than applying numerical techniques to the entire pollen count. Numerical analyses of both kinds are used in this thesis, and are discussed further below. A further difficulty with zonation based upon pollen assemblages, whether whole assemblages or selected groups of taxa, is that pollen changes may well take place in several taxa over several pollen spectra so that the placing of a pollen zone boundary may be in effect a compromise within a series of transitional levels. Alternatively, the 'transitional' levels may themselves have to be recognised as a separate pollen zone. It is relatively rare, unless vegetation changes are particularly rapid following radical environmental disturbances, for pollen, spectra to record other than gradual plant community change. It is more apt to think of vegetation change occurring as a continual process, rather than considering pollen zone boundaries as marking dramatic changes between pollen zones which represent static conditions (Walker 1982). Sharp pollen curve fluctuations on many pollen diagrams are often the result of wide sampling intervals, and thus relatively long time periods, between counted levels. In the present study, where sampling intervals are very fine and thus time intervals may be measured in years rather than in decades, sharp pollen changes should hardly ever occur due to autogenic vegetation development, but only be observed where rapid vegetation successions have been set in train, and the pollen input from different pollen source areas has been radically altered by changed vegetation patterns, following woodland disturbance. In these circumstances, both sharp and gradual changes may occur at the same level in pollen diagrams as taxa in one community, perhaps dryland trees, may be severely affected as pollen producers due to their clearance, while taxa in an adjacent but different community, perhaps part of the mire flora, may remain unaffected by clearance and become relatively more important in the pollen rain. It is clear that the pollen curves of those taxa which are most affected by woodland disturbance will be the ones most sensitive as indicators of the presence or absence of that disturbance. Since the investigation of the effects of forest disturbance upon vegetation communities is the prime research topic of this study it is logical to use the most sensitive pollen curves as a basis for the zonation of the pollen diagram, as these will most closely mirror the variability in the pollen data set which is caused by palaeoecological events directly relevant to the research topic.

2.7.2 Zonation Criteria

In accord with the above criteria it has been decided to adopt a zonation system which is based upon the presence or absence of pollen evidence of woodland disturbance, as revealed in the major pollen types. The North Gill diagrams contain successive groups of pollen spectra which are characterised either by pollen of deciduous woodland taxa (mainly Quercus, Ulmus, Tilia and Alnus), or by the pollen of herb and shrub taxa and that of trees not regarded as members of the mixed-oak deciduous woodland group, such as Pinus or Betula. The former group of spectra are regarded as reflecting closed-canopy undisturbed woodland, and thus periods of woodland 'stability', while the latter are interpreted as reflecting the effects of woodland disturbance, by whatever cause, and subsequent regeneration through seral communities. Since the phases of supposed disturbance are discrete, being separated by phases in which tree pollen predominates, they may function as pollen assemblage zones although they may not be as internally homogeneous as the phases of woodland stability.'Disturbance' in this terminology is a general descriptive term applied to perturbation of woodland plant communities, perhaps even involving their actual full or partial destruction, which implies an allogenic process. It incorporates both conditions created by the initial disturbance process and the conditions characterised by vegetation diversity which are passed through during the subsequent regeneration and return to more 'stable' communities. 'Stability' in this terminology does not imply an unchanging community, but refers to a situation in which community changes are regulated by autogenic, ecosystemic factors and trends. The pollen of these 'stable' plant communities dominates the intervening phases when disturbance evidence is not apparent, and they may be interpreted as periods of restored woodland cover, although perhaps of a changed or incomplete character. Thus the woodland history at each individual pollen site at North Gill is described by an alternating sequence of stable (s) phases and disturbed (d) phases. These phases are ecologically interpretive as well as descriptive, but do not in themselves comment upon the origin of disturbance events, but are designed only to define them biostratigraphically. They are thus true pollen assemblage zones, but are based upon a restricted and selective range of pollen types sensitive to a particular set of ecological conditions, those pertaining before, during and after woodland disturbance. They may thus be used as a basis for a more subjective interpretation of the pollen data in terms of the possible presence or absence of human activity and forest clearance. Systems of pollen zonation based upon cultural inferences have been employed by previous authors (Birks 1965, Moore 1973, Simmons and Innes 1981), but while the great majority of prehistoric disturbance events may in fact have had a human cause, there are natural events which can cause disturbance within forest on a large or small scale, from storm winds to the death and fall of individual senescent trees. In fact the fall of individual large trees within modern woodland has been shown (Perry and Moore 1987) to cause vegetation succession at the site of tree fall which gives rise to pollen spectra approximating those associated with the *Ulmus* decline at the end of Flandrian II. It is therefore preferable to avoid the implication of cultural cause in diagram zonation itself, although the vegetation changes may well be interpreted in cultural terms.

2.7.3 Zonation Taxa Selection

While initial s/d phase zonation of individual pollen diagrams must be made on the basis of that pollen diagram alone, the disturbance sensitive taxa selected as the basis for zonation must also lend themselves to possible correlation with the pollen records from other nearby sites. Part of the research aims of this study is to evaluate the ability of fine resolution pollen analysis to detect spatial differences in vegetation communities at a detailed temporal scale. Exact temporal correlation of individual spectra will never be possible at this scale of resolution, for exact age equivalence cannot be assumed from biostratigraphic correlation (Hedberg 1976, Mangerud *et al*. 1982), as sedimentation rates and rates of successional response in vegetation will mean that the nature, scale and duration of vegetation change after disturbance will differ according to the distance of each pollen sampling site from the centre of disturbance. Such factors of scale and complexity in ecological interpretation (Oldfield 1970) will be of fundamental importance in deciding which components of the pollen rain should form the basis of comparability for correlations. This tremendous spatial variability between the curves for individual taxa is what this study is designed to observe, but it means that all of the pollen types which have a high level of local variability are of no value for correlation. Some of the taxa involved in the disturbance cycle at North Gill come into this category, including all of those, like Corylus/Myrica or Salix, which show a positive response to disturbance events. It is not practical to use these very locally derived pollen spectra for correlative zonation, for coeval local vegetation at the compared sites may very well be radically different, over even a very small distance such as a few tens of metres, due to variations in local community mosaic patterning because of site-specific edaphic or other factors, particularly in the dynamic, successional 'patch' vegetation following disturbance. One of the taxa adversely affected by disturbance, Alnus, has already been categorised as probably exhibiting very variable and extreme local growth at the edges of the mire itself, due to alder wood in the stratigraphy, knowledge of its present ecology and superabundant pollen percentages in certain cases. As with taxa like Gramineae, Cyperaceae and Calluna, alder is a taxon whose abundance is likely to be affected by local hydrological factors likely to cause considerable diachroneity in both its establishment and in particular its decline across the site as a whole. Rybnickova and Rybnicek (1971) have considered the recognition and elimination of highly local pollen spectra from ecological evaluation of pollen data and suggest that it is not possible to separate the dryland and wetland components in the alder pollen curve, but that the latter is likely to be highly dominant in situations similar to that of North Gill. In a series of papers Janssen (1959, 1970, 1973, 1981, 1986) has examined the ecological implications for pollen data of the local against the extra-local component in the pollen rain of several taxa. Alnus shows a consistent dominance of the local over the extra-local component, with a marked reduction of Alnus pollen frequencies at a short distance away from wetland alder carr. This agrees with data from sites away from streamside locations in Flandrian II in the North York Moors (Simmons and Innes 1982). It is necessary, therefore, that all taxa which may be recognisable as predominantly local must be excluded from any role in pollen zone definition from which any correlations may be made. At North Gill this applies to alder as with any taxon likely to be associated with the mire and its margins.

The s/d pollen zonation at North Gill has therefore been defined on the behaviour of extra-local pollen data only, being taxa affected by woodland disturbance on the dryland area near to, but not on or immediately adjacent to, the mire area itself. The two taxa primarily used as the basis for the s/d zonation are therefore Ulmus and Quercus. The Ulmus decline is recognised on all diagrams and is a secure extra-local and indeed regional feature. Although a number of factors may be implicated in the fall of elm pollen itself, there is sufficient evidence of associated disturbance of woodland coincident with it to justify its inclusion within the s/d scheme. It forms a biostratigraphic marker horizon of wider significance in that it is also recognised as a chronostratigraphic feature. Quercus has also been chosen as a single-curve pollen indicator because, even if correlations are made for pollen productivity (Andersen

1973), oak seems to have formed the major element of the pre elm-decline dryland woodland in the environs of North Gill and thus the major, and most consistent, extra-local component of the pollen rain within the North Gill pollen catchment. In addition, its pollen curve behaves in a consistent manner in regard to other pollen types at all observed sites, being low in phases which other pollen indicators would suggest are of disturbance type, and high during phases which the rest of the pollen evidence would suggest are of stable type. No other pollen type shows such representative behaviour throughout the period under study in being consistently in accord with the general trend towards disturbed or stable conditions. This is probably due to an ubiquitous but even distribution of oak within the woodland around the North Gill site, with no major chronological or spatial variations in this distribution except where adversely affected by disturbance. Detailed changes within the Quercus pollen percentage and concentration curves are therefore considered to be uniquely sensitive to disturbance at this site, and are thus used as an index of the presence or absence of disturbance and as the basis for s/d zonation. This is in accord with the approach of Walker and Wilson (1978) and Green and Dolman (1988), who advocate giving emphasis to the behaviour of a very few, and perhaps even only one, pollen types which are selected as the most consistently sensitive to the ecological process under study. The intuitive view that the Quercus curve is the only curve consistently diagnostic of disturbed or stable conditions is largely confirmed by numerical analysis (see below). At each site the local s/d pollen phases are labelled numerically from the base of the diagram upwards and each number is categorised by the addition of a lower-case s or d suffix.

With the independent site zonation defined, an attempt is made to correlate the individual s/d phase successions and establish a sequence of summary s/d phases applicable to the site as a whole. Wider correlation of the North Gill pollen data may be achieved by referring them to the sub regional pollen assemblage zone scheme set up to the Eastern Central Watershed of the Moors by Simmons and Cundill (1974). The Ulmus decline at North Gill is equated with the Flandrian II/III transition on both biostratigraphical and chronostratigraphical grounds (Burleigh et al. 1976) and so the pre Ulmus decline spectra are correlated with sub regional zone EGM Alnus - Ulmus - Quercus - Tilia, and the post Ulmus decline spectra with EGM Alnus - Quercus. The prefix EGM refers to 'Egton - Glaisdale Moors'.

2.8 Numerical Analyses

The PCA programme used in the analyses presented in this paper is PCARMODE, written by H. J. B. Birks and supplied by B. Huntley (e.g. Birks and Berglund 1979, Huntley and Birks 1983). This is an R-mode method (Prentice 1980) which calculates both component loadings for the variables (pollen taxa) as well as component scores for the individual samples (counted levels). As recommended by Birks and Berglund (1979) only those pollen types which attain 5% of total land pollen or more at any single level were considered for inclusion in the analysis by PCA, since taxa with lesser values are of little importance in numerical analysis, and contribute little to the variation of the data set. A wide range of variation, however, inevitably exists in the absolute numbers of pollen grains counted for each pollen type, due to natural variations in pollen production and transport among individual taxa. Heavy pollen producers may thus dominate an analysis, and a taxon's percentage representation in a pollen count may not correspond to its representation in the vegetation. Pollen abundance, therefore, need not reflect a taxon's relative significance in an assemblage from the point of view of ecological interpretation. Since this study seeks to detect ecologically relevant information it was decided to employ a type of calculating matrix which standardises the data and gives added weight to lower pollen producers which yet may be of high ecological significance. A correlation matrix (Prentice 1980) was therefore used. Ruderal herbs are low pollen producers but of ecological significance in regard to woodland disturbance, and so in the analysis all ruderal herb counts were combined and regarded as a single pollen group which then attained the 5% limit. Within this composite group were included *Plantago lanceolata*, *Melampyrum*, *Rumex*, Chenopodiaceae. *Cirsium*, *Artemisia*, *Taraxacum*-type, Cruciferae, *Silene*-type, *Stellaria*-type, *Urtica*, *Scabiosa*, *Senecio*-type, and the fern *Pteridium*, all classified as possible indicators of open or disturbed conditions. The pollen types included in the PCA are *Betula*, *Pinus*, *Ulmus*, *Quercus*, *Alnus*, *Corylus/Myrica*, *Salix*, *Calluna* and Ruderal Herbs. The results are shown in Chapter 4.

The newer technique of DCA (Hill and Gauch 1980) has also been applied to North Gill data, using the program DECORANA supplied by Dr. B. Huntley and Dr. J. Turner of the Department of Botany, University of Durham. This program is capable of processing large numbers of samples and taxa and enables a whole pollen data set to be analysed, unlike the rather simpler PCA, and Prentice (1986) considers DCA to be very effective in revealing underlying structure in complex vegetation data. The results of the DCA are shown in Chapter 5.

CHAPTER THREE

SELECTION OF THE STUDY SITE AND RESEARCH TOPIC

3.1 Selection Criteria

The selection of a suitable research site is fundamental for the success of any pollen based palaeoecological study (Jacobson and Bradshaw 1981, Prentice 1985) for, as discussed in previous chapters, factors such as basin size and sediment type will govern pollen assemblage taphonomy and therefore pollen interpretation. This is particularly so in research studies such as the present one, with a well defined set of research aims and problems, which have the purpose of testing the capabilities of research techniques and methodologies by the acquisition of high quality, high resolution data. In order to optimise the quality and value of the results obtained, and thus to test fully the potentialities of the research techniques, the choice of the most suitable field area and research site is clearly critical.

There are several criteria for FRPA which need to be met in site selection. The first is that the site sediments are suitable for the close sampling required for fine resolution pollen analysis. Peat is to be preferred to lake sediments, to reduce the probability of post depositional mixing. Rapidly accumulated raised bog peats are to be avoided, even though fresh peats such as those sampled by Garbett (1981) minimise the time interval between samples. Their fibrous nature makes them difficult to sample efficiently; hummock and hollow microtopography puts their horizontality in question and differential growth rates make pollen concentration and time interval per sample vary considerably through the profile. These problems can be minimised by the use of amorphous, well humified peats such as upland basin or blanket peats (Moore 1988, Moore et al. 1984), without undue loss of temporal resolution per sample. The horizontality of such sediments, at the micro-scale, is a prime requirement and is more likely in more amorphous, humified peat. The absence of fresh macrofossil remains in much of the well humified upland peats is a further point in their favour, being necessary for successful thin sectioning. The exposure of peat stratigraphic sections to view is a major benefit of upland blanket or basin sediments, where streams have often cut down through organic deposits, so that the lithostratigraphy may be inspected in detail and profiles for analysis chosen more precisely.

A good pollen stratigraphy is clearly vital to the suitability of a site for FRPA, and high pollen concentration is required to allow the counting of sufficient pollen grains per thin-sectioned sample, at an increasing scale of resolution, so that low pollen content per sample does not become a limiting factor in the analysis. Good pollen preservation is a further requirement, since FRPA is sufficiently time consuming without the problem of difficult identification due to deteriorated pollen and because it is important in palaeoecological study at this degree of refinement to be able to consider entire pollen assemblages without being limited by differential loss of pollen taxa through poor preservation. The chosen site must also have a proven pollen record of palaeoecological change, preferably of a well defined, short lived, transitory nature (so that it may be observed in its entirety by FRPA) but of a type which brings about rapid, significant spatial changes in plant communities. A forest clearance episode of limited duration and intensity followed by regeneration of tree cover is the sequence of palaeoecological events most likely to result in such short term but high visibility changes in the pollen record. Clearance within a closed, and if possible primary, woodland environment would be most suitable, for the local pollen rain in such a situation would be dominant, with little non-woodland 'noise' of clearance type pollen present in the more regional element of the pollen rain. Interpretation of pollen changes consequent upon clearance would then be largely unconfused by pollen changes taking place at a distance from the study site, the woodland matrix preventing import of non-woodland pollen taxa. Woodland provides a stable background pollen rain within which the effects of disturbance are clearly visible.

Site size is a further important variable, the effects of which need to be defined in selecting sites for analysis. Jacobson and Bradshaw (1981) have recommended that a small basin within woodland provides optimum conditions for the interpretation of local vegetation change in terms of spatial plant successions. A few tens of metres may be ideal for this, but if multi-profile analysis is a research aim, then a basin size of a few hundred metres, or a number of adjacent smaller basins, will be required. Multi-profile analysis at the FRPA scale also demands that secure correlation between profiles be possible, for spatial interpretation requires the assessment of contemporaneous pollen spectra, or as nearly so as is possible within the limits of the palynological method. A combination of bio- and litho-stratigraphic marker horizons which act as time-equivalence levels is the ideal situation, so that the same clearance event may be recognised in more than one profile. Pollen zone boundary changes of the early and mid Flandrian provide the best such biostratigraphic markers, with the Ulmus decline at the Flandrian II - III transition perhaps the least diachronous, especially over very short distances. Lithostratigraphic marker horizons include inwashed, exogenic mineral sediment which may be traced continuously throughout the site, although these may be disruptive to the pollen stratigraphy. Several such inwash horizons occur at and before the Ulmus decline (Simmons et al. 1975) and the scale of forest clearances and the predominantly closed forest conditions of the mid-Flandrian make that broad time period most suitable for the testing of FRPA as an instrument for the detection and explanation of the spatial patterning of successional vegetation changes.

The above criteria have been taken into account in the selection of the research topic, the study area and the research site.

3.2 The Research Topic

The topic chosen for study is the impact of man upon the vegetation during the period of the Mesolithic - Neolithic transition, which may be regarded as the latter half of the chronozone Flandrian II (c. 6000 - 5000 BP), culminating in the Ulmus decline. The explanation of this biostratigraphical marker horizon in terms of early agricultural practices by prehistoric man has long been favoured (e.g. Iversen 1941, Garbett 1981, Scaife 1988), despite the existence of other causative factors such as disease, climate or pedology, although this is not universally accepted (Groenman-van Waateringe 1983). This was due to its apparent contemporaneity with the earliest Neolithic cultural remains in Britain and its association with pollen evidence of weeds of cultivation. Thus the Ulmus decline became accepted as the earliest feature attributable to human activity on pollen diagrams. It was equated with the first forest clearance, the first introduction of agricultural techniques and the arrival of a 'Neolithic' economy. The activities of Neolithic agriculturalists, with food production land-use methods involving clearance of land for crops and livestock, may be expected to be reflected in the pollen record.

On this basis the pre Ulmus decline Flandrian was assumed to mean pre Neolithic and pre agricultural: a period when human influence upon the environment was of only the most transient kind. It was equated with the Mesolithic cultural period, during which man's technology was limited and his economy was extractive, based upon hunting, fishing and the gathering of vegetable foods. It was also the period of the rapid establishment and dominance of fully developed forest ecosystems, which pollen diagrams seemed to show as having been undisturbed, as non-tree pollen frequencies were uniformly low and the accepted herb pollen indicators of cultivation or pasture were absent. No features of pre elm decline pollen diagrams were considered likely to have been of anthropogenic origin.

In looking at the relationship between Mesolithic man and the environment during the pre elm decline period, therefore, prehistorians and palaeoecologists were traditionally inclined to take a minimal view, being concerned with assessing the effects of very weak cultural forces (prehistoric hunter-gatherer societies) on well established natural biological systems (mature boreal and deciduous forests). During the Mesolithic the effects of natural forces could be expected to have been greatly dominant over the effects of cultural ones, so that where the composition of vegetation communities was concerned, climatic, topographic and edaphic factors would have been of much greater importance than human land-use methods. Man, like the other organisms in the ecosystem, would have organised his ways of life in response to environmental stimuli. The spatial and temporal distribution of human population would thus have been governed by the seasonal changes in the availability of food resources, a process in which man would exercise no control. The 'functional' nature of much of the Mesolithic artifactual evidence from north west Europe lent credence to this view of a society and technology constrained by environmental parameters (Mellars 1976a). The basic woodworking - projectile point character of Mesolithic tool assemblages supported the concept of a society adapted to postglacial forested conditions. Thus the archaeological and palaeobotanical data were compatible in supporting the view of pre Neolithic people in Britain as having been in harmony with, but subject to, the natural environment.

In the last few decades however, some research has tended to challenge many assumptions about the environmental relationships of the Mesolithic, the timing and nature of the transition to the Neolithic way of life and the value of the elm decline as an eco-cultural benchmark. In particular, the great increase in the volume and resolution of palynological work in the last few decades has produced data which seem to be incompatible with the view that Mesolithic foraging communities were completely subject to the biophysical environment. These more detailed pollen studies have allowed the recognition of sporadic, small scale and temporary episodes of vegetation disturbance, usually involving reduction in woodland cover, in pollen spectra of pre Ulmus decline, and therefore conventionally pre Neolithic, age. At present, most British examples are from upland contexts during Flandrian II (Simmons and Innes 1985, 1987). The pollen evidence suggests that these disturbances represent the creation of localised breaks in the forest cover, usually followed by the regeneration of some form of woodland after succession through seral plant communities. That many of these disturbance horizons are associated with charcoal points to fire often having been one of the processes associated with clearance. Even though at least some of these pre Ulmus decline forest clearings were created by natural disturbance events such as lightning, windthrow, flood or landslide, it seems very likely that many were due to the activities of Mesolithic populations and their use of fire. The deliberate application of fire to the forest during the Mesolithic as an agency for environmental alteration remains an explanation which has found favour with many palaeoecologists (Simmons 1969a, Mellars 1976a, Welinder 1983a).

The earlier published evidence for Mesolithic age forest disturbance was reviewed by Smith (1970) who concluded that if postglacial foragers were to have used fire to effect vegetation change on an habitual basis they could have had a considerable impact upon the development of vegetation communities. This hypothesis has encouraged an understanding of Mesolithic society which is based upon man's role in the ecosystem and which includes the possible deliberate management of woodlands within a conscious land-use strategy designed to manipulate the ecosystem to human advantage (Simmons 1975a, 1975b, Jacobi et al. 1976).

3.3 Evidence for Flandrian II Woodland Disturbance

Whether woodland management was practiced during the Mesolithic or not, there are many examples in Flandrian II where major woodland disturbance took place at the site scale. The sampling intervals employed in many pollen studies were too wide to permit their interpretation in any other than broad terms, so that the retrieval of data relevant to short term ecological change often did not occur. Many examples of pollen data linking Mesolithic man with forest disturbance are analyses of deposits associated with Mesolithic flint artifacts. Thus Walker (1956) noted the coincidence of weed pollen grains with the flint horizon at Stump Cross in the Pennines, while a similar association of cultural and pollen evidence occurred at nearby Dunford Bridge (Radley et al. 1974). Recurrent burning and clearance has been noted during Flandrian II in the Pennines at Quick Moss (Rowell and Turner 1985) and Pawlaw Mire (Sturludottir and Turner 1985). Significantly these are sites at which a fine sampling interval has been employed, suggesting that wider sampling intervals may sometimes not reveal small, short lived events of this kind. Most sites record only single phases of disturbance, to which attention was drawn often by a charcoal horizon; Valley Bog (Chambers 1978) and Malham Tarn Moss (Pigott and Pigott 1963) being examples of this type. A further feature of these upland sites is their apparent concentration at mid to high altitude in the vicinity of the local spring-line. Thus in the south Pennines these pollen sites correlate quite closely with the zone of maximum concentration of Mesolithic flint sites (Jacobi et al. 1976), a correlation repeated for the North York Moors (Spratt and Simmons 1976) and the northern Pennines (Turner and Hodgson 1983). A continuing literature search (Innes in prep.) has revealed well over two hundred examples of pre Ulmus decline forest clearance from Britain. These are not discussed in detail here, for they are not central to the topic of this thesis and many have been considered elsewhere (e.g. Edwards and Ralston 1984, Simmons and Innes 1985, 1987, Innes and Simmons 1988, Howard-Davis et al. 1988). It may be noted, however, that they occur in both lowland and upland situations; several locations seem to have been the site of fire disturbance on more than one occasion; the incidence of disturbance appear to rise in the latter half of Flandrian II, particularly in the uplands, so that perhaps frequency of disturbance increased towards the end of the period (Simmons and Innes 1985). In addition, many disturbance events are associated with the rise of Alnus which defines the Flandrian I - II transition (Smith 1984). A most important feature of some later Flandrian II clearance horizons, however, is the presence of cereal-type pollen grains, usually in combination with a range of cultivation types (Behre 1981) although sometimes as isolated records. Several such examples have been reported (Edwards and Hirons 1984), and their numbers are increasing as more highly detailed pollen studies are completed (Robinson 1988). Some of the most convincing examples are found in upland situations, as at Soyland Moor in the Pennines (Williams 1985) where the cereal phase is dated to 5820±95BP (Q-2394). If these large graminoid grains of cereal-type do represent cereal cultivation, it would seem that a period of several centuries prior to the Ulmus decline may be regarded as contemporary with early farming cultures in Britain, presumably the first stages of the Neolithic settlement of the country. This raises the possibility that other later Flandrian II clearances, which at present have yielded no record of cereal pollen, may also be of Neolithic origin and more detailed analyses may reveal evidence of farming activity. This implied Neolithic presence well prior to the elm decline is balanced, however, by 'late' radiocarbon dates for Mesolithic sites which indicate that Mesolithic cultures persisted almost to the time of the elm decline. Such Mesolithic sites are present in the uplands, such as at Dunford Bridge B (Radley et al. 1974) in the Pennines, with a date of 5380±80BP (Q-799) which is analogous with dates for the elm decline in lowland northern England, e.g. 5468±80 (Neasham Fen) and 5305±55 (Mordon Carr) recorded by Bartley et al. (1976) and 5240±70 (West Hartlepool) by Tooley (1978). The elm decline in the northern English uplands is uniformly later in date, however, with examples of 4794±55BP (Valley Bog, Chambers 1978) and 4720±90 (Fen Bogs, Atherden 1976) from the Pennines and North York Moors respectively.

It would seem, therefore, that the period between about 6000BP and 4700BP may be regarded as a time of transition between the Mesolithic foraging and the settled Neolithic farming ways of life (Simmons and Innes 1987). The timing and rate of the cultural economic changes which took place during this time clearly varied from place to place. Even in a spatially restricted area such as the central Pennines, however, there seems to have been a long period of overlap between cultural and economic traits which lasted for several centuries, if the dates from Soyland Moor and Dunford Bridge B are correct. It may even be that the long coexistence of the two economic strategies represents a slow adoption of food production techniques by indigenous Mesolithic populations (Simmons and Innes 1987) with even the elm decline itself being a result of long term Mesolithic activity in some instances (Sturludottir and Turner 1985). There is clearly a need to examine later Flandrian II pollen evidence of forest clearance in much more detail than hitherto, for the ecology of these later pre elm decline clearances (Simmons and Innes in press) may reveal much about their origin and character, and thus about the land-use strategies of their originators and the Mesolithic - Neolithic transition. This has therefore been chosen as the research topic for this thesis, for FRPA, as discussed above, should be capable of yielding the highly detailed palaeoecological data which are required to address this research problem. Both the criteria outlined at the start of this chapter and the evidence from the Pennines of Mesolithic/Neolithic overlap suggest that the northern English uplands would be a suitable field area for the research. The area chosen is the North York Moors, which has a sound palaeobotanical and archaeological research background in the selected topic.

3.4 The North York Moors

3.4.1 Introduction

A comprehensive analysis of the North York Moors study area is not required here, for previous publications contain very detailed reviews of the area's history and character. Only a brief account of factors relevant to the present study will be undertaken here, and reference to more detailed sources will be made in the text. The North York Moors is the most easterly major upland unit in England, separated from the much higher Pennines by the lowland vales of Mowbray and York. It is a relatively small upland area, less than sixty kilometres in length, separated from the Yorkshire Wolds on the south by the Vale of Pickering, and bounded to the north by the Tees basin. The edges of the upland, including the eastern coastal area, are steep and so the study area is geographically well defined. The highest point, on Urra Moor, reaches only 454m O.D., but much of the central summit area, termed the Central Watershed, lies above 300m, so that the upland forms a plateau surface rather than comprising individual hills. The escarpments which bound this upland plateau are steep, so that the Central Watershed forms a discrete geographical entity, emphasised further by the steep sided valleys which incise it and reduce its area considerably. From its westerly high point the summit plateau inclines in an easterly direction, but gradients are low and the relatively flat landscape is a feature of the area. The physiography of the North York Moors upland is consequent upon its geology.

3.4.2 Geology

As the upland parts of the North York Moors were never covered by the Devensian glacial ice-sheet and thus never subject to major glacial erosion and deposition (Hemingway 1982), it follows that the topography and soil type of those areas are closely dependent upon the underlying solid rock geology. The geology of the North York Moors has been reviewed in detail by Hemingway (1974, 1982), and the surface distribution of the major rock types is shown in figure 2.

To the west of the North York Moors upland are lowland areas composed of Triassic Bunter Sandstones and Keuper Marl, now mainly masked by a covering of glacial drift, and fringing the area on the south is the Cretaceous Chalk of the Yorkshire Wolds. The upland itself is composed of rocks of the Jurassic System, the earliest of which are termed the Lias and comprise soft clays, shales and limestones. Liassic deposits of the Lower Jurassic are exposed primarily to the western side of the upland, but also appear in the lower parts of the dales and at the coast. The Central Watershed area, and indeed the bulk of the moorland area of the North York Moors, is composed of rocks of Middle Jurassic age consisting of a succession of sandstones and shales of probable deltaic origin which are termed the Ravenscar Group. The resilient nature of these deposits has protected the softer Lias beneath and allowed the central area to assume its present topography. Of particular significance in this respect is the Scarborough Formation (Grey Limestone Series) which is composed of shales, silty sandstones, ironstones and impure limestones and forms the topmost deposit across most of Egton, Rosedale, Glaisdale and Danby High Moors on the central summit plateau, although capped on occasion by the Moor Grit, a massive, strongly-bedded quartzite. These Middle Jurassic strata have moulded the topography of the central North York Moors. Upper Jurassic rocks, mainly Calcareous Grits and Oolites, known as the Corallian Series, are exposed in the southern parts of the Moors and the Cleveland Hills, and are responsible for the imposing escarpment which delineates the moorland area. The latest Jurassic deposit in the area is the Kimmeridge Clay, which underlies the alluvial veneer of the Vale of Pickering.

The present structure of the North York Moors was established in mid Tertiary times by major earth movements, uplift of the Jurassic strata creating a series of gently folded anticlines and synclines. It is this Tertiary uplift which is responsible for the character of the Moors, including the pronounced eastwards tilt of the region. The major folds are modified by a number of minor folds with a north-south axis and these have had the effect of converting what was hitherto essentially an east-west drainage pattern to one which is radial in nature, dissecting the main massif on the upland with the lowland dales. The structure established by the uplifting and folding processes was subsequently modified during the remainder of Tertiary time by a gradual denudation of the upland, all deposits of Tertiary age being removed entirely and the uplifted Jurassic block being reduced to its present subdued topography. Major planation surfaces may be recognised on the Moors (Gregory 1962, Hemingway 1982) which form stages in this process of erosion. The highest is termed the Summit Surface at above 400 metres, below which is the High Moors Surface which is considered to lie between 350 and 390 metres O.D. Very gentle gradients are the main feature of these surfaces, producing the relatively flat plateau landscape which is responsible for the essential character of the Central Watershed area. Glacial drift deposited by the ice-sheets girdles the upland to the north and west to heights of up to 200 metres O.D. Along the coast drift rises to 150 metres and extends across the entrance to the Vale of Pickering. Drift, however, does not cover the Central Watershed, nor is it present in the Valleys to the south, although it does appear in Eskdale and Glaisdale to the north. It seems, therefore, that the central upland area of the Moors remained unglaciated, above the level of the ice sheet, throughout the last glaciation. Extreme periglacial conditions would, however, have caused some erosion due to solifluction processes. Indeed, solifluction deposits occur in a number of locations upon the Moors, although quite thin in the higher areas (Hemingway 1982). The absence of ice cover has allowed the distinctive flat topography of the Central Watershed to persist.

3.4.3. Soils

Poor, acid soils predominate upon the high areas of the Moors, having been subject to a high degree of podsolisation. There is great homogeneity of soil type upon similar rock strata within the area (Anderson 1958) and it would seem that other variations which occur are the result of topographical factors. This apparent dependence of soil cover upon rock type has prompted the suggestion (Jacks 1932) that podsolisation and acidity may have been the natural characteristics of soils in the upland parts of the Moors throughout the post glacial period. More recent studies (Dimbleby 1952a, 1952b, 1954) have shown however, that brown earth soils once existed upon the upland areas of the Moors, supporting natural forest vegetation, and that the present podsol soils are in fact degenerated acid brown earths. Buried soils of brown earth type have been discovered sealed beneath Bronze Age barrows upon the high Moors (Dimbleby 1962), their pollen content showing that woodland conditions once prevailed in areas now dominated by heath.

Throughout the North York Moors region it would appear that topography, and consequently drainage, is the regulating factor which determines soil development in any particular area, with the general nature of the soil established by the underlying rock type. Where sandstones are the parent material, for example within the Ravenscar Group of the higher plateaux, drainage is free and leaching is rapid, so that stagnopodsols of various types are common, with lithomorphic rankers lying directly upon sandstone bedrock. Heavy clay soils, characteristically brown earths, exist in the valleys where the softer Liassic rocks are exposed, contrasting strongly with the acid soils of the adjacent high moors. Some variety does exist within the upland acid soils, however, due to differences in drainage and lithology. Carroll and Bendelow (1981) recognise three main soil units on the high plateaux. The first occurs on the shales and mudstones of the Ravenscar Group around the edges of the Central Watershed and comprises a strongly acid, impermeable, clayey stagnohumic gley soil. Stagnogley -podsols occur around sandstone outcrops in this soil unit, which has a peaty or humic surface layer.

The second plateaux unit occurs upon the sandstone rocks of the Central Watershed and comprises podsols and stagnopodsols. The latter typically have a peaty topsoil with an ironpan horizon. Podsol soils have a bleached upper mineral horizon due to heavy leaching, with free drainage over a nutrient-poor sandstone bedrock. Where some drainage impedence occurs, gleying of the soil profile leads to the formation of humic stagnopodsols. The third major unit occurs on flat areas or in depressions having surface organic horizons greater than 40cm in depth. The limestones, shales and sandstones of the Scarborough Formation support mainly organic soils, especially those of the raw peat type which consist of blanket peat of a fibrous or amorphous consistency. They are derived from oligotrophic plant communities and are thus highly acid. Such soils have also formed over basin peat on the Central Watershed plateaux.

The distribution of organic soils, and particularly of deeper basin peat deposits, on the Central Watershed has been described by Cundill (1977). A number of separate centres exist, usually associated with depressions around spring heads on the flanks of the watershed itself. Glaisdale Moor, Egton Moor, Danby Moor and Westerdale Moor in the central area support such centres, where peat depth may exceed four metres. On the eastern moors similar areas exist at May Moss and Harwood Dale, while in the western moors large areas of deep peat are known on Urra Moor, Arden Great Moor and Bransdale Moor. Other areas contain smaller deposits of deep peat. Upland basin peats often have wood remains within the profile and at the base, while the shallower blanket peats which cover the watershed, and connect the basin areas, in general do not. Basin peats rest upon fossil soils, minero-organic deposits or solid rock and usually comprise amorphous and woody peats overlain by cotton-grass and sphagnum bog peats. There is also Flandrian II peat recorded in glacial meltwater channels, termed 'slacks' or 'swangs' in this area, at high altitude. This age is confirmed by pollen analysis (Simmons 1969c) and by radiocarbon dating of basal samples from a channel mire on Fylingdales Moor (Shotton and Williams 1973) which yielded dates of 7230±130BP (Birm-315) and 7070±130BP (Birm-316).

3.4.4. Present vegetation

Although some afforestation is taking place on the edges of the upland plateaux, almost the entire surface of the Central Watershed is covered by an homogeneous heath community, within which heather is almost entirely dominant. This Callunetum community is artificially managed for grouse, its dominance maintained by repeated, controlled burning which promotes fresh heather growth. Occasionally accidental fires occur which can devastate large areas of moorland, with regeneration very slow to occur. Much of the eastern Central Watershed has suffered heavy damage in this way in recent years, and much remains covered with scorched peat and regenerating moss or grass vegetation. Variations in the *Callunetum* occur which correspond to peat depth and wetness. On the wetter deep peats *Erica tetralix* and *Eriophorum* may be common, with some *Sphagnum* and *Juncus* in spring-head flush situations. On shallower peats, especially on rockier ground over sandstone, *Vaccinium* may be important. *Pteridium* may challenge the heather for dominance in areas of freer drainage, particularly in the steeper slopes of the plateau edge, but in general heather moor is the characteristic present vegetation of the watershed area.

3.4.5 Flandrian II Chronology and Vegetation History

The timing of the environmental changes and the development of vegetation communities which took place in the upland North York Moors during the mid Flandrian are quite well known as a result of a number of research publications (e.g. Simmons 1969a, Simmons and Cundill 1974, Spratt and Simmons 1976, Jones 1978, Jones *et al*. 1979, Atherden 1979, Simmons and Innes 1982, Innes and Simmons 1988). Comparison of pollen profiles from throughout Britain (Birks *et al*. 1975, Huntley and Birks 1983) shows that the pollen record for the North York Moors has shown little deviation from the general southern British pattern which is applicable as far north as central Scotland (Godwin 1975) beyond which forest history is rather different. Within the overall pattern, however, smaller scale changes would certainly have existed between the North York Moors and other regions, and within the North York Moors itself, due to environmental factors such as soils, topography and climate. Thus, even in mid Flandrian I, there was an altitudinal difference in vegetation patterns, for while the deciduous trees Ulmus and Quercus appear at this time in the lowland areas, within a closed forested environment, they are almost absent from sites at higher altitude, for example May Moss at 244m O.D. (Atherden 1979). The boreal forest was of contrasting types, with Betula dominant in the lowlands but Pinus, with Corylus/Myrica, more important at altitude. When pollen spectra become available for the upland plateaux, near the end of Flandrian I at Glaisdale Moor, at 372m O.D. (Simmons and Cundill 1974) they confirm this contrast. Pinus and Corylus/Myrica were dominant in an open woodland with few deciduous trees, and with heather and herb values suggesting the existence of open areas. At the same time a dense oak-elm-birch forest dominated the lowlands, with Alnus becoming significant and little evidence of breaks in the forest cover. An intermediate situation existed at mid altitude, where high tree pollen values indicate a continuous tree cover, but of greater openness and diversity, with pine, hazel and oak in a mixed woodland.

The major interest of this thesis, however, is with the Flandrian II chronozone, the period of maximum extension and development of closed 'Mixed Oak' forest (Simmons and Tooley 1981) mainly comprising the deciduous broadleaf trees Quercus, Ulmus, Alnus and Tilia. The beginning of Flandrian II is defined by the rise to high pollen frequencies of Alnus which unfortunately is radiocarbon dated at only one site in the North York Moors, West House Moss (Jones 1977), as 6650±290BP (Gak-2706). This is a late date with a high standard deviation value compared to dates for the same feature from other areas. In the Tees basin to the immediate north of the North York Moors it is dated to 6962±90BP (SRR-103) at Neasham Fen (Bartley et al. 1976) and in Lancashire it is dated to 7107±120BP (Q-916) at Red Moss (Hibbert et al. 1971). Around 7000BP has been generally regarded as the norm for the rise of Alnus, but Smith and Pilcher (1973) have shown the event to be diachronous and the rather later date from West House Moss does seem compatible with other dates from upland northern England. Chambers (1978) reports the Alnus rise as occurring after 6779±75 BP (SRR-95) at Valley Bog in upper Teesdale. Very late dates have been recorded from the north Pennines, such as 5300±40BP (SRR-1412) from Pow Hill (Turner and Hodgson 1981), and at Quick Moss (Rowell and Turner 1985) the Alnus rise occurs well into the fifth millenium before present. The late date for the Alnus rise in the North York Moors is therefore consistent with the pattern for upland northern England as a whole.

At the start of Flandrian II closed, deciduous woodland was established upon the lowland plains of the area (Jones 1976b) with Ulmus, Quercus, Tilia and Alnus the major components. Upon the uplands of the North York Moors, however, Quercus and Corylus/Myrica appear to have been the major dryland trees, with Alnus in the damper situations. Tilia was not greatly important until late in the period, with Ulmus consistent but in moderate amounts. Pinus seems to remain an important woodland constituent in the uplands during early Flandrian II, and does not disappear entirely at lowland sites. The highest plateaux of the Moors appear to have carried only light woodland in Flandrian II and substantial values for Calluna and Pteridium, with woody taxa Corylus/Myrica, Betula and Pinus possibly referable to scrub rather than true woodland, suggest that open areas were maintained. Indeed, non-tree pollen values are high enough at upland sites like Loose Howe and White Gill (Simmons and Cundill 1974) to suggest that the highest areas may not have carried woodland at all, but merely a belt of scrub or grass-heath referred to as the 'hyper-forest' zone by Simmons (1975a, 1975b).

A well defined fall in elm pollen frequencies marks the end of Flandrian II, and in the uplands of north east Yorkshire the limits of this chronozone are defined (c.f. West 1970) by two radiocarbon dates; 4720±90BP at Fen Bogs (T-1084; Atherden 1976) and 4767±60BP at North Gill (BM-426; Burleigh _et_ _al_. 1976). These dates are late when compared to elm decline dates from regional type sites from northern England at Din Moss (5390±70BP, Q-1063; Hibbert and Switsur 1976) and Red Moss (5010±80BP, Q-912; Hibbert _et_ _al_. 1971). Lowland areas adjacent to the North York Moors also show early dates, as in the Durham lowlands at Mordon Carr (5305±55BP, SRR-475; Bartley _et_ _al_. 1976). The Pennines, however, have similarly late elm decline dates (4794±55BP, SRR-91; Chambers 1978) suggesting a dichotomy between upland and lowland for the date of the Flandrian II-III transition. It would appear (Simmons and Innes 1982) that there was considerable internal variation within the North York Moors' mid Flandrian forest communities. While it remains very likely that much of the land surface was indeed occupied by tracts of close-canopied deciduous forest, in numerous locations vegetation successions had been arrested or deflected so as to deviate from this model while in others environmental factors were such that a situation of steady-state, thermophilous broadleaf forest was never achieved. A mosaic of local and sub-regional communities therefore existed, and it remains to consider to what degree this floristic diversity was of natural origin or the results of ecosystem disturbance by human populations.

3.4.6 Flandrian II Forest Disturbance

Pollen data interpreted as connecting Mesolithic man with vegetation change were reported by Dimbleby (1961, 1962) in his analysis of soil profiles from the highest parts of the North York Moors. He investigated the pollen content of mineral soil from immediately below a microlithic flint site at White Gill, on Westerdale Moor, at which charcoal was associated with the cultural remains. The proportion of non-tree pollen to tree pollen in this sample was only 39%, indicating that the landscape of the area prior to the Mesolithic occupation had been densely wooded. In the pollen sample from above the occupation layer, however, this ratio had increased to 104%, while birch, hazel and heather pollen had increased in frequency at the expense of mixed-oak forest trees. A more open type of woodland had come into being around the site and the juxtaposition of charcoal, flints and pollen evidence of floristic change suggested that the activity of Meolithic man may have been responsible.

A particularly well defined pre elm decline disturbance event was described by Simmons (1969a, 1969b) from North Gill on Glaisdale Moor, which is in a similar situation to White Gill on the Central Watershed plateau of the North York Moors. Simmons reported a basin peat profile which incorporated a thick, basal charcoal layer containing a pollen assemblage remarkable for a large ruderal herb component, including Artemisia, Rumex, Urtica, Senecio, Chenopodiaceae, Taraxacum-type and Plantago lanceolata. Frequencies for Quercus and Alnus were very low, while trees and shrubs likely to be encouraged by opening of the forest canopy were increased, including Salix, Prunus, Fraxinus, Corylus/Myrica and Betula. Taxa favoured by fire clearance were well represented during this phase of disturbance, particularly Melampyrum, Pteridium, Corylus/Myrica and Pinus. In addition, basal peat layers were formed largely from the moss Polytrichum, a coloniser of newly burned ground. This disturbance event was radiocarbon dated to 6316±55BP (BM-425; Burleigh et al. 1976). Simmons noted fluctuations of a similar nature towards the end of Flandrian II at a point in the profile where a fine silt and charcoal layer occurred, suggesting a recurrence of environmental disturbance. Recent re-examination of the site has confirmed this (Innes 1981).

Evidence of Flandrian II pollen fluctuations indicative of woodland disturbance comparable to that described from North Gill has been recorded from several other sites in the North York Moors. The location of all such sites is listed in Table 1, together with their geographical characteristics. Most of the sites have been discussed in detail elsewhere (Simmons and Innes 1982, Innes and Simmons 1988) and so only a brief review of the evidence will be undertaken here. Jones (1976b) records a phase in early Flandrian II at Seamer Carr in the north west of the study area. The stability of the broadleaf forest surrounding a small lake was apparently disturbed, with heliophyte taxa increasing their pollen representation. Peaks of *Corylus*/*Myrica*, *Pteridium* and *Pinus*, and the beginning of a constant *Fraxinus* presence, combine with the appearance of *Artemisia*, *Plantago major*, *Rumex*, Cruciferae and Compositae to suggest the creation of open ground and scrub communities not far from the lake. Similar evidence has been reported by Tooley *et al*. (1982) from a neighbouring part of the same site, where skeletal remains of *Cervus elaphus* (red deer) were stratified in organic sediments at a level where considerable disturbance of the vegetation was recorded in the pollen spectra. Radiocarbon evidence has shown the deer bones to be of post elm decline date, and thus unconnected with the pollen evidence of disturbance. Sediment containing the latter has been dated to around 7360±120BP (Birm-882). *Post mortem* sinkage of faunal remains seems to have occurred. The vegetation disturbance is correlated with the transition between Flandrian I and II and is characterised by the appearance of open habitat types, Plantago lanceolata, Pteridium, Stellaria, Artemisia and Rosaceae, and the rise in frequency of Corylus/Myrica, Fraxinus and Calluna at the expense of tree pollen.

Recent work at Seamer Carr, in the Vale of Pickering not far from Star Carr, by Cloutman (1988) shows major disturbance of the local vegetation at the transition between Flandrian I and II. A thick band of charcoal occurs at the level of the Alnus rise, together with pollen of grasses, Melampyrum, Artemisia, Rumex, Compositae, Potentilla and Filipendula. Tree and shrub pollen frequencies fall at this level. Similar evidence has been recorded by Innes (unpublished) at nearby Flixton Carr.

The Flandrian II deposits at Ewe Crag Slack (Jones 1978) record two episodes during which reductions in tree pollen values, primarily Quercus and Alnus, are coincident with the introduction of herbaceous indicators of cleared ground, in particular Melampyrum and Artemisia. Pteridium and heliophyte shrubs were also encouraged, with expansions in frequency for Corylus/Myrica, Salix, Sorbus and Fraxinus reflecting a more open woodland. Inwash stripes of mineral material occur at the level of the pollen fluctuations.

Similar phenomena are recorded from Fen Bogs (Atherden 1976) and West House Moss (Jones 1977) where dislocation of woodland ecosystems and the creation of open areas are represented by an increased contribution of ruderal and regeneration types to the pollen assemblage, accompanied by the deposition of charcoal and silt inwash in the mire. Two drainage channel mires were investigated by Simmons (1969a) both of which showed indications of minor opening of the forest prior to the elm decline. At Lady Bridge Slack a phase occurs during which tree pollen values fall, mainly because of a marked diminution of Alnus frequencies, although Pinus and Fraxinus are temporarily increased. Peaks of Melampyrum, Rumex, Plantago major-type and Pteridium were recorded, together with a Salix maximum at one level. An equally well defined phase of disturbance occurs at Moss Swang, where Melampyrum enters the pollen record for a single level at 87% of tree pollen. Quercus and Alnus are again the taxa subject to clearance, with Betula, Corylus/Myrica, Fraxinus, Rumex, Chenopodiaceae and Taraxacum-type all increasing in frequency. The intensity of this woodland disturbance is analogous to that from Tranmire Slack in mid Flandrian II (Jones 1978) where on two occasions the local deciduous woodland was apparently removed, allowing a wide range of ruderal herbs to contribute to the pollen record, including those listed above, and with the addition of Plantago coronopus, Epilobium and Plantago lanceolata. Peak values of Pteridium, Corylus/Myrica, Fraxinus and Gramineae occur, and an inwash stripe of mineral material again accompanied clearance.

Similar evidence is forthcoming from several sites at high altitude on the summit plateaux of the North York Moors, in addition to those at North Gill and White Gill described above. A sequence of such disturbance in mid and late Flandrian II has been recorded from around the headwaters of Collier Gill (Simmons 1969a, Cundill 1971) in each case stratified with charcoal fragments. The lowermost phase corresponds to the onset of peat formation and has been radiocarbon dated to 5504±108BP (BM-427; Burleigh et al. 1976). Each phase records reductions in tree pollen frequency and the expansion of a typical suite of post-fire indicators, Corylus/Myrica, Melampyrum, Pteridium, Rumex, Artemisia and Salix. In the light of these investigations, fluctuations in the pollen record published by Erdtman

(1927, 1928) with a replacement of *Quercus* and *Alnus* by *Corylus*/*Myrica*, may also be interpreted as forest disturbance effects.

Other examples of Flandrian II woodland clearance in an upland context have been described from May Moss (Atherden 1979), Trough House (Cundill 1971), Glaisdale Moor and Loose Howe (Simmons and Cundill 1974) and Bonfield Gill Head (Simmons and Innes 1981, 1982). Simmons and Cundill (1969) have re-examined Dimbleby's site at White Gill, confirming his general conclusions. Further profiles at North Gill, and new sites at Bluewath Beck Head, Botany Bay and Small Howe, have also revealed clear disturbance evidence of this type (Innes 1981). In each case the familiar pattern of charcoal, sometimes with mineral inwash, combined with the introduction of a variety of heliophyte herb and shrub pollen to the assemblage and a fall in tree pollen values, was observed. These upland sites are located either by spring-heads at the edge of the central watershed, or within localised depressions in the summit plateau itself. At Bonfield Gill Head a sequence of three Flandrian II disturbance and recovery phases culminated in an elm decline horizon which contained *in situ* tree stumps, dated to 4890±80BP (Har-4229), indicating recolonisation of woodland on the site at the time of the elm decline. The charcoal deposition history at the site was such that (a) both large pieces and microscopic particles had accumulated in the profile during fire-disturbance phases in Flandrian II, and (b) a reduced but significant microscopic fraction occurred in Flandrian II non-disturbance phases, yet charcoal was not present above the elm decline. Taking the tree-stump evidence into account, this suggests that regular burning of the vegetation took place both locally and regionally around Bonfield Gill in Flandrian II, but ended at the elm decline, allowing the establishment of forest trees in a locality previously kept open by the recurrent presence of fire. The sudden removal of fire as an ecological factor from the landscape of this part of the upland, following its repeated presence, suggests that a natural cause for the ignition of these fires was much less likely than a human one. Pollen evidence of disturbance is correlated very strongly with the abundant presence of charcoal in the profile, and two of these disturbance phases are dated to 5670±90BP (Har-4225) and 5170±90BP (Har-4226). The repetitive nature of the forest disturbance at Bonfield Gill Head has been recorded from a number of upland Flandrian II sites (Table 1) and has been discussed by Simmons and Innes (1985).

In summary, the North York Moors is a most prolific area for evidence of Flandrian II forest disturbance, especially in the upland where the evidence is clearest at sites like Bonfield Gill Head and North Gill.

3.4.7 Flandrian II Archaeology

The archaeological evidence for the North York Moors during Flandrian II belongs to two main cultural traditions; the latter part of the Late Mesolithic and earliest, pioneer phase of the Neolithic (Spratt 1982). The Later Mesolithic is represented upon the North York Moors by sites with a geometric microlithic assemblage, characteristic of the 'narrow blade' tradition recognised by Radley *et al.* (1974) for the Pennines and applicable throughout Northern England for the period following *c.* 8600BP (Switsur and Jacobi 1979). Microlithic assemblages are dominated by narrow rod-like points, by small triangular shapes or by trapezes. Although rods appear to be the main microlithic type in the study area, triangles are by no means uncommon, and are actually dominant at the site of Cock Heads (Radley 1969). It would appear that a regionally homogeneous industrial tradition existed at this time, although the increased range of implement shapes in the Late Mesolithic has caused some degree of variation between individual sites. A further difference in this later period is in the great increase in the actual number of sites recorded, the great majority of which occur on the high plateaux of the Moors, clustering around spring-head locations. Their assemblages reveal a very high ratio of microliths to other tools and clearly they represent small, temporary hunting camps where the taking of game, and thus the use or manufacture of projectile points, was the primary function. A number of these sites have been fully excavated. The sites at Farndale Moor and White Gill are fully discussed by Radley (1969) while other recent studies are those of Clarke (1973) at Peat Moss on Bilsdale Moor, and of Jacobi (1978) at Cockayne Ridge, on Bransdale Moor. While microliths are found throughout the moorlands, certain areas are especially prolific, particularly East Bilsdale, Westerdale, Farndale and Bransdale Moors. A second type of Later Mesolithic site has been recognised from lower altitude on the edges of the upland, as at Upleatham, with a less microlith-dominated assemblage which suggests a different function to that of the high altitude hunting camps (Spratt and Simmons 1976, Spratt 1982), with a high proportion of scrapers represented. The adoption of geometrically shaped microliths may have been a response to new requirements for food procurement in the Late Mesolithic forested landscape, since these tools could presumably have been hafted to form a wide variety of projectiles for hunting, as well as cutting tools for plant gathering (Clarke 1976). Narrow blade geometric microliths continue to dominate flint assemblages, particularly in the uplands, until the end of the Mesolithic, and an approximate date for the termination of this kind of microlithic assemblage, and thus for sites of 'pure' Mesolithic culture, is provided by the date of 5380±80BP (Q-799) at Dunford

Bridge B in the Pennines (Radley _et al_. 1974), although it is quite possible that Mesolithic cultures persisted beyond this time. The date of the Late Mesolithic - Neolithic transition in the North York Moors is as yet uncertain although it may be presumed to have occurred during the final part of Flandrian II and was probably a gradual process. The earliest radiocarbon date for Neolithic cultural remains is 5040±90BP (NPL-73; Spratt 1982) from East Ayton long barrow, which precedes the upland dates for the elm decline in this area by a few centuries. Whether or not Late Mesolithic groups were replaced by or coexisted with Neolithic groups at this time is not known. As noted above, however, radiocarbon dates for Flandrian II cereal pollen records in northern England (Simmons and Innes 1987) would suggest a considerable period of overlap, if cereal records must be defined as representing Neolithic settlers. Spratt (1982) points out that Neolithic flints have been found on several Mesolithic sites in the North York Moors, although unstratified. Occurring at both medium and high altitude, these sites may suggest a degree of continuity and coexistence in the occupation of the study area during the Mesolithic - Neolithic transition. The Neolithic flints are almost exclusively of arrowhead type on the upland Mesolithic sites, but include both flints and axes on the lowland sites. There has been no Neolithic pottery found on Mesolithic sites in the North York Moors. Selected archaeological sites for the North York Moors are shown on figure 3.

CHAPTER FOUR

NORTH GILL - THE STUDY SITE

4.1 Introduction

From the foregoing descriptions of the research topic and the study area of the North York Moors, and based upon the criteria necessary to meet the research aims of this thesis, the site of North Gill has been selected as the study site at which to test the resolution limits and ecological potential of multi-profile FRPA. Both North Gill (Simmons 1969a, Innes 1981, Simmons and Innes 1988a, 1988b) and Bonfield Gill Head (Simmons and Innes 1981, 1988c) show strong evidence of multiple phase late Flandrian II forest disturbance. The latter site has been rejected, however, because the abundance of wood fragments in the profile could prevent sampling for FRPA at critical levels, and because the site is considerably smaller than the North Gill basin and thus less suitable for multi-profile work.

North Gill (NZ726007) is located upon Glaisdale Moor (Figure 4) and lies within an upland basin peat area which surrounds the spring-head of the North Gill stream at altitudes around 370m O.D. The peat infill of this basin is relatively shallow, being two to three metres in most areas, although more than four metres occurs in places. The previous study of the site has shown that the basal metre of sediment contains charcoal layers, mineral inwash bands, wood remains and a variety of peat types, all of which show spatial variability in dimension and composition across the site. Since clear pollen evidence of disturbance exists at the site, it is likely that some of these stratigraphic units result from the effects of that disturbance. The range and quality of ecological evidence preserved at North Gill suggest that the site will prove most suitable for more detailed study by multi-profile FRPA; investigation of the succession of vegetation changes near different parts of the site might clarify the size, intensity and spatial distribution of the effects of forest clearance. It is first necessary to demonstrate that the litho- and pollen stratigraphic records at North Gill are capable of correlation across the whole site, and thus of replicable multi-profile FRPA.

4.2 Lithostratigraphy

The lithostratigraphy of North Gill was investigated by the close inspection of stream-side peat faces and by a series of borings taken along a grid of lateral and longitudinal transects across the site around the North Gill stream (Innes 1981, Simmons and Innes 1988a). These transects extended 375m downstream and 90m across the stream and as all boreholes were levelled and their depths and strata recorded, it was possible to calculate surface topography, peat depth and sub-peat topography across the area (figure 5). All details are contained in Innes (1981). Significant features are that peat depth is greater at the top of the stream, near the spring-head itself, and that erosion has been such that peat has been removed or severely truncated in parts of the stream valley, between transects B-C, G-H and L-M, which are likely to have formed early situations for peat inception. Inspection of peat profiles exposed by the stream allowed study of lateral changes in the gross stratigraphy, and it appeared that two main charcoal layers existed at North Gill, the upper one often accompanied by a silt layer, although at some points the situation was confused by distortion and sub-division of the layers, or by their absence presumably due to erosion.

Additional boreholes have been taken over two hundred metres to the west of the stream and have recorded peats of over three metres depth at that distance. The North Gill basin peat deposit was for much of its history probably confined to the immediate valley of the stream. The new boreholes have also defined the limits of the two charcoal layers in the area of the stream, and these are shown on figure 6. Discontinuities in these distributions are probably erosion effects. The two charcoal distributions are broadly similar, with the upper charcoal perhaps a little more concentrated towards the western part of the site.

Synthesis of the borehole and section data made possible the recognition of nine strata which, although varying substantially across the site, are sufficiently distinct to be regarded as lithostratigraphic units applicable to the site as a whole, and useable as markers to assist spatial correlation of pollen profiles. These are shown in figure 7, numbered consecutively from the base of the succession and given the designation NG-L.

<u>Unit NG-L1 Solid Rock</u>

The solid rock of the Ravenscar Group is the basal lithostratigraphic unit which is subjacent to the basal organic strata at certain parts of the site, most particularly at point 4B, 4J and 4N upon figure 5. These are situations of steeper slopes and it is likely that the exposure of the bedrock has followed removal of mineral soils by erosion. Where observed, the sandstone is fractured and decomposing, contributing a rotting 'ranker'-hardrock foundation. Impure limestones of the capping Scarborough Formation form the solid rock base north of transect L.

<u>Unit NG-L2 White Clay</u>

Over much of the site, and especially within the lower stream channel, bedrock is covered by several centimetres of stiff, white clay containing occasional angular fragments of sandstone derived from the underlying stratum. This clay does not extend far from the stream channel and underlies the mineral soil at this site. It is interpreted as a solifluction deposit derived from the surrounding slopes during the severe periglacial conditions of the Late Devensian period (Hemingway 1982).

Unit NG-L3 Mineral Soil

A sandy, yellow-orange, mineral material is the pre-peat land surface over most of the site, and this is considered to be a fossil soil profile. Where the hillslope is shallower the upper levels of the soil grade into a minero-organic material, although at other points, mostly where slopes are steeper, a sharp break may be seen between pure sandy soil and the supervening biogenic strata. In the flat 'basin' areas of the stream channel, inclusions of wood (mainly Alnus) and organic material, including charcoal pieces, occur in the upper soil profile, suggesting that at least the upper layers may not be in situ but transposed by water action. Rounded quartz pebbles are often to be found in the soil. Iron staining is prominent within the profile, and the mineral soil appears to be a well-leached acid stagnopodsol. A friable structure of large coarse mineral particles is consistent across the sampled area, varying little with depth, which is at no point very great. Sandstone fragments often occur in the lower levels. Where the soil rests upon white clay, the clay-soil interface is at all points sharp and well defined.

Unit NG-L4 Lower Charcoal

A basal charcoal layer is identified as the first post-soil deposit at North Gill. It is thickest in the flat 'basin' areas of the stream channel where it occurs as a charcoal-organic stratum of up to six centimetres in depth. Analysis of the charcoal shows a mixture of large, angular pieces and much smaller smooth, rounded, micro-fragments, the former considered to be indicative of rapid introduction from close by, through inwash or mass movement, and the latter perhaps of wind transport. In the lower part of the site (points 4K to 4Q on figure 5) the charcoal horizon is associated with charred wood pieces, mainly Alnus, and contains a high mineral fraction, occasionally forming silt lenses, indicating that burning of woodland and some soil instability was coincident with this onset of biogenic accumulation. Fingers of charcoal and silt intrude into the underlying soil and these are interpreted as occupying old root channels. There appear to have been three main centres of deposition along the stream channel, with a maintenance of thickness towards the western part of the site, and a rapid attenuation of the layer to the east. The deepest deposits are those found in isolated depressions in the stream channel where conditions for accumulation were at their best. The charcoal layer as a whole extends for some distance to the west (figure 6).

Unit NG-L5 Amorphous Peat

The lower charcoal horizon is everywhere covered by a variable depth of dark brown amorphous peat, which thus forms the basal deposit on areas where the charcoal is absent, in particular on the eastern part of the site. It is at its thickest in the centre of the sampled area, between transects E and M, where it reaches up to 75cm depth, but thins out markedly towards the northern extremity of the site. Although its internal structure is quite amorphous, in places it incorporates large pieces of wood, some of which exhibit signs of charring and are evidently detrital in nature. The great majority are Betula or Alnus with occasional Salix and Corylus. Tree trunks of a diameter greater than 30cm occur, some Betula wood pieces appear to be of root material, rather than branches, and tree stumps occurred in the peat at the lower end of the stream. The upper part of this peat is very well humified and apart from the wood little macrofossil presence was recorded within it. It did include, however, speckles of charcoal dust at intervals, of small size and evenly distributed across the site. At the base of this amorphous peat, a Polytrichum moss peat recorded by Simmons (1969a) was recognised between transects H and J. Only a small area was found and the layer may have been partly removed by erosion since the earlier investigation. It appears to be represented only on, and westwards of, longitudinal transect 4, and is not recorded to the east of the site. Little charcoal content was recorded within it. Its stratigraphic relationship to the basal charcoal horizon is unclear; near the stream channel exposures it seems to underlie the charcoal, yet away from the stream to the west and in some places by the stream it is clearly stratigraphically superior to the charcoal deposit. It could well be that two different moss peat deposits exist, which predate and postdate the charcoal respectively.

Unit NG-L6 Upper Charcoal

At the upper border of the amorphous peat a second charcoal layer occurs which is much thinner than the basal charcoal horizon and nowhere attains more than three centimetres in thickness, generally being little more than one centimetre. It resembles the basal layer however, in being most persistent to the west (figure 6). The charcoal particles are in almost every case very small, although abundant, and the large jagged pieces characteristic of the basal layer are absent. A thin layer of charred birch bark fragments rests upon and within the charcoal at several places. The fire responsible for this charcoal layer may therefore have occurred further away from the sampling site with fewer of the resulting fragments capable of incorporation in the bog without comminution.

Unit NG-L7 Silt Inwash

Immediately superior to the upper charcoal layer is an inwash stripe of mineral material. It is thickest at transects G and H, and is not recorded above transect E. While thickest in mid-site, the mineral layer is here incorporated within an organic matrix, which includes tiny fragments of charred birch bark. The inwash stripe is, although thinner, much more discrete to the south of the site and is composed almost entirely of coarse sandy particles, which may be evidence of sorting and washing during transport downstream. Below transect Q, where the profile gradient increases suddenly, this stratigraphic unit is no longer recorded. If it ever existed further downstream, it has been removed with the peat overburden by recent erosion. The silt layer is confined as a discrete stratigraphic unit to transect 4, and deposition of the inwashed material evidently took place predominantly in the centre of the stream channel, particularly in areas of low gradient.

Unit NG-L8 Humified *Eriophorum* Peat

The succeeding stratigraphic layer is well humified peat with a macrofossil component of *Eriophorum*, particularly in the lower layers. This completely covers the site and increases in thickness towards the north, reaching 2.4 metres at transect C and above. In its upper layers it includes silt horizons which are prominent on parts of the site, but these are known to be later in date than the concern of this study.

Unit NG-L9 Fresh *Eriophorum*, *Sphagnum* and *Calluna* Peats

The uppermost biogenic stratum is represented by a poorly humified peat composed mainly of *Eriophorum* and *Sphagnum*, with occasional horizons containing ericaceous fragments and rootlets, mainly of *Calluna*. It increases in thickness towards the northerly limit of the site.

The nine strata shown in figure 7 do vary internally, particularly in macrofossil content and factors such as degree of humification. Also, sometimes their boundary limits are sharp and well defined while at others they are much more gradual in character. Some variation does occur in their dimensions, for the charcoal and silt layers especially vary in thickness and in places appear to be complex in form. For example on occasion the silt inwash stripe appears to be composed of separate smaller silt layers within an organic matrix. Such small scale variation is, however, what would be expected from spatial changes in deposition related to microtopography. The other important stratigraphic components, the moss peats and the wood macrofossil remains, are not continuous but occur in patches on small areas of the site. Their spatial and chronological integrity is therefore not secure, and they cannot be considered to be summary stratigraphic units. With a series of units defined, it is possible to construct a lithostratigraphic conspectus profile for the site, intended to summarise the general sequence of depositional events (figure 7). Unit descriptions and notation follow Troels-Smith (1955). Substantia humosa is used to describe the amorphous organic material of units NG-L4 to L7 rather than Limus at this stage as its mode of origin remains to be established. It would appear, however, that of the post-mineral soil units, NG-L5, NG-L8 and NG-L9 are autogenic, caused by the natural development of the mire, while units NG-L4, NG-L6 and NG-L7 are allogenic and intrusive, caused by dynamic events outside the mire system, and may be used as benchmark horizons for the site.

4.3 Pollen Analysis

In order to prove that the North Gill pollen stratigraphy is suitable for multi-profile FRPA two of the pollen records of previous workers at the site are subject to close scrutiny and their pollen stratigraphies are compared. Firstly the Flandrian II sections of the North Gill 'a' and 'b' diagrams of Simmons (1969a) are redrawn to be compatible with the other pollen diagrams in this thesis, as discussed in chapter two, and are shown as figures 8 and 9. Eight distinct phases are recognised at NGa and two at NGb on the basis of fluctuations in the Quercus pollen curve, with alternating high and low representations of oak pollen percentages. Phases NGa-2, NGa-4, NGa-6 and NGb-1 are therefore considered to represent phases of disturbance of woodland, wherein Quercus pollen percentages are reduced as well as other tree pollen types. Alnus, for example, is present in very low frequencies in NGa-2. Herb and shrub indicators of open conditions such as Corylus/Myrica, Pteridium, Pinus and Melampyrum show enhanced frequencies in one or more of these phases. Phase NGa-8 is also regarded as a disturbance phase due to the fall in Ulmus pollen, shown by a radiocarbon date of 4767±60BP (BM-426), to be the Ulmus decline at the end of Flandrian II. The intermediate pollen phases, during which Quercus frequencies remain high, are regarded as periods of stable, undisturbed woodland.

Secondly, the pollen record from North Gill 3 (Innes 1981) is redrawn as figures 10 and 11, comprising the basal 60cm of peat which correspond to the Flandrian II and Flandrian II - III transition at that site. Seven pollen phases are recognised, again determined by the frequencies shown by the Quercus pollen curve. A very clear Ulmus decline occurs at the beginning of phase NG3-7, which must represent the Flandrian II - III transition. This therefore forms a basis for the correlation of NG3 and NGa. Three phases occur below the elm decline which have sharply reduced Quercus pollen frequencies and NG3-1, NG3-3 and NG3-5 are therefore regarded as phases of woodland disturbance. Again indicators of open conditions Corylus/Myrica, Pinus and Pteridium and several weed types, rise in frequency when Quercus is low. The intervening phases of high oak pollen values and correspondingly low representation of clearance indicators, NG3-2, NG3-4 and NG3-6, are designated phases of stability during which the local oak woodland remained undisturbed.

Correlation of the two North Gill pollen data sets may be made at the Ulmus decline levels in both diagrams, so that the start of phases NGa-8 and NG3-7 forms a time equivalence horizon. These post elm decline phases are referable to the regional pollen assemblage zone 'EGM Alnus - Quercus' of Simmons and Cundill (1974). Earlier phases at each site are referable to regional p.a.z. 'EGM Alnus - Ulmus'. Correlation of the pollen phases of NGa, NGb and NG3 is shown in Table 2, also characterised as of 'd' or 's' type. Three pre Ulmus decline disturbance phases occur in both pollen profiles, followed in turn by phases of stable vegetation, and these are therefore correlated. This correlation cannot be completely certain without a series of radiocarbon dates, but the pollen sampling intervals in each case are relatively small, one or two centimetres, so that it is unlikely that further phases of disturbance have been missed for that reason. Also, the profiles are spatially very close, within a few tens of metres probably, so that the absence from one profile of a major disturbance phase present in the other is most unlikely. There is not evidence for any significant loss of sediment by erosion from any one profile which could cause misinterpretation of the sequence. At the very least, the division of the pre Ulmus decline disturbance history at these sites into three distinct phases seems justified as a working hypothesis. The alignment of the two NGb pollen phases with the earliest of these three episodes is supported by their lithostratigraphic position relative to the basal sediments of NGa. NGa differs from NG3 in having a high Quercus 's' phase before the earliest phase of disturbance at the profile, whereas that disturbance horizon at NG3 forms the basal unit of the pollen stratigraphy. This is easily explained due to variations in the microtopography of the North Gill stream valley, with a slightly earlier date for peat inception at NGa perhaps due to more favourable conditions for organic accumulation there. The stratigraphic presence of moss peats below the basal charcoal layer, as discussed above, would support this conclusion. The high frequencies for Alnus in phase NGa-1 show that the low alder values in the earliest 'd' phases at the sites are the result of localised clearance of alder in Flandrian II, rather than because of a pre Alnus-rise age which the date of 6316±55BP for NGb-1 might just suggest was feasible in an upland context. On the basis of the pollen phase correlations at these three sites, a series of 'S' and 'D' phases from S1 to D4 have been proposed which may be applied to the site as a whole. Multi-profile pollen analysis and FRPA will be used in this thesis to test the validity of this summary zonation scheme for North Gill.

4.4 Numerical Analysis

Since the identification of three disturbance phases at the site relies upon subjective assessment of the pollen data, the pollen spectra from the three correlated profiles have been tested further by subjecting them to numerical analysis, so that the character of the pollen fluctuations and the validity of the zonation may be confirmed by more objective means. PCA was applied to the twenty-five levels of NGa (numbered consecutively 1 - 25 from the top level) and the seven levels of NGb (numbered 26 - 32 consecutively) shown on figures 8 and 9. The thirty-two levels of NG3 shown on figures 10 and 11 (code numbers 33 - 64) were also analysed in this way. The combined data set of sixty-four levels was then subject to PCA. In each analysis only those taxa which exceeded 5% of total land pollen, as listed in chapter two, were included in the analysis. The summary site disturbance zonation S1 to D4 is used to label the PCA diagrams.

The results of PCA on the North Gill 'a' and 'b' (NG1969) data set are presented as figure 12, figure 13 and Table 3. Figure 12 shows stratigraphic plots of the sample scores on the first three principal components. The S and D phases from Table 2 are also shown. The agreement between numerically recognised pollen stratigraphic changes and the original zonation scheme is generally very good. The positioning of zone boundaries and the internal homogeneity of individual zones seem therefore to be confirmed by this technique. Table 3 lists the principal component loadings for each individual pollen type on the first five components. These loadings represent the correlation coefficients between the original pollen variables and the principal components, and so pollen types which have the highest positive or negative loadings on a component are those most strongly to be identified with it. It follows that the loadings may be used to interpret the meaning of the components in terms of ecology and vegetation history.

The first North Gill a and b principal component accounts for 33.81% of the total variance of the data and has high positive correlations with Pinus, Salix, Betula and Ruderal Herbs, and lower positive correlation with Corylus/Myrica. It has high negative correlation with Alnus and lower negative correlation with Quercus. Stratigraphic component plot 1 on figure 12 therefore reflects high counts for pine, willow, birch and ruderals in the disturbance phases and particularly in the phase D1 at both a and b profiles. Their dominance is less apparent in the later D phases and appears not at all in phase D4. High counts for alder occur in the stability phases, and the abundant alder pollen count of mid phase S2 is quite clearly distinguished. The component distinguishes, therefore, between deciduous woodland and herb-shrub seral type communities characteristic of disturbed and regenerating woodland.

The second principal component accounts for 21.0% of the total variance and has high positive correlations with Quercus, Ulmus and Calluna. It has high negative correlation with Alnus. Stratigraphic component plot 2 on figure 12 therefore reflects higher counts for oak, elm and heather in the later phases of woodland stability and higher counts for alder during the earlier woodland stability phases. Little variation is registered on this component in the phases of disturbance at all. The dominance of alder in mid phase S2 is again well shown, but S1, S3, S4 and all the rest of S2 reflect supremacy of oak and elm. This component therefore distinguishes differences in the character of the undisturbed woodland, between earlier, wetter alder dominated woods and generally later oak and elm dominated woods on drier areas. The presence of heather in this latter association suggests a more open character to these later oak-elm woodlands, perhaps on more acid soils.

The third principal component accounts for 17.65% of the total variance and has a high positive correlation with Ulmus and a lower positive correlation with Ruderal Herbs. It has a high negative correlation with Corylus/Myrica. Stratigraphic component plot 3 on figure 12 seems to reflect counts for elm during phases of woodland stability which are rather higher, although not greatly, than in phases of disturbance. In general, elm values do not vary greatly (with the exception of phase D4 within which they are low). The main fluctuations seem to be in Corylus/Myrica, being high in phases of disturbance and low in phases of stability. An exception is in phase D1 at NGb where high Ruderal Herb counts occur, rather than high Corylus/Myrica, producing a positive stratigraphic score plot. Phase D4 clearly represents the elm decline, with Corylus/Myrica increasing as Ulmus falls, although that tendency seems apparent in the later stages of phase S4 also. With no other trees badly affected, perhaps disturbance upon better soils is reflected here.

The fourth and fifth principal components account for only 10.28% and 7.86% of the variance respectively, and so are not plotted stratigraphically on figure 12. Component four has high positive correlations with Betula and Calluna, however, and negative ones with Corylus/Myrica and Ulmus. Component five has a higher positive correlation with Quercus and a higher negative one with Calluna. These two components may reflect differences in soil quality, with areas of open deciduous woodland on drier, less acid soils distinguished from areas where soil acidification had taken place and heathland associations had become established.

The relationship of the individual North Gill a and b pollen levels is shown by their relative positions when the component scores for the first principal component are plotted against those for the second (figure 13a) and third (figure 13b). The levels are numbered according to the code described above, and symbols are used on these and the other PCA plots which refer to the eight S/D phases of Table 2. The two parts of figure 13 show that some grouping of points does occur. Primarily, levels within disturbance phases (shaded symbols) are clearly differentiated from those within stability phases (open symbols), with the exception of phase D4 which plot within the broad group of S phase levels on figure 13a. Variation within this S group is determined largely by the importance of *Alnus* in their deciduous woodland type assemblages, thus levels 15 and 16 (mid phase S2) form high *Alnus* outliers, while the later S4 phase levels have high *Quercus* and low *Alnus*. Phase D4 levels are however, clustered outside the S group of levels on figure 13b, because of component three's correlation with low *Ulmus* counts and high *Corylus*/*Myrica* counts. Little pattern exists within the S group on figure 13b. Some wide divergence between the D group of levels does occur on both these diagrams, and this tends to separate those with high *Corylus*/*Myrica* counts from those with a higher proportion of *Pinus*, *Salix* and Ruderal Herbs.

The results of PCA on the North Gill 3 data set are presented as figure 14, figure 15 and Table 4. Figure 14 shows stratigraphic plots of the sample scores on the first three principal components, and again these show close agreement with the S/D phase zonation. If anything, agreement is better than at North Gill a and b.

Table 4 lists the principal component loadings on the first five components. The first North Gill 3 principal component accounts for 38.19% of the total variance of the data and has high positive correlations with Ruderal Herbs, *Pinus* and *Corylus*/*Myrica* and a low one with *Salix*. It has high negative correlations with *Alnus* and *Quercus* and a lower one with *Ulmus*. Stratigraphic component plot 1 on figure 14 therefore distinguishes the disturbance phases, with high pine, weeds and hazel, from the woodland stability phases, with high alder, oak and elm. The peak values of phase D1 are not matched in phases D2, D3 and D4 because in these later phases pine and ruderal pollen is less abundant and hazel accounts for most of the disturbance-type pollen alone. With alder, oak and elm contributing almost equally to the deciduous woodland component on this plot, little variability exists between stability phases.

The second principal component accounts for 26.16% of the total variance and has high positive correlations with Quercus, Ulmus and Betula. It has high negative correlations with Salix and Alnus. Stratigraphic plot 2 on figure 14 therefore reflects differences in the local composition of the mixed deciduous woodland around the site. Corylus/Myrica and Calluna have lower positive correlations and so the plot recognises drier mixed oak, elm and birch woodland with an admixture of hazel and heather as dominant later in the site's history, especially in phase S4. During earlier S phases local wet alder and willow carr woodland evidently was important.

The third principal component accounts for 17.09% of the total variation and has a high positive correlation with Calluna and a high negative correlation with Ulmus. Stratigraphic component plot 3 on figure 14 shows that very little variation in the pollen frequencies of these two taxa occur for most of the diagram. Increases in Ulmus pollen accounts for slight peaks in earlier D phases. A more significant rise in elm pollen frequency occurs towards the end of phase S4, but a change to high positive scores in phase D4 reflects a sharp fall in elm values, as well as a considerable increase in Calluna frequencies. This significant change, which corresponds to the Flandrian II - III transition decline of elm, is also represented on component plots 1 and 2. The fourth and fifth principal components account for only 9.16% and 4.98% of total variance and so are not plotted on figure 14. No significant correlation exists on component five, but component four has a high negative correlation with

Betula. Highest birch values occur in the D phases and at the end of phase S4, and so may reflect differences in regeneration communities and some extension of heathland associations as soil changes occurred toward the end of Flandrian II.

The relationship of the individual North Gill 3 pollen levels is shown by their relative positions when the component scores for the first principal components are plotted against those for the second (figure 15a) and third (figure 15b). Code numbers and symbols are as described above. Again some clear groupings of levels emerge, and on both parts of figure 15 the shaded disturbance levels are clearly differentiated from the open symbols of the stability levels. On figure 15a, those D phase levels which are categorised by higher Pinus, Ruderal Herb and Corylus/Myrica values are caused to plot further along the x-axis, which is in effect an axis of disturbance intensity, than the main cluster of D phase levels which have Corylus/Myrica peaks alone. As at North Gill a and b, the later D phases seem less clearly pronounced in their disturbance evidence.

Again, as at North Gill a and b, the S phase levels are divided into two clusters; a main group with high Alnus values and a smaller, later group (later S4) with much reduced Alnus. Figure 15b illustrates how much unlike the Flandrian III (post Ulmus decline) levels of phase D4 are to both S and D phase levels of Flandrian II. The Ulmus and Calluna fluctuations which occur in phase D4 account for the high dissimilarity. Within the Flandrian II levels, however, the disturbance and stability groupings remain distinct.

The results of PCA on individual North Gill pollen profiles have shown recognisable groupings to exist within the data, and that these are broadly similar at both sites. It was therefore decided to compare the pollen sequences further by performing PCA upon a combination of the two data sets, and the results are presented as figure 16, figure 17 and Table 5. Figure 16 shows the stratigraphic plots of the sample scores on the first three principal components, as well as the summary S/D phase zonation. Zone boundaries indicated by the PCA method agree closely with those delimited by the subjective zonation scheme, particularly on component one.

Table 5 lists the component loadings on the first five components for the combined North Gill data. The first principal component accounts for 30.79% of the total variance of the data, less than at each individual site, but this is to be expected with a data set twice as large. There are high positive correlations with *Pinus*, Ruderal Herbs and *Corylus*/*Myrica* and high negative with *Alnus*. Stratigraphic component 1 on figure 16 distinguishes between phases of woodland disturbance, with high positive scores, and phases of woodland stability with high negative scores. The second component accounts for 25.57% of the variance in the data, has high positive correlation with *Quercus*, *Ulmus* and *Betula* and high negative correlation with *Salix* and *Alnus*. Stratigraphic component 2 on figure 16 distinguishes between wet (perhaps carr-type) deciduous woodland with high negative scores and drier, mixed oak woodland with high positive scores. The third accounts for 16.50% of variance in the data, has high positive correlation with *Calluna* and *Corylus*/*Myrica* and high negative with *Ulmus*. Stratigraphic plot 3 on figure 16 distinguishes between pre *Ulmus* decline phases, both of stable and disturbed woodland, and post *Ulmus* decline disturbance. The fourth and fifth components account for 8.78% and 7.56% of the variance in the data only, but significant correlations do occur; high positive for *Ulmus* and high negative for *Betula* on component four, and high negative for *Calluna* on component five.

The component scores for the first principal component on the combined data set are plotted against those for the second (figure 17a) and third (figure 17b). The relationship of the points on figure 17 confirms the suitability of the summary S/D zonation scheme adopted for describing the North Gill pollen data. On figure 17a three distinct clusters of points may be recognised. The first is a group with high negative scores on both axes which represent earlier wooded phases with high alder and willow. The second is a group with high negative scores on the first component and high positive on the second, representing later undisturbed mixed oak woodland with lower values for alder. The third is a group with high positive scores on component one and a range of scores on component two, representing woodland disturbance and the creation of seral herb-shrub associations. The four post-elm decline levels form an outlier to this disturbance cluster, lying much nearer the woodland groupings. The distinctiveness of these four levels as a separate group is shown by figure 17b where they are to a greater or lesser degree removed from the other disturbance levels. On this diagram however, the S and D phase levels are quite clearly differentiated. It would seem that, although some clustering of individual pre elm decline disturbance phases does occur, these are not sufficiently different to be reliably separated from other such disturbance phases by this method, although phase D1 does seem to be rather different from D2 and D3.

The PCA has, however, shown that the subjective recognition of the S/D phases for the whole North Gill site and the identification of three D phases below the elm decline is not invalidated at that level of resolution. It remains to be tested at the FRPA level of resolution. PCA has also shown that <u>Alnus</u> is a most variable component of the pollen data set, and accounts for much of the variability between profiles and within deciduous woodland S phases. *Quercus* is shown to be a much more reliable indicator of the presence or absence of disturbance and supports its use as the criterion for defining those phases.

4.5. Location of FRPA profiles

Close examination of the geographical and stratigraphic character of the sediments at North Gill has shown the site to fulfil the criteria required for further investigation by detailed, multi-profile FRPA techniques.

Stratigraphical

Sediments of late Flandrian II age are represented across the site, and the sections cut by stream erosion allow easy selection and recovery of bulk samples. Several lithostratigraphic units are present which occur as whole-site features. Some units are allogenic and can be used as benchmark horizons across much of the site. The amorphous nature of the peat is of high potential for FRPA work.

Palynology

The elm decline is well marked, and there is clear evidence of repetitive woodland disturbance in late Flandrian II. Individual pollen phases differ sufficiently to allow their recognition by numerical techniques. The pollen evidence is sufficiently similar to be correlated between profiles, yet different enough to suggest that real spatial variations between profiles do exist. Pollen preservation is very good and pollen concentration evidence (Innes 1981) supports the conclusions of the relative analysis. It should be possible both to correlate and contrast the pollen evidence from multiple profiles.

Geographical.

The location and morphology of the site seem ideal for such a study. The size of the basin (about 400 x 40 metres), which has well defined limits, would have remained fairly constant in late Flandrian II and early Flandrian III. It was probably small enough to have received a high proportion of its pollen rain from only several tens of metres away (Jacobsen and Bradshaw 1981), depending upon the density of the woodland canopy, the area within which a fire disturbance/regeneration/stability cycle of late Flandrian II date almost certainly occurred. It is, however, large enough to allow several profiles to be taken at regular intervals, far enough apart to detect any spatial variations in the pollen rain which might have occurred. Finally, throughout the period under study the site appears to have been either within woodland, in a clearing within woodland or close to the upper woodland edge, so that it should be sensitive to the effects of early human activity in the way discussed by Edwards (1982).

Several points on the North Gill stream were therefore chosen as locations for new pollen diagrams, with a view to their analysis at the FRPA level. The choice of individual sediment profiles to be subjected to FRPA was governed by two main factors. Firstly the strategic requirements for, as far as possible, pollen profiles to be fairly regularly spaced across the North Gill site to assist spatial interpretation, with each major area of the transect represented. Secondly, at the local scale the sediments themselves had to be morphologically suitable to make the FRPA sampling technique practical. Selection was restricted to points where peat profiles could be examined in stream cut section, so that sediments suitable for FRPA sampling could be chosen. The location of the pollen profiles described in this thesis, as well as that of the earlier sites of Innes (1981) are shown on figure 6. The profile of Simmons (1969a) is not shown as its location is not known exactly, although it is close to North Gill 3. Of the new sites, five were selected, after analysis at the centimetre level, as suitable for further investigation by FRPA. Site 1A was located very close to the site of North Gill 1 of Innes (1981). The other FRPA profiles were designated NG4 to NG7 respectively and were located at regular intervals of approximately eighty metres from NG1A upstream. All sectors of the stream valley thus included a FRPA profile. Those pollen profiles considered unsuitable for FRPA, for reasons explained below, were designated NG8 to NG10. Areas below NG1A, above NG7 and outside the North Gill valley where peat sections were unavailable, were not considered for analysis.

CHAPTER FIVE

NORTH GILL 5

5.1 Introduction

The deep peat faces exposed by stream erosion in the central part of the site, between lateral transects H and K, were inspected in detail in the field and a site was selected (figure 6) where the various lithostratigraphic units were well defined and where factors of horizontality and humification of sediment appeared to be favourable. This location was designated North Gill 5. Although the main purpose at North Gill 5 (NG5) was to provide a FRPA record for the central North Gill area, the site has also been used to test the horizontal integrity and spatial replicability of the pollen stratigraphy at the coarser, one centimetre level of resolution which is in itself quite a detailed level of investigation for traditional pollen analysis. NG5 was chosen for this initial test of replication of pollen data because, although that part of the stream channel has quite a high gradient in places, NG5 seems to occupy a microbasin area with negligible gradient and good sediment horizontality. The testing of local pollen profile replicability was required (Edwards 1983) because if pollen assemblages were not consistent over very short horizontal distances such as less than a metre, there would be little point in attempting to compare profiles separated by several tens of metres and interpret their inconsistencies in terms of spatial factors. Twin profiles are therefore presented from North Gill 5, and these are termed NG5A and NG5B, the latter being 30 cm upstream from NG5A. Only the basal one metre of organic sediment was retrieved from each profile in monolith tins, the top of the tins being regarded as the profile zero datum in each case, because preliminary sampling had shown this part of the profile to contain the Flandrian II and early Flandrian III horizons and the later sediments are not relevant to this research. Identical analyses were then performed at one centimetre intervals upon both NG5A and NG5B.

5.2 North Gill 5A

5.2.1 Lithostratigraphy

After field and laboratory investigation, the following lithostratigraphy was recorded.

Stratum 1 Below 110 cm

Bedrock, comprising fractured slabs of local impure limestone.

Stratum 2 110 - 100 cm

Gs4, Sh^4+

Nig.1, strf.0, elas.0, sicc.2, lim.sup.2

A coarse, yellow sand with a slight organic presence and some root staining.

Stratum 3 100 - 89 cm

$Sh^4$2, Ga 1, anth.1

Nig.3, strf.0, elas.0, sicc.2, lim.sup.1

Highly amorphous, well humified, dark brown peat with variable proportion of medium sand and charcoal.

Stratum 4 89 - 80 cm

Tl2, $Sh^4$2, Dl++, Th^3+

Nig.2, strf.0, elas.0, sicc.2, lim.sup.1

Wood peat, comprising both rootlets and detrital fragments, in an amorphous organic matrix.

Stratum 5 80 - 76 cm

$Sh^4$4

Nig.3, strf.0, elas.0, sicc.2, lim.sup.2

Brown amorphous peat.

Stratum 6 76 - 73 cm

$Sh^4$2, Ag 1, anth. 1, Dl+

Nig.3, strf.0, elas.0, sicc.2, lim.sup.1

Amorphous organic material with charcoal and layers of medium and coarse silt. Occasional bark fragments.

Stratum 7 73 - 64 cm

$Sh^4$4

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Stratum 8 64 - 62 cm

$Sh^4$2, anth.2

Nig.3, strf.0, elas.0, sicc.2, lim.sup.1

Black amorphous peat with charcoal.

Stratum 9 62 - 55 cm

$Sh^4 4$, $Th^2 +$

Nig.3, strf.0, elas.0, sicc.2, lim.sup.1

Brown amorphous peat.

Stratum 10 55 - 20 cm

$Th^3 3$, Th(*vagi.*)$^3 1$

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Well humified herbaceous *turfa* peat with some *Eriophorum* macrofossils.

Stratum 11 20 - 0 cm

Th(*vagi.*)$^2 2$, $Th^3 2$

Nig.2, strf.1, elas.1, sicc.3, lim.sup.0

Humified *Eriophorum* peat.

5.2.2 *Pollen Stratigraphy*

The pollen record at NG5A has been divided into seven phases which are characterised as of either disturbance (d) or stability (s) type. These have been used to zone the relative pollen diagrams (figures 18 and 19) and are also applied to the pollen concentration diagrams (figures 20 and 21) from the profile. They are used to describe the pollen stratigraphy at NG5A. As in all other profiles from North Gill, unless otherwise stated percentages are of AP+G and concentration figures are 10^3 grains cm^{-3}.

NG5A - 1 d 99 - 87.5 cm

The basal phase is characterised by disturbance type taxa, with *Corylus*/*Myrica*, *Betula* and *Pinus* high and *Salix* and *Fraxinus* important. N.A.P. frequencies are high, with *Rumex*, *Melampyrum* and *Pteridium* the most significant ruderal taxa. Quercus (<40%) and Alnus (<50%) frequencies are low, while Ulmus is steady at about 20%. Pollen concentration values support the evidence of the percentage data, although individual curves are more erratic, with disturbance type taxa most important. Charcoal of all size classes occurs, with microcharcoal present in abundance. Peak Neurospora values occur near the start of the phase.

NG5A - 2 s 87.5 - 75.5 cm

Dominated by extremely high Alnus frequencies (80%) and defined by a sharp rise in Quercus (>50%), with Ulmus (20%) also important and Tilia rising to almost 10%. Disturbance type trees and shrubs are much reduced, Corylus/Myrica falling below 50% at the end of the phase. Sphagnum and Polypodium increase and few herbs other than wetland types are recorded. Alnus concentration is very high (>60) at the start of the phase, but falls thereafter, a feature shared by all major taxa. Quercus concentration is little changed from the previous phase. Gramineae concentrations are the lowest of the profile. Charcoal representation is restricted to a low presence of microscopic particles only.

NG5A - 3 d 75.5 - 71.5 cm

Defined by a sharp fall in Quercus percentages (30%) while Alnus (20%) is also very greatly reduced but Ulmus remains unchanged. Disturbance indicators Corylus/Myrica, Betula, Pinus, Salix and Calluna show peak values. N.A.P. pollen and spores increase to high values with Filicales, Sphagnum and Gramineae prominent, but Melampyrum, Rumex and Pteridium are most significant. Other ruderals like Artemisia and Senecio-type occur. Concentration values mirror the percentage changes faithfully among almost all taxa, although Quercus almost retains the same representation as the previous phase. All charcoal size classes show peak values for both percentages and concentration, although less abundant than in phase NG5A-1. High Neurospora percentages accompany the charcoal peak, and its concentration, although moderate (10), is the highest of the profile.

NG5A - 4 s 71.5 - 63.5 cm

Defined by a sharp rise in Quercus frequencies to 60%, with a more modest recovery of Alnus (50%) and occasional peak values (30%) for Ulmus. Corylus/Myrica still important (60%). Very low N.A.P. record represented almost entirely by mire taxa, particularly Gramineae, Cyperaceae, Rosaceae and peak Sphagnum percentages. All concentrations are low, rising towards the end of the phase, except for consistently high gramineae and Sphagnum. Quercus concentrations almost match those of Alnus. Little charcoal recorded except a minor microscopic presence. A major expansion in the values for Gelasinospora reticulata begins.

NG5A - 5 d 63.5 - 40.5 cm

Defined by a fall in Quercus frequencies to 30% while Alnus, after an initial fall to 20%, remains only slightly lower than in the previous phase at 40%, and Ulmus is unchanged. Corylus/Myrica, Betula, Pinus and Salix show greatly increased frequencies while Calluna, after an initial peak, remains low. The diversity of the heliophyte shrub record increases. Melampyrum consistently registers over 10%, while Rumex, Pteridium and Filicales are increased and many other ruderal types, including Plantago lanceolata occur. Quercus and Alnus concentrations remain steady, although the latter shows an initial fall, but disturbance indicator concentrations are very high, with Corylus/Myrica showing peak values of 72. N.A.P. values echo those of the percentage diagram, with Melampyrum abundant at 5. Twin peaks of microcharcoal occur, but larger charcoal fragments are few and *G. reticulata* shows occasional high values.

NG5A - 6 s 40.5 - 29.5 cm

Defined by a very sharp rise in *Quercus* to 60%. *Tilia* increases markedly but *Alnus* frequencies rise only slightly. Indicators of disturbance are much reduced, although *Corylus*/*Myrica* maintains values over 50%. *Betula* and *Pinus* fall very sharply, as do *Salix*, Filicales and *Melampyrum*. Sporadic ruderal taxa occur such as Chenopodiaceae and *Artemisia*, but N.A.P. pollen is represented mainly by rising Gramineae and Cyperaceae percentages, while *Sphagnum* also increases. Pollen and spore concentrations almost all fall to very low levels, the exceptions being *Quercus* and Gramineae which are maintained, and Cyperaceae which shows peak values. Charcoal records are very low, but *G. reticulata* is present in high frequencies.

NG5A - 7 d 29.5 - 20 cm

Defined by a fall in *Ulmus* pollen percentages which also occurs in the concentration data, *Quercus* is unaffected, but *Alnus*, *Betula* and *Corylus*/*Myrica* all increase. Peak *Calluna* frequencies occur at the start of the phase and remain high while a substantial *Erica*-type curve occurs for the first time. *Fagus* is recorded. Several ruderal herb types are present and Gramineae and Cyperaceae values are high, while Cerealia-type and a consistent *Plantago lanceolata* curve are recorded. Overall concentrations are low, with the exception of individual taxa at certain levels, such as Gramineae, but confirm the trends of the percentage data. Charcoal levels are insignificant.

5.3 North Gill 5B

5.3.1 Lithostratigraphy

After field and laboratory investigation of the duplicate profile at NG5B, the following lithostratigraphy was recorded.

Stratum 1 below 108 cm

Bedrock, comprising fractured slabs of local impure limestone.

Stratum 2 108 - 99 cm

Gs4, Sh^4+

Nig.1+, strf.0, elas.0, sicc.2, lim.sup.3

Coarse, orange-yellow sand with a slight organic presence.

Stratum 3 99 - 89 cm

$Sh^4$2, Ga1, anth.1

Nig.3, strf.0, elas.0, sicc.2, lim.sup.1

Highly amorphous dark brown peat with high charcoal and sand fraction.

Stratum 4 89 - 82 cm

Tl2, $Sh^4$2, Dl+

Nig.3, strf.0, elas.0, sicc.2, lim.sup.1

Wood peat, mainly rootlet material but with some detrital fragments within a well humified organic deposit.

Stratum 5 82 - 73 cm

$Sh^4$4, Th^3++

Nig.3+. strf.0, elas.0, sicc.2, lim.sup.0

Well humified, dark brown amorphous peat.

Stratum 6   73 - 71 cm

Sh^{4}2, Ag 1, anth.1, Ga++

Nig.2, strf.0, elas.0, sicc.2, lim.sup.2

Amorphous organic material with charcoal and a high silt fraction, and some sand.

Stratum 7   71 - 60 cm

Sh^{4}4, Th^2+

Nig.2, strf.0, elas.0, sicc.2, lim.sup.1

Brown amorphous peat.

Stratum 8   60 - 58 cm

Sh^{4}3, anth.1

Nig.3, strf.0, elas.0, sicc.2, lim.sup.1

Dark brown amorphous peat with charcoal.

Stratum 9   58 - 54 cm

Sh^{4}4, Th^3++

Nig.2, strf.0, elas.0, sicc.2, lim.sup.1

Brown, well humified peat.

Stratum 10   54 - 18 cm

Sh^{4}2, Th^{2}2, Th(*vagi.*)^2+

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Brown, well humified herbaceous *turfa* peat with slight *Eriophorum* presence.

Stratum 11 18 - 0 cm

Th(*vagi.*)^{2}2, Th^{3}1, Sh^{4}1, Tb(*Sphag.*)^3+

Nig.2, strf.0, elas.1, sicc.2, lim.sup.0

Humified *Eriophorum* peat with herbaceous rootlets and a small bog moss presence.

5.3.2. Pollen Stratigraphy

The pollen stratigraphy at NG5B has been divided into seven phases of s or d type, and these have been used to zone the relative pollen diagrams (figures 24 and 25) and are also applied to the pollen concentration diagrams (figures 26 and 27) and the charcoal percentage and concentration data (figures 28 and 29).

NG5B - 1 d 99 - 87.5 cm

Characterised by low *Quercus* percentages, particularly at the base of the profile, where oak is less than 20%, being replaced mainly by *Betula*, which accounts for up to 60%. *Alnus* is also low in the earliest few spectra at under 20%, while *Corylus*/*Myrica* (>70%) is very high. *Alnus* recovers to moderate frequencies, but *Quercus* remains well below its undisturbed woodland values of later in the diagram. The phase remains characterised by secondary type taxa *Betula*, *Pinus* and *Corylus*/*Myrica*. *Ulmus* is steady around 20%. *Melampyrum* shows peak frequencies in the earliest levels of up to 20%, subsiding to more moderate levels in the rest of the phase, where other disturbance type taxa *Potentilla*, *Rumex*, *Succisa* and *Pteridium* are important. Concentrations are very high at the start of the phase, then falling, and closely support the percentage data. Abundant charcoal of all size classes occurs, again in highest percentages and concentrations at the start of the phase, where *Neurospora* is also most important.

NG5B - 2 s 87.5 - 73.5 cm

Defined by a sharp rise in Quercus frequencies to over 50% and also characterised by the expansion of Alnus percentages to abundance at over 80%. Betula, Pinus and Corylus/Myrica are reduced from their peak values of the previous phase, although the latter falls significantly only towards the end, when Salix also falls and Tilia increases (10%). Disturbance herbs like Melampyrum and Rumex continue to be recorded, but in low values. Sphagnum and Filicales increase, and aquatics occur. Concentration values fall to low levels in the later part of the phase. Charcoal values are low throughout, but a consistently high curve for Gelasinospora reticulata occurs.

NG5B - 3 d 73.5 - 69.5 cm

Defined by a sharp fall in Quercus pollen frequency to 30% and also characterised by the reduction of Alnus to 29% from its super-abundance of the previous phase. Very high values for Betula, Pinus, Corylus/Myrica, Salix and Calluna among the tree and shrub flora and also high N.A.P. values with peaks in Melampyrum, Rumex and Pteridium and rising frequencies for Gramineae, Filicales and Sphagnum. The same pattern is shown by the concentration data, while the charcoal presence is much increased, particularly in microcharcoal which is highest at the start of the phase and just before. The phase is radiocarbon dated to 5760±90BP (HAR-6615).

NG5B - 4 s 69.5 - 59.5 cm

Defined by a sharp rise in Quercus pollen frequency to 60%. Alnus rises to almost 50%, but does not regain the dominance of the previous s phase, while Tilia increases and Ulmus remains unchanged. The secondary pollen types of tree and shrub community are much less important than in the previous phase, with only Corylus/Myrica still present in high, although reduced, frequencies. Gramineae rises to 60% and Cyperaceae and Sphagnum are also much increased. Disturbance type herbs are almost absent. Total concentrations are steady throughout, and confirm the percentage data. Charcoal values are not high and almost confined to the microscopic size class, while a consistent curve for G. reticulata is maintained.

NG5B - 5 d 59.5 - 40.5 cm

Defined by a sharp fall in Quercus frequencies to 30%. Ulmus and Alnus percentages are virtually unchanged. Betula, Pinus, Salix and Corylus/Myrica increase sharply and remain high throughout the phase, while Tilia frequencies are reduced. The diversity of heliophyte shrubs recorded increases. N.A.P. values are high because, although Gramineae, Cyperaceae and Sphagnum percenctages decline, Filicales rise to 40% and Melampyrum is abundant at almost 20%. Rumex, Pteridium and Filipendula all are enhanced and the range of ruderal types increases. Concentration data correspond to the percentage evidence, except that Gramineae and Cyperaceae concentrations are maintained whereas percentages show a decline. Little macroscopic charcoal occurs except at the beginning of the phase and microcharcoal, while high, is not as high as in previous phases. The start and end of the phase have radiocarbon dates of 5450±80BP (HAR-6616) and 4990±80BP (HAR-6619) respectively.

NG5B - 6 s 40.5 - 30.5 cm

Defined by a sharp rise in Quercus frequencies. Ulmus and Alnus percentages are unchanged, but Tilia rises during the phase to more than 10% and Fraxinus becomes important. Betula, Corylus/Myrica, Salix and especially Pinus are all greatly reduced in value. Calluna expands towards the end of the phase. N.A.P. frequencies are low, with Gramineae and Cyperaceae the only significant herbs recorded. Sphagnum values are high. Ruderal herbs are almost absent. Concentration evidence confirms the percentage data. Only a low microcharcoal presence occurs. G. reticulata shows a small peak in percentage values.

NG5B - 7 d 30.5 - 22 cm

Defined by a sharp fall in Ulmus pollen frequencies from 20% in the previous phase to a minimum of less than 3%. Both Quercus and Alnus show slightly enhanced percentages and there is some increase in Betula and, especially, Corylus/Myrica, the latter reaching almost 80%. Erica-type forms a consistent curve. Gramineae reaches 70%, its highest on the diagram, but other N.A.P. types are present in moderate values. Peaks in Plantago lanceolata and Pteridium occur, but other ruderal taxa are present as isolated grains only. Concentrations are generally very low, but Gramineae in contrast is abundant, reaching almost 40. Very little charcoal is recorded.

5.4 Comparison of Profiles

The exercise of preparing closely adjacent pollen diagrams at the centimetre interval level of resolution has proven to be most instructive regarding the degree to which replicability of pollen data may be expected between profiles, a prerequisite of multi-profile correlation (Edwards 1983). The first conclusion must be that in almost all significant respects the comparability of the NG5A and NG5B diagrams is extremely good. The same number of pollen phases occurs at each, with four phases of disturbance, the last associated with the elm decline, separated by three well defined phases of woodland stability.

In this they accord well with the evidence from NG3 and NG1969, and in the central part of North Gill at least, a consistent pattern of disturbance - influenced woodland history seems to be recorded. The elm decline radiocarbon date of 4730±80BP (HAR-6620) at NG5B correlates very well indeed with that of 4767±60BP (BM-426) from NG1969 for the same feature. Other correlations of pollen phases between the earlier profiles and the new, more detailed diagrams from NG5 can not be proven, although the probability of the central North Gill group of profiles sharing a common history of disturbance in mid and late Flandrian II would seem to be quite high. Certainly the series of phases recorded in the two closely adjacent NG5 profiles are so similar that they must be regarded as recording the same sequence of events. The consistent series of radiocarbon dates at NG5B suggests that between phase NG5B-3 and the Elm Decline, mean peat accumulation was remarkably steady at about five centimetres per century despite any short term changes following forest disturbance in the stream catchment. A major hiatus therefore seems unlikely at NG5B, and hence also at NG5A, and this is supported by the nature of the pollen curves, being a mixture of sharp changes, gradual changes and continuity between different taxa at equivalent levels.

As well as the gross phase succession being very similar between the two profiles, there is close comparability in the character of the pollen frequencies for individual taxa within particular phases. This is true not only for non-local taxa which would be expected to have had their pollen signal 'smoothed' by transport factors, but also for highly local taxa plants or extremely rapidly changing successional plant communities. Many examples occur: the twin Sphagnum peak of phase 4; the peak of Cyperaceae at the end of phase 4; peak of Melampyrum at the base of phase 1; high Gramineae in phases 4 and 7; a single level abundance of Calluna at the phase 6-7 boundary; the Corylus/Myrica reduction in the second half of phase 2; the Erica curve of phase 7; the peak in Potentilla in phase 4; increased Alnus in the centre of phase 1; the sudden reduction in Salix midway through phase 2; all of these pollen features occur in both diagrams and many more could be cited. That so many disparate features of the diagrams are so clearly analogous suggests that the two profiles were experiencing virtually the same pollen and spore rain from all pollen sources. It also shows that the pollen assemblages at the centimetre level were in most cases sufficiently sensitive monitors of vegetation change to register accurately even very minor variations in plant community structure without these being masked by random fluctuations in pollen production, transport or deposition. Pollen changes on these diagrams seem to be records of actual events, rather than artifacts of profile-specific taphonomic conditions. That the pollen data sets from the two profiles are virtual replicates suggests that in this case at least there have been no significant complicating factors, such as vertical pollen displacement (Clymo and Mackay 1987), which have operated randomly to alter pollen stratigraphies and blurr the ecological record. The pollen spectra at NG5 thus seem to have been independent of such processes, having temporal integrity over at least limited spatial distances. It appears that even small scale pollen changes in these diagrams may be interpreted as replicable, and therefore reliable, indicators of environmental conditions. That the reliability of the data is so good at the centimetre level supports its selection for investigation at the FRPA level.

Some variability does occur between the NG5A and NG5B diagrams, however, which must be considered. There are several levels on each diagram which appear to be aberrant in that they record isolated high or low frequencies of individual taxa. Good examples are the very high Betula values near the base of NG5B - 1 which have no corresponding peak in the NG5A - 1 phase. Very low Gramineae frequencies occur at a single level near the end of phase NG5A - 2 which are not replicated in NG5B - 2. Single level aberrations such as these fall within the range of natural pollen rain fluctuations, with occasional stochastic changes in pollen production which may cause temporary extreme variation in pollen counts for individual taxa. Should these happen to coincide with that level of the peat deposit sampled for pollen analysis they will then appear on the pollen stratigraphy, but have no value for inter-profile comparison. Pollen types, even of some ecological importance, which occur in one diagram but not the other likewise do not signify major differences between the two profiles. For example NG5A records both Fagus and Cerealis-type pollen in NG5A - 7, neither of which important taxa occurs at NG5B. Further counting of samples from the latter profile would probably record these grains, however, and little can be read into their absence over so short a distance. Similarly NG5A-1 contains significant Fraxinus and few of the minor shrub types, whereas the opposite is true in NG5B-1. Whether such reciprocal variability could be of significance remains to be seen, but the presence or absence of individual low producer pollen types can hardly be so. Coincidentally, 55 pollen and spore types were recorded in both diagrams, but 10, about 18% of all types recorded, were not common to both diagrams. This is quite a substantial degree of heterogeneity for a combined data set of about 1,000 grains counted at each of well over 100 levels.

Such a result is hardly surprising, however, for although NG5A and NG5B are very similar, covering about the same time span and recording the same vegetation changes, the centimetre level samples are not contiguous and in any case contain composite pollen assemblages of several years' pollen rain. At the rate of deposition suggested for NG5B by the radiocarbon dates and concentration data (c.f. Middeldorp 1982), each centimetre of sediment at NG5 may represent about twenty years' accumulation. Any two individual spectra from the two NG5 pollen profiles can be at best only penecontemporaneous, and so variations in the range of pollen types recorded are to be expected, even between adjacent profiles. This lack of exact temporal correlation between spectra from within pollen phases which must themselves correlate as biostratigraphic units is the cause of random frequency differences in the curves for individual taxa between the two profiles. Thus although phase 5 at both NG5A and NG5B may record the same disturbance event, the pattern of the Melampyrum, or any other, pollen curve will not be the same at both sites, for no two individual pollen spectra will be exact correlatives. Any spatial differences occurring over the distance of thirty centimetres will compound this variability.

Of more importance are differences between the two profiles which cover two or three centimetres or which involve the longer term behaviour of pollen curves. These may reflect real differences in vegetation patterns. They are very few at NG5, however, and in no case of major importance. Of interest here is a well marked reciprocal fall in Alnus and rise in Calluna which occurs at the start of phase NG5A - 5, but is not replicated in the corresponding position in NG5B - 5, except perhaps much more faintly. This may reflect real vegetation change which has escaped record at one profile, although the reason for its absence is unclear. There is no real evidence to support the idea of an hiatus or sediment mixing and hence 'smoothing' of pollen curves at this point at NG5B. The other pollen curves show no signs that the NG5B pollen stratigraphy is defective in any way. Other variations are that Quercus and Alnus values are much lower at the time of peat inception at NG5B than at NG5A, although other taxa are comparable. Perhaps a slightly earlier date of peat accumulation at NG5B may explain this. Other, more trivial, differences occur such as the more persistent curve for Plantago lanceolata in phase NG5A - 7 than in NG5B - 7.

With the exception of a few features of a few curves, however, and accepting the range of natural variability which will affect such pollen data sets, it is clear that the two pollen stratigraphies from NG5 are very closely comparable indeed. Not only does the disturbance and stability pattern of woodland history closely correspond at both profiles, but the analogous trends and fluctuations of their pollen curves show that the character of the vegetation changes around NG5 has been accurately preserved in the pollen record. The character of the NG5 pollen curves themselves shows the site to be highly suitable for more detailed analysis.

5.5 Numerical Analysis (DCA) of NG5B

In order to test the subjective zonation of the North Gill 5 pollen stratigraphy, the pollen data from the profile which was radiocarbon dated and to be chosen for FRPA, NG5B, were analysed using techniques of numerical ordination. PCA has already been used to subdivide and correlate the NG3 and NG1969 data sets and has proved very successful in separating disturbance from stability phases. PCA only takes into account a limited amount of variability within the whole pollen record, however, being limited to those taxa contributing more than 5% of total pollen, athough in practice that will account for most of the variability present. Greater ecological insight may be gained from a numerical ordination which takes the whole data set into account, however, and for that reason the technique of detrended correspondence analysis (DCA) was applied to the NG5B pollen stratigraphy. The large number of samples and taxa which constitute the NG5B pollen record are easily handled by DCA, which can take into account presence and absence values as well as weighting for relative abundances within pollen counts. It is therefore well suited to vegetation community data (Hill and Gauch 1980, Prentice 1986). The results of the DCA are shown on figures 30(a) and 30(b) which represent plots of ordination on the first and second, and first and third axes respectively. All taxa recorded at NG5B are included in the analysis. The numbers on figure 30 represent the 78 pollen spectra counted at NG5B, beginning at the top of the pollen diagram.

Despite the complex and heterogeneous nature of the data set, the DCA ordination separates the data into a number of readily definable clusters of points, and the stratigraphic relationships of these are shown by the connecting line on figure 30. Six discrete clusters occur on the plot of the first and second axes (figure 30a) and these conform very closely with the disturbance and stability phases recognised subjectively from the percentage pollen diagrams, figures 24 and 25. The basal phase, NG5B - 1, plots separately as points 67 - 78, the outliers of the cluster reflecting individual high or low values for alder within the low alder context of the phase. The high alder phase, NG5B - 2, plots as a fairly tight cluster at the extremity of the first axis (points 53 - 66), with the exception of the uppermost point, 53, which has reduced alder and is transitional to the disturbance dominated phase NG5B - 3. This phase (points 49-52) forms a tight cluster near the origin of both axes. It is widely divorced from phase NG5B - 4 (points 39-48) which is a stability dominated cluster. Points 39 and 40 form slight outliers to this cluster, apparently due to low Gramineae and high Cyperaceae values, which is the converse of all the other levels in that phase.

NG5B - 5 (points 20-38) forms a tight cluster which correlates very closely with the cluster which represents phase NG5B - 3. These two disturbance type phases are thus indistinguishable within the limits of this ordination technique, their pollen spectra being most similar. Points 20 and 21 form slight outliers to this group, having lower birch and hazel and slightly higher oak than the other levels. Points 1-19 plot near the extreme end of the second axis and form a tight grouping (points 10-19) which corresponds to phase NG5B - 6, upon which is superimposed a rather straggly spread of points (1-9) which represents phase NG5B - 7, the post elm decline levels. As with the PCA, the DCA ordination technique seems to be unable to separate clearly on the first two axes the post elm decline pollen spetra from those of Flandrian II. Although adjacent, the phases of stability NG5B - 4 and NG5B -6 can be distinguished and plot as separate but very similar groupings, unlike the disturbance phases NG5B - 3 and NG5B - 5 which overplot completely. Quite minor but consistent differences in only a few taxa, primarily Pinus, Tilia, Cyperaceae, Rosaceae and Corylus/Myrica appear to be sufficient to differentiate the two stability phases, whereas the two disturbance phases are comparable in virtually every respect. The basal d phase, NG5B - 1, is quite distinct from the other two d phases, although clearly of disturbance character. This separation is apparently due to differences in a few taxa only, primarily lower Gramineae in NG5B

- 1 and lower Melampyrum except in the basal three levels which are much closer to the composite d cluster. The abundant alder values of NG5B - 2 are sufficient to explain its distancing from the other s phase cluster. Although the elm decline is not a distinctive feature in the grouping of points on the first two ordination axes, it is clearly picked out when the first and third axes are plotted against one another (figure 30b), and in this it resembles the results yielded by PCA.

The DCA results contain a great deal of useful ecological information since the axes are directly related to environmental gradients. With fifty-five taxa of widely differing life-form and habitat included in the ordination, however, the factors influencing these gradients are several and their interpretation complex. The first axis of the ordination, however, appears to express variation in mire pH status as represented by mire community succession, with neutral alder dominated carr plotting far along the axis, and more acidic peat types dominated by grasses, sedges and Sphagnum plotting near its origin. Phase NG5B - 1, with low values for all four of these pollen types, plots in an intermediate position.

The second axis of the ordination differentiates between Flandrian II fire-induced disturbance, with low Quercus and high Melampyrum, Pinus, Salix and Corylus/Myrica, and phases during which that factor is absent. Fire disturbance levels plot near the origin of axis 2, while others plot much further along it, to what degree depending upon the reltive presence of pyrophyte taxa. The small but significant difference in pine values between the first and second halves of NG5B - 2, for example, is largely responsible for the binary character of that phase's cluster. Thus, the three Flandrian II d phases are very clearly differentiated from the other levels, which themselves are separated into non-acid carr and acid bog types.

The third axis of ordination is more difficult to interpret, for it appears to be influenced by more than one factor. It seems, however, to express variation in moisture status, with drier mire vegetation plotting further along the axis and wetter communities located closer to its origin. Thus high Sphagnum values cause points to polot very low on axis 3, while Cyperaceae, Erica and Alnus all tend in that direction also. The latter forms a very tight wet carr cluster, not being influenced by the disturbance taxa gradient of axis 2. On axis 3 grasses appear to indicate a drier bog surface. It is the increasing wetness indicated by falling Gramineae values in levels 1 - 3 that causes them to plot nearer the centre of figure 30b, unlike the rest of phase NG5B - 7, points 4 - 9, which are clearly separated from the rest of the plotted points. Axis 3 thus also distinguishes Flandrian III, post elm decline disturbance levels as a separate grouping, with low Ulmus and high Plantago lanceolata diagnostic features.

In summary, therefore, DCA has proven successful in summarising the major directions of variation for a complex pollen data set which represents diverse plant communities. It has confirmed the evidence from the more selective data set previously examined by PCA, that the presence and absence of disturbance is the major source of community variation, together with mire community succession caused by mire hydrology and nutrient status. Furthermore, because disturbance is the factor influencing variation along one of the major axes of the ordination, the technique can be used to zone the pollen data by diagnosing individual points as of s or d type, since in DCA the axis scale units represent true ecological distances and thus can be interpreted in directly comparative community terms (Hill and Gauch 1980, Prentice 1986). The DCA results from NG5B have confirmed the diagram zonation criteria used at that profile, by showing that Alnus values vary in response to changes in local hydrological condition (axis 1 and axis 3) rather than woodland disturbance (axis 2), the latter being the controlling factor with regard to taxa such as Quercus, Pinus, Salix, Corylus/Myrica and Melampyrum primarily. For example, although level 53 shows an Alnus value intermediate between the peak frequencies of NG5B - 2 and the low values of NG5B - 3, figure 30a shows it to be clearly of stability type, plotting closer to the stability end of axis 2 than most of the rest of the levels in phase NG5B - 2. It is the high oak and low pine, hazel and Melampyrum values of level 53 which keep it firmly within the stability part of the figure 30a plot, although its lower Alnus values cause it to be an outlier from the phase NG5B - 2 cluster, and to plot much closer to levels from phases NG5B - 4, NG5B - 6 and NG5B - 7. The DCA technique thus supports the subjective s/d zonation of the NG5B diagram and the use of the Quercus curve as diagnostic of the presence or absence of disturbance within the pollen stratigraphy. Although there is insufficient space to allow numerical techniques to be used upon the rest of the pollen profiles presented in this thesis, their use in PCA at NG3 and NG1969, and in DCA at NG5B supports the s/d zonation criteria employed in the other pollen profiles from North Gill.

5.6. Vegetation History at NG5

The pollen records in the two profiles are so similar, and correlation of phases so clear, that NG5 may be considered as a unit for the purposes of the reconstruction of vegetation history. The basal phase records a very clear episode of pre elm decline vegetation disturbance. The presence in quantity of taxa known to be successful in post fire habitats, such as Melampyrum, Pteridium, Pinus and Corylus/Myrica, together with the considerable charcoal presence, points to fire disturbance of the local vegetation having preceded the beginning of peat growth at this site, with the consequences in terms of vegetation regeneration recorded in the pollen spectra of NG5 - 1. The fire apparently took place within oak and alder woodland and it may be surmised that the alder populations were associated with wetter stream valley habitats, and oak perhaps more abundant upon the sandy, drier soils of the slopes beyond. The fire clearly had the effect of creating some open ground as well as merely opening of the forest canopy for ruderal herb taxa and some soil inwash reflect devegetated terrain presumably on slopes around the stream valley. Wetland herbs also found suitable habitats either in streamside situations or upon the incipient mire. Very high Neurospora values suggest that burning took place at or very close to the site itself (Van Geel 1978), and this would support the theory that in situ paludification (Moore 1988) may have caused peat formation to begin within the basin areas of the stream valley itself. Although the deforestation brought about by the fire which preceded phase 1 had a considerable impact upon tree pollen frequencies, it does not seem to have effected any lasting reduction in tree cover for deciduous woodland dominates the following phase of vegetation stability when indicators of disturbance, although not absent, are very scarce. Alder is particularly abundant and the presence of detrital wood in the profile, as well as some roots and stumps, suggests an alder dominated carr woodland around NG5 itself, within a closed canopy broadleaf forest which remained largely undisturbed, although with a significant proportion of more light demanding trees such as ash and hazel. The area of organic sedimentation was probably quite restricted still and growth of peat was slow.

Indications of fire disturbance return to NG5 during phase 3 as once again oak and alder woodland was replaced by successional vegetation in which pioneer herb communities regenerated towards tree cover through a range of scrub woodland types in which hazel played a major role but which included niches for birch and willow, probably in damper locations. Destruction of the dense alder carr of NG5 takes place at the very beginning of this phase, and begins a few levels prior to the main effect on oak percentages used to define phase 3. A combination of increasing peat sedimentation rates and actual destruction by fire may have been the cause. Removal of local alder stands seems to have preceded the main impact upon the dryland oakwood. Considerable destabilisation of terrestrial ecosystems occurred, for the scale of the pollen fluctuations and the charcoal and soil inwash indicates a clearing in the forest of some extent, although actual dimensions cannot be estimated. The disturbance gave an impetus to peat growth due to input of drainage water from the devegetated area, with some bog communities existing alongside open water pools. The consequences of the fire in the forest around NG5 in phase 2 were relatively severe.

While renewed oakwood dominance characterises the fourth phase at NG5, the dense alder carr which previously existed there seems to have been unable to regenerate for the moderate values of Alnus indicate a more dispersed pattern of alder populations in the neighbourhood of the central North Gill area. The stable dryland mixed oak forest was relatively unbroken around the site. There are no real indications of any surviving open areas and only the grass-moss-sedge flora of the mire itself would have diversified the forest matrix of the wider landscape.

The third episode of deforestation around this site is interesting for its destructive effects seem to have been restricted to the oak population of the mixed oak forest. That alder does not show any response to the disturbance during almost all of the phase suggests that it perhaps was not growing as a component of the mixed woodland, but spatially restricted to the stream valley. Hazel, birch and willow all respond to oak canopy recession in a positive way, suggesting their actual presence within the affected area as understory or secondary taxa. Alder is only marginally reduced in frequency from that of the previous, undisturbed, phase. An explanation for this might be that almost all of the alder pollen received at NG5 was at this time carried by water from populations growing in the valley upstream. Stream flow is a primary mode of alder pollen transfer (Brown 1985), and the consistency of the <u>Alnus</u> curve after its recovery from the lowpoint of phase 3 could point to the presence of alder stands in the upper stream valley which were largely unaffected by fire disturbance on the drier areas upslope from the mire. Difficult to explain is the brief fall of alder and increase in heather which occurs at the start of NG5A - 5 but not at NG5B - 5. This is not an artifact of the calculation method, since the two shrub types are in different ecological groupings and the concentration data confirm it. The two profiles are too close together to be able to detect real spatial vegetation differences of this magnitude. Differences in pollen taphonomy may account for the dichotomy, with NG5A perhaps a higher point of the mire surface by a few centimetres at this time, failing to receive water-borne alder pollen and having a very local input of heather pollen, both factors changing with raised water tables due to increased run off of water after devegetation in the catchment causing accelerated deposition, a common post deforestation feature (Moore 1975, Brown and Barber 1985).

In other aspects the vegetation history of phase 5 at NG5 is very similar to that of the previous disturbance episodes at the site. Similarly the succeeding phase of stable oak woodland is closely comparable to phase 4 in being dominated by closed canopy deciduous forest. Even the minor heliophyte shrubs which indicate the increased openness of the woodland in the disturbance phase, like Viburnum, Prunus and Crataegus, are almost absent. Although increased grass, sedge and moss curves indicate continued development of the mire towards oligotrophic bog, the dryland areas were still heavily forested and contained no significant open terrestrial habitats.

The character of the forest disturbance at the time of the elm decline is a departure from the previous disturbance pattern however. Fire has ceased to be the mechanism for disturbance, and the cereal and plantain evidence, instead of the familiar post-burn Melampyrum dominance, points to a removal of elm, presumably on better soils further removed from the profile, and the creation of clearings for pasture and cultivation. Some of these were to become heathland areas, with Calluna increasing. The processes operating at the elm decline will be discussed further below. The changes in the woodland landscape were clearly of a different kind to thse of Flandrian II, however, with the local and extra-local oak population not subject to disturbance, although opportunities were created for the expansion of hazel, birch, ash and even alder amongst the woodland communities in the pollen catchment area of NG5.

5.7 NG5B FRPA

The existence of three phases of pre Ulmus decline forest disturbance at North Gill, which had been demonstrated by previous investigation at NG3 and other profiles, has thus been established as also occurring at NG5, where the horizontal integrity of the pollen stratigraphy, at least over a limited distance, was proven by adjacent pollen diagrams. The second such phase of disturbance (phase 3 in both profiles) was chosen for more detailed investigation by FRPA. The basal phase was rejected because the pollen evidence showed that no record of pre disturbance conditions existed, and so a full ecological cycle of stability - disturbance - stability vegetational changes was not available for study. Also the basal levels contained very large pieces of sand and charcoal which would make fine sampling difficult. The third disturbance phase (phase 5 at both profiles) was also rejected due mainly to its great size of around twenty centimetres, which would have required the counting of well in excess of 200 spectra at the FRPA level. This was an impractical number if it were to be repeated at several profiles, as was intended. The four centimetre length of phase 3 was more practical in this respect. In addition, although phase 5 contained very clear indications of disturbance, the vegetation changes recorded in phase 3 appeared to be even more dynamic and involved radical shifts in the pollen curves of almost all major taxa, whereas in phase 5 taxa such as Alnus, Gramineae and Calluna were not significantly affected. Moreover the sediments of phase 3 were much more amorphous and well humified than those of phase 5, which comprised an herbaceous turfa, and phase 3 was thus more likely to thin section successfully.

FRPA was therefore conducted upon phase 3 at the profile of NG5B, which was chosen in preference to NG5A because its inorganic fraction was lower than that of the latter profile, where a slightly more discrete silt layer occurred which could have hampered thin sectioning. In terms of pollen stratigraphy the two profiles are almost indistinguishable in this phase. The well humified, amorphous nature of the sediment at phase NG5B - 3 facilitated its freezing and thin sectioning, and contiguous sub-samples of one millimetre thickness were obtained without any difficulty. Detailed laboratory examination of the sediment incorporating phase NG5B - 3 (Stratum 6 at the one centimetre scale) showed that the lithostratigraphy could be refined further between 75 and 68 cm depth, as follows.

Sub - Stratum 1 750 - 730 mm

$Sh^{4}4$

Nig.3, strf.0, elas.0, sicc.2, lim.sup.1

Brown amorphous peat.

Sub - Stratum 2 730 - 726 mm

$Sh^{4}2$, Ag 1, anth.1

Nig.2+, strf.0, elas.0, sicc.2, lim.sup.1

Homogeneous charcoal, silt and amorphous organic material.

Sub - Stratum 3 726 - 719 mm

$Sh^{4}3$, anth.1, Ld^{4}++

Nig.3, strf.0, elas.0, sicc.2, lim.sup.1

Amorphous organic material with tiny charcoal fragments.

Sub - Stratum 5 714 - 680 mm

$Sh^{4}4$, Ld^{4}++

Nig.3, strf.0, elas.0, sicc.2

Dark brown amorphous peat.

5.5.1 FRPA Pollen Stratigraphy

The FRPA pollen stratigraphy at NG5B has been divided into ten zones of s or d type and these are used to zone the relative pollen diagrams (figures 31 and 32) and are also applied to the pollen concentration diagrams (figures 33 and 34) and the charcoal diagrams (figures 35 and 36).

Zone NG5B - A s 750 - 748.5 mm

Defined by high Quercus frequencies, also having high Alnus, Tilia and Ulmus percentages. Corylus/Myrica in moderate frequencies (50%), and other trees present in low values, although Fraxinus also present. No ruderal herb or other indicators of disturbance present. Concentration values agree. Very little charcoal.

Zone NG5B - B d 748.5 - 742.5 mm

Defined by a gradual fall of Quercus percentages to less than 50% in mid zone, before a gradual recovery. Alnus experiences a consistent decline in this zone, falling to 50% at its end. Tilia and Ulmus are generally increased. Corylus/Myrica and Calluna show enhanced frequencies and Pinus and Betula also increase, although remaining in moderate amounts. Ruderal indicators of disturbance are few, although Rumex and Melampyrum occur. The concentration evidence confirms this pattern. No change is recorded in the level of microcharcoal in the sediment.

Zone NG5B - Ci s 742.5 - 737.5 mm

Defined as a zone of s conditions due to a clear rise of Quercus frequencies to almost 70%. Alnus, however, falls to a very low level of 40%. Indicators of disturbance are all reduced to low frequencies, however, supporting the s categorisation of the zone, including Betula, Pinus, Corylus/Myrica and Calluna. Tilia also declines, while Ulmus is unchanged at 20%. No significant ruderal herb records occur. Filicales and Sphagnum increase in frequency. A slight increase occurs in microcharcoal frequency, and a small peak occurs in Gelinospora reticulata.

Zone NG5B - Cii s 737.5 - 730.5 mm

Defined as a further zone of s conditions by maintained high Quercus percentages of 60%. Distinguished from the previous zone by a marked recovery of Alnus frequencies to almost 60%. Disturbance favoured trees and shrubs are uniformly low, although Corylus/Myrica does increase towards the end of the zone. N.A.P. pollen low, with Gramineae steady at 20%. Occasional records of disturbance types like Melampyrum, Rumex and Pteridium. Filicales and Sphagnum gradually fall. Microcharcoal frequencies, however, gradually rise and some larger fragments are present. Isolated records of Neurospora occur.

Zone NG5B - D d 730.5 - 725.5 mm

Defined by a sharp fall in Quercus pollen to 30%, at which level it remains throughout the zone. Alnus also falls, although less gradually, to the same level. Major increases occur in the percentages of regeneration type trees and shrubs, particularly Corylus/Myrica (80%), Pinus (30%), Calluna (30%) and Betula (30% initially, then declining). Salix forms a significant curve for the first time, and a consistent Prunus presence occurs. Peaks of Melampyrum and Pteridium occur, and

Gramineae rises to over 30%. A small peak of *Plantago lanceolata* is present, with sporadic grains of other ruderals. The concentration evidence echoes that of the percentage data. A continuous presence of small charcoal fragments occurs, while peak charcoal frequencies of up to 60% are recorded in mid zone. *Neurospora* percentages are high.

Zone NG5B - E s 725.5 - 718.5 mm

Defined as a zone of s character by a small but clear increase in *Quercus* pollen frequencies to almost 40%. The other major pollen curves support this designation although their changes are not great. *Pinus* falls to a low point of 10%, *Corylus/Myrica* marginally to 70%, *Calluna* to 15% and *Pteridium* is only intermittently recorded. *Alnus* increases slightly to 40%, but *Betula* is undiminished. *Fagus* occurs. Ruderal herb records still occur, with indicator taxa *Melampyrum*, *Plantago lanceolata* and *Succisa* still important, and Gramineae increases to 40%. Rosaceae, *Potentilla* and *Ranunculus* are significant. A slight small charcoal record exists, but microscopic charcoal frequencies are relatively low. Peak values of *Gelasinospora reticulata* occur.

Zone NG5B - Fi d 718.5 - 708.5 mm

Defined by a sharp fall in *Quercus* frequencies to little more than 20%. *Alnus* also falls (25%) while *Tilia* is reduced but *Ulmus* remains steady. *Corylus/Myrica*, *Betula*, *Pinus*, *Salix* and *Calluna* values are the highest recorded in the profile. N.A.P. values are very high, although Gramineae actually falls slightly. *Melampyrum* values consistently approach 10% while *Pteridium* and *Plantago lanceolata* frequencies are high in the early and late stages of the zone respectively. A range of other, probably open habitat, herbs (*Epilobium*, Cruciferae, *Artemisia*, *Rumex*) occurs. Small charcoal fragments are present and microcharcoal rises later in the zone, as does *Neurospora*.

Zone NG5B - Fii d 708.5 - 700.5 mm

Defined as a zone of d conditions by the low frequencies of *Quercus* (30%) although these are greater than the previous zone. *Alnus* remains very low although recovering towards the end of the zone. *Betula*, *Pinus* and *Corylus/Myrica* show gradual declines in frequency but remain in high values and the shrubs *Salix* and *Calluna* behave similarly. N.A.P. values fall relative to the previous zone, but ruderal types are still important, *Melampyrum* being consistently present although in moderate values, as are *Rumex* and *Pteridium*. Microcharcoal occurs in substantial percentages, declining from the maxima of zone Fi.

Zone NG5B - Gi s 700.5 - 696.5 mm

Defined by a sharp increase in *Quercus* pollen frequency to 50%. *Alnus* and *Ulmus* percentages are unchanged. *Corylus/Myrica*, *Betula* *Calluna* and, especially, *Pinus* are reduced in value markedly. *Fagus* is recorded, and *Hedera* increases. Gramineae, Cyperaceae and *Sphagnum* percentages are much increased. Filicales is reduced, and open habitat herbs are not common, although *Melampyrum* remains significant and a grain of *Plantago lanceolata* occurs. Microcharcoal is present only in low values.

Zone NG5B - Gii s 696.5 - 680 mm

Defined by a further rise in *Quercus* frequencies to over 60%. *Tilia*, *Alnus* and *Ulmus* are unchanged, while *Fraxinus* forms a continuous curve. *Betula*, *Pinus* and *Calluna* decline, while *Corylus/Myrica* occurs in frequencies similar to those of the previous zone (60%). Gramineae, Cyperaceae, Rosaceae and *Sphagnum* persist in high percentages. Ruderal herb records are reduced to occasional grains. Microcharcoal representation falls to very low levels, but *Gelasinospora reticulata* shows consistently high values.

5.8 Interpretation of NG5 FRPA

The initial conclusion to be drawn from the NG5B FRPA record is that the technique has proven to be most successful in providing a detailed record of vegetation history. The FRPA diagram comprises a combination of both sharp and gradual changes in pollen frequency which suggest that neither hiatus in deposition nor vertical mixing of pollen spectra has blurred the environmental record. Both pollen and charcoal curves fluctuate in a manner which seems sensible and there are no grounds for believing that the spectra do not represent sequential and therefore reliable data. That the pollen stratigraphy can be divided into discrete FRPA zones which are internally consistent and which are ecologically intelligible suggests that it forms a dependable record of changes in vegetation patterns and communities, supporting the conclusions of previous authors (Garbett 1981, Sturludottir and Turner 1985).

Indeed, the FRPA data are closely relateable to the NG5B - 3 pollen curves at the coarser level, for the major changes which occur in phase NG5B - 3 may be recognised within the FRPA zones, but accompanied by a much greater degree of detail regarding individual taxa and community groupings. The beginnings of the FRPA record represents conditions of broadleaf woodland stability with no indications that breaks in the tree cover were being created around NG5B and this correlates very well with the final stages of phase NG5B - 2, with the zone NG5B - A alder curve being rather lower than the great alder abundance of the phase. Whether or not exogenic factors were responsible for this decline of alder, the negative trend continues into zone B where the gradual alder fall is coincident with a readily discernable oak pollen reduction which points to some disturbance of the deciduous woodland. Whether this episode was of limited extent or situated at some distance from NG5B is conjectural, but the small increases in heather, hazel and pine and the sporadic ruderal herb grains do not provide evidence of a major reduction in tree cover. No evidence of fire near to the site exists, so that this first disturbance of the forest must have been quite ephemeral, although the smooth fall and recovery of the pollen curve for oak, for example, shows it to be a real episode of woodland recession and regeneration. It is not recognisable upon the NG5B centimetre diagram, presumably too small to have been picked up at that sampling interval, or too far from NG5B to register more than faintly. The steady fall in the alder curve suggests that during this zone, however, alder populations were substantially reduced locally and their removal from part of the stream valley is likely. This trend continues in zone Ci, with alder populations much reduced in comparison with the start of the FRPA profile, but oak recovers to such a degree that the minor deforestation of zone B clearly had no lasting impact upon the oakwood cover, and dense closed canopy forest was restored nearby. This stage in vegetation history illustrates very well that the oak and alder populations must have been spatially distinct around this site, for the contrasting behaviour of their two curves is hardly compatible with their mutual association in the woodland. The most plausible explanation for the continued demise of alder in a zone when fully wooded stable vegetation occupied the dryland landscape is that a large proportion of the alder population had been growing within the stream valley as carr vegetation and had been badly affected by hydrological changes, perhaps promoted by the previous disturbance event. The rise of heather and Sphagnum at this time could be part of that process of change in the mire character and a much reduced local alder population may have been restricted to the oakwood away from the mire. The partial recovery of alder to moderate frequencies in zone Cii, while stable mixed oak woodland was maintained around NG5 reflects continued autogenic changes in edaphic and hydrological conditions in the landscape, in the absence of any disturbing influences upon the vegetation. This high oak, moderate alder stage correlates quite well with the final level of phase NG5B - 2, and should correspond with it on stratigraphic position. A close equivalence exists, however, between the beginnings of major forest disturbance on both the FRPA (730 mm) and centimetre (73 cm) profiles. This disturbance was presumably very close to NG5B and of some considerable magnitude for inwash of charcoal and eroded mineral soil show that deforestation by fire took place and created a substantial area of open ground within the oakwood. Neurospora values suggest that burning took place close to the bog margins, although the transitional changes at the pollen zone Cii to D boundary show that fire did not extend to the peat surface itself and cause loss of sediment, supported by the absence of large charcoal pieces (Tolonen 1986). The end of stable zone Cii, for example, sees small reciprocal changes in oak, pine, hazel, alder, willow and Melampyrum which presage the much more radical changes in pollen frequencies which mark the start of zone D. The collapse of alder and, particularly, oak populations at this time must represent real removal of oak forest and its replacement by open ground and in time by rapidly changing scrub, at first dominated by birch if the initial Betula peak of zone D is a true record of disturbance, and then by hazel, pine and heather. Records for Plantago lanceolata will represent some grassland as well as the post-fire field layer indicated by Melampyrum. Opportunities for Prunus and Rubus came into being in the highly diversified post-burn successional areas.

While the dramatic deforestation evidence of zone D is closely comparable to that of NG5B - 3, there is no similar correlation apparent between the succeeding zone E and the data at the centimetre level. A slight but quite clear zone of oak and alder recovery occurs in zone E, with concomitant small scale declines in pine and hazel, which is not visible at the coarser level of analysis, presumably being too short lived to be recorded. Reduced charcoal and the presence of ash, beech and high birch, as well as oak and alder increases, indicate the establishment of a secondary type of woodland. Disturbance, or at least open ground, continued nearby, however, for Melampyrum and other weed types are still present. More stable conditions did not remain for long, for a third and most severe zone of woodland recession, Fi, causes a renewed replacement of oak and alder forest by herb and shrub seral communities, again following sufficient destabilisation of surrounding areas to allow erosion of mineral soils and charcoal fragments into the mire. The deforested areas must have been substantial for a wide range of ruderal herbs occurs, many like Melampyrum and Rumex in high percentages. Peak Plantago lanceolata values point to open, grassy areas and less often recorded weeds like Epilobium, Cruciferae, Artemisia and Chenopodiaceae suggest a rich herb association in the freshly cleared areas. Concentrations are low during this phase and the presence of gyttja sediment, aquatic pollen and open water microflora like Mougeotia and Zygnema (Van Geel 1978) shows that flooding conditions occurred at the bog surface at NG5, forming shallow pools. Again, as in the case of inwashed material in the profile, increased input of water from devegetated slopes would be responsible for this.

Although zone Fii is also a disturbance zone, the level of impact upon the woodland is much less, so that a gradual recovery of tree population must have occurred. Continued disturbance must have been at a distance from NG5, or else regeneration after the very severe forest recession of Fi must have been naturally slow. A gradual reversal of the pollen evidence occurs, with both oak and alder increasing, but still low, and disturbance related taxa slowly declining. The more grassland or bare ground weeds fade from the pollen record, while the 'open woodland' herbs like Melampyrum are reduced.

The gradual restoration of oak woodland continues in zone Gi, when Quercus values have risen sufficiently for it to be regarded as a stability zone, although minor indications that the forest canopy was not yet fully closed remain. This process continues in zone Gii when full closed canopy oakwood was achieved and indicators of open conditions are insignificant. Alder, it appears, never regained its lost ground in the stream valley, and the steady but moderate values of zone Gii must reflect its general oakwood population. The high grass and Sphagnum frequencies might suggest that the stream valley mire had become too acidic an environment for it to regenerate there.

The primary conclusion to be drawn from the trial application of FRPA to the NG5B profile is that the technique has succeeded remarkably well in yielding reliable, yet highly detailed, ecological data which can be used to study vegetation change at very short temporal intervals. That no mixing or blurring of the FRPA spectra has occurred is rather surprising , and must be due to a constant and sequential deposition of sediment at NG5B which is unexpected during a time of vegetation change when allogenic environmental factors were having significant influences upon the influx of sediment into the mire. The key to this gradual deposition may be the presence of a shallow mire pool upon the sampling point which allowed a measure of low energy sedimentation which may not have occurred upon an exposed peat surface. This possibility will be tested at other profiles at North Gill. Even if NG5B represents optimum sedimentation conditions, the quality of the FRPA data is very high indeed. The most instructive finding is that the rather homogeneous disturbance phase NG5B - 3 in fact comprises three distinct minor episodes of disturbance, each of different strength and character which may reflect complex spatial relationships. The revelation that phase NG5B - 3 is composite and is really the aggregation of a cluster of smaller disturbances has great implications for its interpretation, which will be discussed further below. The technical success of the method at NG5B, and the greatly refined level of ecological data which it has yielded, justify its application to other profiles at North Gill in order to test its limitations and potentialities further.

CHAPTER SIX

NORTH GILL 1A

6.1 Introduction

After the validity of the FRPA method was proven for the profile of NG5B it became necessary to extend the use of the technique to other parts of the North Gill site in order to test its resolution limits, one of the main research aims, to find out whether the high quality of the FRPA results at NG5B was unique to that profile or could be reproduced elsewhere, and to provide a spatial dimension to the ecological data recovered from NG5B, by multi-profile correlation. A site was chosen at the lower end of the North Gill stream valley at a point where the peat stratigraphy exposed in stream section appeared to be suitable and the peat was of the right, amorphous consistency. The site was located within a few metres of the previously analysed profile North Gill 1 (Innes 1981) which had proven to be anomalous in having only two pre elm decline phases of disturbance recognised in its pollen stratigraphy whereas other profiles examined by Innes (1981) had all contained three. A sampling interval of up to two centimetres in parts of the Flandrian II peat had meant that the NG1 pollen data were not a complete record of events and disturbance evidence may have escaped notice in that pollen diagram. A more detailed profile would answer this question and so the new profile was placed adjacent to NG1, which was in any case situated among the most suitable sediments for detailed analysis, and was designated North Gill 1A (NG1A).

6.2 North Gill 1A

The location of this profile is just upstream of lateral transect R and lies upon site transect 3 (figure 6), within the lowermost peat face exposure in the North Gill valley, and was chosen to investigate vegetation history around the lower end of the valley and furthest from the springhead and the upland plateau. Sampling was undertaken at a point where a complex succession of stratigraphic units, including charcoal, sand, detrital wood and minero-organic material, appeared to be most horizontal and the basal metre was recovered in monolith tins.

6.2.1. Lithostratigraphy

After field and laboratory examination, the following gross lithostratigraphy was recorded, although some of the units were clearly capable of more detailed subdivision (see below).

Stratum 1 Below 120 cm

As4, Gg(maj)+

Nig.0, strf.0, elas.0, sicc.2, lim.sup.3

Stiff white clay with quartz and sandstone pebbles.

Stratum 2 120 - 114 cm

Gs4

Nig.1, strf.0, elas.0, sicc.2, lim.sup.1

Coarse yellow sand.

Stratum 3 114 - 108 cm

Gs4, Sh^4+. Dl+

Nig.1, strf.0, elas.0, sicc.2, lim.sup.0

Coarse yellow sand with some slight organic content and detrital wood fragments.

Stratum 4 108 - 100 cm

Gs2, $Sh^4 2$, Dl+, anth.+

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Minero-organic material with small presence of detrital wood and charcoal.

Stratum 5 100 - 89 cm

$Sh^4 2$, Gs1, Ag1, Dl+

Nig.2+, strf.0, elas.0, sicc.2, lim.sup.0

Amorphous peat with high sand and silt fraction and wood pieces.

Stratum 6 89 - 81 cm

$Sh^4 3$, Dl1

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Brown amorphous peat with very small wood fragments.

Stratum 7 81 - 79 cm

$Sh^4 2$, anth.2, Ag++

Nig.3+, strf.0, elas.0, sicc.2, lim.sup.0

Dark amorphous peat with many small charcoal pieces and some silt.

Stratum 8 79 - 75 cm

$Sh^4 4$, Th(vagi)++

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Brown amorphous peat. Slight presence of Eriophorum at 76 cm.

Stratum 9 75 - 72 cm

Sh^{4}2, Ag1, anth.1, Ld^4++

Nig.2+, strf.1, elas.0, sicc.2, lim.sup.0

Amorphous peat with high fraction of organic mud, and bands of charcoal and silt.

Stratum 10 72 - 68 cm

Sh^{4}2, Th(*vagi*)^{2}2, Th^3+

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Amorphous peat with high macrofossil content of *Eriophorum*.

Stratum 11 68 -62 cm

Sh^{4}4, Th^3++

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Well humified, amorphous peat.

Stratum 12 62 - 53 cm

Th(*vagi*)^{3}4, Th^3++

Nig.2, strf.0, elas.1, sicc.2, lim.sup.0

Humified *Eriophorum* peat.

Stratum 13 53 - 50 cm

Th(*vagi*)^{2}2, Dl2, Th^3+

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Humified *Eriophorum* peat with *Calluna* twigs.

6.2.2 Pollen Stratigraphy

Samples for pollen analysis were removed from the NG1A profile at one centimetre intervals and the resulting pollen diagrams are shown as figures 37 and 38. These have been sub-divided into seven phases characterised by disturbance or stability type assemblages. These phases are also applied to pollen concentration diagrams (figure 39 and 40) and to charcoal diagrams (figures 41 and 42). Units of quoted figures are as in chapter five. The local phases are described as follows.

NG1A - 1 d 108 - 101.5 cm

Defined as a phase of disturbance by low *Quercus* percentages relative to the rest of the oak curve. *Ulmus* is steady at 20%. *Pinus* and *Betula* are the tree taxa which are most increased, but *Salix* rises through the phase and *Alnus* and *Corylus*/*Myrica* are also high. Weed pollen is not high, restricted to moderate values for *Melampyrum*, *Rumex* and single grains of ruderal types. Mire herbs are prominent and Gramineae increases at the end of the phase. High Filicales frequencies occur. Concentration values confirm the percentage changes, whole charcoal values are low.

NG1A - 2 s 101.5 - 80.5 cm

Defined as a phase of stability by high *Quercus* frequencies (60%). *Ulmus*, *Tilia* and *Alnus* are also high, the latter especially so late in the phase, rising to almost 80%. *Corylus*/*Myrica* remains as high as in the previous phase, except for at the beginning when both itself and *Alnus* fall temporarily, while *Salix* shows peak values of 65%. Less abundant but still high *Salix* frequencies persist for most of the zone, although absent at the end. Moderate Gramineae frequencies account for most of the N.A.P., but herb pollen grains occur throughout, usually wetland types, but with occasional small ruderal peaks. The Calluna curve is consistent at 20%.

NG1A - 3 d 80.5 - 78.5 cm

Defined as a disturbance phase by a sharp fall in Quercus frequency (45%) and including peaks in Betula, Pinus and Salix percentages. Alnus values decline gradually through the phase, and Corylus/Myrica is also reduced. Peaks in N.A.P. types include Gramineae, Rumex, Melampyrum, Pteridium and Filicales. The concentration spectra support the percentage data and high charcoal counts for the small and micro-size classes occur.

NG1A - 4 s 78.5 - 74.5 cm

Defined as a stability phase by high Quercus frequencies (60%). Betula, Pinus and Calluna are low and Salix is virtually absent. Alnus and Corylus/Myrica both fall sharply to around 40%. Fraxinus and Tilia are significant. Gramineae values remain high but other herb taxa are very low and mainly of wetland type. The Sphagnum curve increases. Concentrations are low and bog growth seems to have been rapid. Only oak is similar in concentration to the previous phase. Charcoal values are very low.

NG1A - 5 d 74.5 - 71.5 cm

Defined as a disturbance phase by a sharp fall in Quercus to 35%, after which it gradually recovers. Betula, Pinus, Alnus, Corylus/Myrica and Salix all increase to peak values. Fraxinus and Fagus rise but Tilia is reduced. Calluna increases and is abundant in mid phase. A wide range of herb types is recorded including many ruderals as well as wetland types. Pteridium, Melampyrum, Rumex and Plantago lanceolata are particularly increased. Filicales and Sphagnum also rise to peak values. Cerealia pollen is recorded. Concentrations are generally high, and particularly so for Corylus/Myrica (40). Charcoal is abundant and peaks occur in Neurospora and Gelasinospora reticulata.

NG1A - 6 s 71.5 - 59.5 cm

Defined as a phase of stability by a rise in Quercus frequencies to 60%. Ulmus reaches almost 30% and Tilia is important. Alnus falls to 35% and Corylus/Myrica is also much reduced. Fraxinus remains present but indicators of disturbance are very low indeed. N.A.P. is represented mainly by Gramineae and Sphagnum. The few other herbs present are mainly wetland types. Total concentration is low. Charcoal is very low also, while sporadic peaks in Gelasinospora reticulata occur.

NG1A - 7 d 59.5 - 50 cm

Defined as a phase of disturbance by a very marked fall in Ulmus pollen frequency, from 30% to 8%. Quercus, Alnus and Corylus/Myrica remain high in the first half of the phase, but all three fall very sharply indeed in the upper levels, when Betula and Calluna become abundant, although the latter is very important throughout. Fraxinus and Fagus also rise late in the phase. Gramineae, Cyperaceae and Sphagnum expand in frequency late in the phase, when non-tree pollen is greatly increased as a proportion of total pollen. Many ruderal herb grains are present in the later stages of the phase, with Pteridium and Plantago lanceolata curves rising to high frequencies. Melampyrum is almost absent. The concentration evidence supports the percentage data, and show Calluna to be most abundant. Charcoal frequencies are low, while Gelasinospora reticulata is consistently present.

6.2.3 Pollen Stratigraphy at 5mm Intervals

The pollen profiles at NG5 were initially counted at one centimetre intervals before proceeding to FRPA investigation, and the same procedure has been adopted at NG1A. It has been decided however, to investigate at NG1A the value of an intermediate degree of resolution, that of 5mm intervals, so that the relative merits of a twofold increase in resolution may be weighed against those of the centimetre interval and those of the tenfold increase used during one millimetre FRPA sampling. This should provide a measure of the improvement in data resolution to be expected from less extreme FRPA sampling, for one millimetre sampling may not in every research design be either practical or desirable, so that less detailed sampling may have to be adopted.

Accordingly, additional samples were taken from the same pollen profile at NG1A and the sampling interval closed to 5 mm. It was felt unnecessary to do this upon the whole of the profile, and so the 5 mm relative pollen diagrams (figures 43 and 44) begin in mid phase NG1A-2, at the upper limit of the minero-organic sediment, and continue until near the end of phase NG1A-7, beyond the Elm Decline. They therefore include the two later Flandrian II phases of disturbance. The NG1A centimetre phase zonation is retained for the 5 mm diagrams, which include pollen concentration data (figures 45 and 46) and charcoal data (figures 47 and 48). The boundaries of the pollen phases have therefore been defined more closely, but the more detailed pollen stratigraphy has yielded relatively little additional ecological information, tending to confirm the trends apparent from the coarser level diagram while in some areas increasing the quality of the data. Thus the counting of intermediate levels has allowed the identifiction of only eight additional taxa, none of which are critical to the interpretation of the data. The most significant result of the closer sampling interval has been to confirm the accuracy of the phase boundaries and the internal integrity of the pollen spectra assemblages. Thus while phase boundaries have been moved five millimetres up or down the profile in response to the finer sampling, the boundaries have lost none of their definition, being as sharp at the 5 mm level as at the 1 cm. No mixing of assemblages and thus blurring of the ecological signal has resulted. In contrast, while curve changes of indicator taxa remain sharp across phase boundaries, within the phases themselves the intermediate levels have led to a smoothing of curves, so that previously sharp fluctuations have tended to become more gradual, supporting these data as internally sequential records of vegetation history.

Of equal importance, unusual single-level features of the 1 cm diagram are diagnosed as reliable palynological events. A good example is the 70% peak in *Calluna* values which occurs at 73 cm with a cereal grain, *Fagus*, *Fraxinus* and a sharp *Salix* fall. The identification of a similar spectrum at 725 mm reduces the chance that this is a result of contamination of some kind, and increases its reliability as a record of environmental change. In particular the presence of *Melampyrum*, *Pteridium*, *Rumex* and other ruderals in the level prior to the fall of *Quercus* at the start of phase NG1A-3 is unusual, but shown to be a true record of events by the recognition of these indicators in three pre *Quercus* fall levels on the 5 mm interval diagram. In conclusion, the 5 mm level count has proven most valuable in allowing a more secure assessment of the importance of particular features of the pollen stratigraphy. It has also confirmed the integrity of the data set as a whole by supporting the internal consistency of pollen phases and the significance of the boundaries between them. On balance, however, insufficient extra ecological insights have been gained to change the interpretation of the pollen data in terms of stability and disturbance vegetation successions, although it has improved it in detail. It would seem, therefore, that initial analyses at the one centimetre level are as useful as at the 5 mm level in establishing the s/d history of a profile as a prelude to FRPA at the millimetre level. Initial analysis at other North Gill profiles will therefore continue to be at the centimetre interval of resolution.

6.2.4 Vegetation History at NG1A

The very clear fall in elm pollen percentages at the NG1A-6/NG1A-7 boundary is considered to be the Ulmus decline of the Flandrian II-III transition, by analogy with the evidence from the similar feature radiocarbon dated at NG5B. The three disturbances which predate the feature, as at NG5B, are therefore regarded as of Flandrian II age.

The earliest disturbance phase NG1A-1 records a removal of oak populations near to the site, providing opportunities for the expansion of ruderal weeds and secondary shrubs and trees like hazel, birch and pine. Alder is also apparently favoured by the oakwood disturbance, and this change may have prompted the establishment of alder carr in the shallow stream valley due to local paludification and peat inception. Potamogeton and rising grass and sedge counts reflect the establishment of marsh and aquatic habitats as part of this process. Abundant willow and grasses and persistent aquatics after the restoration of oak woodland at the start of NG1A-2 may point to some continued local flooding in the valley, probably as a response to changed hydrology after deforestation, Sphagnum moss becoming established. Some instability of slopes near this point may have continued, as the weed pollen types are still present in low amounts. Very dense deciduous woodland of terrestrial and carr types characterises the stable conditions of phase 2, with almost total dominance of oak with subsidiary hazel, supported by elm and lime, in the dryland forest which surrounded NG1A. Abundant alder and willow formed the local streamside carr, the latter diminishing gradually as alder achieved dominance through community successions. The shady, moist nature of this Flandrian II broadleaf forest is shown by the importance of Polypodium and Hedera, presumably as epiphytes, with several fen and carr herbs. Small peaks of open habitat herbs occur in mid phase 2 which might suggest either local soil instability of the valley side or that the tree canopy was not entirely closed, but the oakwood and carr associations shows no signs of significant disturbance.

The next real indications of vegetation change occur in the final levels of phase 2 where ruderal types like Melampyrum, Pteridium and a number of others recur, although without coincident tree pollen changes. These follow in phase 3 when real disruption of oak populations occurs and pine, willow and birch respond, presumably expanding to colonise the open areas. There are no changes in the distributions of either alder or hazel, so that neither taxon was involved in the successional changes following disturbance. Interpretation of this sequence of events is unsure, but an opening of the oak canopy by fire, charcoal being present, which allowed an increase in herb pollen but did not reduce oak pollen levels, due to the dominance of that tree in the local forest, until more advanced stages of succession when birch and willow had been stimulated to regenerate and flower by increased light levels in the clearing. Hazel needs quite intense fires to allow it to achieve local dominance and so the absence of any rise in Corylus/Myrica in phase 3 may suggest that the fire was insufficiently intense to achieve that result. Also, the fire could have occurred in part of the oakwood where hazel was not an important understory shrub, the area disturbed being close to NG1A but quite small in extent.

The restoration of the dryland oakwood was very successful, with elm and lime and some ash demonstrating that although dense it was of a secondary nature in part. The return of oak to dominance coincides with the sharp fall in the abundance of alder, as well as the near extinction of willow. The demise of the local carr vegetation around NG1A occurred, but was probably due not to exogenic disturbance of the alder and willow populations as much as to hydrological changes within the mire itself. Sphagnum moss rises steadily and more acid edaphic conditions and mire flora seem to have succeeded mesotrophic carr.

The final Flandrian II phase of disturbance at NG1A is different in many respects from those which precede it, not least in its magnitude. The scale of the tree pollen fluctuations is very great, with major deforestation of oak and lime and the expansion of many successional taxa, including birch, pine, hazel, willow and alder. Major deforestation must have occurred for the great expansion of bracken and Melampyrum. Most significant is the record of cereal type pollen with weeds of cultivation, a considerable amount of Plantago lanceolata and abundant Calluna pollen recording soil acidification, grassland pasture and broken ground. Agricultural activity seems to have been the cause of this disturbance phase. Its effects, although of major impact on the woodland, had few lasting consequences, as deciduous forest returns to NG1A in phase 6 and there are few indications of the persistence of open areas, herb pollen being absent except for taxa associated with the developing bog. This stable forest ecosystem survived intact until the Elm Decline itself, when a phase of woodland change occurs which is again different to those which had occurred previously. Oak became more abundant within the forest than before, with only elm populations significantly reduced. Hazel, birch and alder all expanded their distribution as a result of this woodland change, which was caused by clearance for cultivation, pollen of cereals and arable weeds becoming recorded. The intensity of this deforestation rose in late phase NG1A-7, for Calluna, Plantago lanceolata and Pteridium are abundant, so that grassland and heathland expanded greatly in area. Fire was apparently not involved in this forest recession, charcoal and Melampyrum being unimportant. A major phase of 'landnam' and a severe impact upon the woodland characterises the post Elm Decline levels at NG1A.

6.3 Phase NG1A - 3 FRPA

The pollen analyses at the one centimetre and five millimetre levels demonstrated that three disturbance phases occurred prior to the Elm Decline at NG1A and the second of these, NG1A-3, was chosen for FRPA in order to be compatible with the research strategy at NG5B, although it can not be presumed as yet that the second Flandrian II d phases at both sites represent the same palaeoecological event. Millimetre thick samples were taken through sediment which included phase NG1A-3 at a point where the strata seemed most horizontal. The micro-stratigraphy was as follows.

Sub-Stratum 2 850 - 800 mm

$Sh^4 2$, Dl2, $Ld^4 +$

Nig.3, strf.0, elas.0, sicc.2, lim.sup.1

Amorphous peat with a considerable proportion of tiny wood pieces.

Sub-Stratum 2 800 - 790 mm

$Sh^4$2, anth.2, Ld^4+, Ag+

Nig.4, strf.0, elas.0, sicc.2, lim.sup.1

Black amorphous peat rich in charcoal powder.

Sub-Stratum 3 790 - 786 mm

Ag2, anth.2, Sh^4+, Ld^4+

Nig.2, strf.0, elas.0, sicc.2, lim.sup.1

Fine silt and charcoal band in organic matrix.

Sub-Stratum 4 786 - 760 mm

$Sh^4$4

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Dark brown amorphous peat.

6.3.1 FRPA Pollen Stratigraphy

The FRPA pollen stratigraphy of NG1A-3 has been divided into the following eight zones of s or d type which are used to zone the relative pollen diagrams (figures 49 and 50) and are also applied to the concentration diagarms (figures 51 and 52) and the charcoal diagrams (figures 53 and 54).

Zone NG1A - A s 843 - 826.5 mm

Defined as a stability zone by high *Quercus* frequencies (60%). *Ulmus* steady at 20% and *Alnus* very high at 70%. *Corylus*/*Myrica* moderate at 60%, but *Betula* and *Calluna* low at <20%. *Salix* initially high but falls towards the end of the zone. Gramineae is high at 40% but other herb types are low, although *Rumex*, like Rosaceae and Cyperaceae, is consistently present. Occasional ruderals and aquatics recorded.

Concentrations are moderate, with sporadic peak values, and confirm the percentage changes. A little microcharcoal occurs, and Gelasinospora reticulata is common.

Zone NG1A - B d 826.5 - 821.5 mm

Defined as a disturbance zone by a fall of Quercus frequencies to 50%. Salix, Corylus/Myrica, Alnus, Betula and Pinus all increase, with Salix most markedly so. There are few changes in the herb flora except that Melampyrum increases slightly and indicator ruderals like Taraxacum-type and Chenopodiaceae occur. Concentration and charcoal figures remain stable.

Zone NG1A - C s 821.5 - 813.5 mm

Defined as a stability zone by a return of Quercus frequencies to over 60%. Few changes occur in other tree and shrub taxa except that Betula, Salix and Alnus are slightly reduced. Occasional ruderal herbs occur but in general herb and spore counts remain stable. Rumex maintains high values. Concentrations fluctuate little, although Gramineae is somewhat reduced, and charcoal remains low.

Zone NG1A - D d 813.5 - 808.5 mm

Defined as a disturbance zone by a decrease in Quercus frequencies to 50%. Betula and Salix are markedly increased with Alnus and Corylus/Myrica less so. A sharp peak in Melampyrum occurs, with lesser rises in Pteridium and Rumex. Concentration figures confirm the percentage data, with Gramineae also increased. Microcharcoal frequencies rise.

Zone NG1A - E s 808.5 - 799.5 mm

Defined as a stability zone by an increase of Quercus to almost 60%. Tilia also rises, while Salix and Betula fall in value. Other tree and shrub taxa change little. Herb taxa Melampyrum, Rumex and Potentilla are all reduced and values in general are low. Total concentration is unchanged and curves mirror the percentage data. Charcoal values are low.

Zone NG1A - Fi d 799.5 - 790.5 mm

Defined as a disturbance zone by a sharp fall in *Quercus* frequencies to 40%. *Betula* and *Pinus* rise sharply, while *Tilia* and *Fraxinus* also increase. Other tree and shrub taxa remain stable. *Melampyrum*, *Rumex* and *Potentilla* increase, while *Plantago lanceolata* and other herbs occur in low frequencies. Total concentration is steady. Major increases occur in small and microcharcoal size classes and *Neurospora* rises to a peak.

Zone NG1A - Fii d 790.5 - 785.5 mm

Defined as a disturbance zone by continued low frequencies of *Quercus*, although they begin to rise near the end of the zone. *Alnus* falls sharply to 45%. *Corylus*/*Myrica*, *Betula*, *Pinus* and *Calluna* show higher frequencies. Gramineae increases slightly, while *Potentilla*, *Melampyrum* and *Rumex* remain important. *Pteridium* rises to peak values. Concentration values change little. Microcharcoal and *Neurospora* remain high, while *Gelasinospora reticulata* increases.

Zone NG1A - G s 785.5 - 764 mm

Defined as a zone of stability by *Quercus* frequencies of over 60%. *Alnus* remains low at 50%. *Betula* falls sharply in value, and *Salix* and *Pinus* less markedly. Other tree and shrub taxa vary little. Herb and spore values remain relatively steady, although some open habitat types still occur. Apart from isolated peak values, concentrations fall initially after which they recover to moderate figures. Little charcoal is recorded.

6.3.2 Interpretation of NG1A-3 FRPA

The FRPA data from phase NG1A-3 are analogous to those from NG5B in that they form a comprehensible and apparently sequential record of vegetation change at NG1A at the micro-scale. There is virtually no indication that processes leading to pollen mixing have worked to distort the ecological record to any degree, either in the movement of sediment itself or in the transport of pollen within the sediment column, either during incorporation or post depositionally. The profile is a combination of sharp changes, smooth changes and steady curves, and the pollen zones are bodies of sediment with internal pollen assemblage integrity and without the stochastic features which might result from pollen mixing across the chronological gradient of the profile. The second successful result of the millimetre FRPA method at North Gill, following that at NG5B, suggests that the analysis of other profiles by this technique is likely also to yield reliable ecological data. Further profiles at North Gill will therefore be investigated by FRPA.

The vegetation present around NG1A during zone A was dominated by deciduous forest trees and shrubs, with oak and alder most abundant but elm and lime also important, once their lower pollen productivity has been taken into account. Hazel and birch formed important subsidiary components of the woodland, as understory or at forest edge locations. The distribution of the populations of each tree type is difficult to deduce, but the abundant alder percentages and alder fragments below this part of the stratigraphy would suggest that wetter streamside habitats would have sustained dense concentrations of alder, as well as within the wider forest. Carr vegetation may not have occurred, but the declining willow curve would suggest that alder was supplanting willow in more aquatic locations at this time. Aquatic herb pollen, and many marsh and fen herbs, confirm the local existence of pool conditions in the stream valley at this site, as does the presence of other aquatic microfossil indicators such as Mougeotia and Zygnema (van Geel 1978). Significant Hedera, Lonicera and Polypodium values reflect the damp, shady environments associated with the dense vegetation around NG1A at this time.

The disturbance which occurs in zone B seems to have had effects which were confined to the oak populations of the dryland forest, and the alder groves around the profile itself were not affected to any real extent. Willow and birch were the regeneration taxa most encouraged by the removal of oak dominance, with hazel less clearly increased, and this presumably reflects the composition of the pre disturbance forest. The less open character of the woodland around the lower end of the stream valley may have allowed these taxa, with alder, to profit from any break in the oak canopy which was insufficiently intense to cause the creation of significant open ground, but allowed light to penetrate to the forest undergrowth shrubs. Hazel may require a more radical removal of competing tree cover to be able to become locally dominant. Hazel must have been present in the surrounding woodland to register such a consistently high curve in both s and d zones. It may have formed a fringing scrub layer between the valley alder carr and the more mature woodland of the dryland beyond. That the pollen fluctuations of zone B are quite low scale phenomena, with few ruderals and small shifts in tree pollen, could suggest that a screen of shrub vegetation between the mire and the dryland forest acted to reduce the impact of disturbance upon the pollen record. The exception is in the willow curve, and some real local expansion, repeated in zone D, gives rise to the Salix fluctuations of late phase NG1A-2 at the centimetre scale, which are revealed by FRPA as due to repeated disturbance of local woodland. Zone D represents a slightly less ephemeral event which is closely similar to that of zone B. It may have occurred slightly nearer to NG1A, since more charcoal and Melampyrum record the effects of fire more clearly, but it was still not close enough to disturb the NG1A alder wood, and was confined to oak populations once again.

Full restoration of mixed oak woodland communities took place after these small scale disturbances, with little evidence of any lasting environmental effects. The third FRPA d zone appears to represent either larger or closer disturbance of the stable woodland around NG1A, with inwash of charcoal and soil into the profile, a steeper fall in oak values and more ruderal evidence of bare ground or grassland. This zone, which is further divided into Fi and Fii on the basis of the behaviour of the alder curve, corresponds to phase NG1A-3 at the centimetre level. The initial deforestation once again was restricted to the oakwood, with oak removal providing opportunities for birch, pine and ash. The greater proximity of this event is confirmed by the subsequent sharp fall in alder frequencies, and the thin silt layer in zone Fii clearly corresponds with the disturbance of alder populations on the stream valley slopes themselves. Alterations in local mire hydrology as a result of clearance were probably not sufficient cause to explain the alder fall here, for other indicators of hydrological conditions like Salix, Sphagnum, aquatic herbs or aquatic non-pollen microfossils do not change appreciably. That tree regeneration was under way in the dryland oakwood when this late alder fall occurred is clearly seen in the FRPA profile and this allows a more ecologically precise interpretation of this sequence of events than was possible from the low resolution centimetre data. The removal of alder from its local habitats was a major consequence of the disturbances of zone F, for the regeneration of deciduous woodland in zone G did not extend to the recolonisation of the stream banks by alder. Although still a major local component of the forest, the continued lower values of alder in the stable zone G do not reflect the extreme abundance which had existed previously, and which must have been due to almost in situ alder growth at NG1A. Its very local role also seems not to have been adopted by any other taxon, and a more open mire vegetation around the site itself existed from this time on. That total restoration of tree cover did not occur is shown by the persistence of open habitat taxa after disturbance ceased. Some open ground at the ecotone between mire and forest is likely.

The FRPA record at NG1A has increased the precision with which the disturbance of phase 3 may be interpreted, with the fluctuations of zone F representing a sequence of vegetation changes which may have resulted from more than one disturbance impact, with varying spatial relationships to the NG1A site. In particular, however, FRPA has revealed two smaller episodes of disturbance which were not observable in the centimetre level pollen profile of phase 2, but which represent quite distinct impacts upon the deciduous woodland environment. Pollen fluctuations in the centimetre profile of this age which had no disturbance associations have been shown to be due to these small scale events and thus explained ecologically. FRPA at NG1A, as at NG5B, has thus shown itself to be a far more sensitive record of vegetation history than had proved to be possible at the coarser, centimetre level.

6.4. Phase NG1A - 5

The success of the FRPA study of phase NG1A-3, as at NG5B-3, has meant that FRPA will continue to be undertaken at this pollen stratigraphical level if it can be identified at further profiles at

North Gill, so that it may be possible to attempt a spatial interpretation of the fine scale ecological changes taking place during this part of Flandrian II. The final pre Elm Decline phase at North Gill 1A, NG1A-5, has been shown by analysis at the 5 mm level to be also of great interest, however, with evidence of major forest recession and cereal cultivation. More detailed pollen investigation of this disturbance phase was therefore decided upon, and as a prelude to analysis at the FRPA millimetre level, samples were prepared at every 2.5 mm through the phase in order to test the degree to which ecological resolution was improved at a sampling interval intermediate between the 5 mm and 1 mm levels. Pollen analysis will therefore have been performed upon phase NG1A-5 at the 10 mm, 5 mm, 2.5 mm and 1 mm levels, to test whether a direct relationship exists between increasingly fine sampling intervals and increasing resolution of ecological information yielded. It is important to be able to assess at what point in the process of ever finer sampling does the increased expenditure in time and effort cease to be justified by the improvement in ecological data obtained. The sediment of NG1A-5, an amorphous mud-peat, is highly suitable for FRPA and thus also for an empirical study of this kind.

A fresh column of peat which included NG1A-5 was extracted from the monolith tin and samples were taken at intervals of 2.5 mm with a scalpel blade. The microstratigraphy of this column was complex, including some very thin silt layers. As this column was superjacent to that sampled for FRPA at NG1A-3, the sequence of four sub-strata for NG1A-3 FRPA is extended to include the NG1A-5 FRPA column as follows.

Sub-Stratum 5 760 - 747 mm

Th^{3}2, Th(*vagi*)^{3}2

Nig.3, strf.0, elas.0, sicc.2, lim.sup.2

Humified monocot peat with *Eriophorum*.

Sub-Stratum 6 747 - 745 mm

Sh^{4}2, Ag2, Ld^{4}+

Nig.3, strf.0, elas.0, sicc.2, lim.sup.1

Dark brown silt-rich amorphous peat.

Sub-Stratum 7 745 - 743 mm

Sh^{4}2, Ld^{4}2, anth.+, Ag+

Nig.2, strf.0, elas.0, sicc.2, lim.sup.1

Light brown, creamy mud-peat with some charcoal and silt.

Sub-Stratum 8 743 - 739 mm

Sh^{4}4, Ld^{4}+, anth.+

Nig.3, strf.0, elas.0, sicc.2, lim.sup.1

Dark brown amorphous peat.

Sub-Stratum 9 739 - 737 mm

Sh^{4}2, anth.2, Ld^{4}+

Nig.3, strf.0, elas.0, sicc.2, lim.sup.1

Dark brown amorphous peat with charcoal.

Sub-Stratum 10 737 - 735 mm

Ag2, Sh^{4}1, Ld^{4}1, anth.+

Nig.2, strf.0, elas.0, sicc.2, lim.sup.2

Fine silt in a peat-mud matrix.

Sub-Stratum 11 735 - 722 mm

anth.2, Sh^{4}1, Ld^{4}1

Nig.4, strf.0, elas.0, sicc.2, lim.sup.1

Charcoal rich peat-mud.

Sub-Stratum 12 722 - 720 mm

Sh^{4}2, Ag2

Nig.2, strf.0, elas.0, sicc.2, lim.sup.2

Amorphous peat and silt.

Sub-Stratum 13 720 - 690 mm

Th^{3}2, Th(*vagi*)^{2}2

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Humified monocot and *Eriophorum* peat.

6.4.1. Pollen Stratigraphy

The pollen stratigraphy at the 2.5 mm sampling through phase NG1A-5 is shown upon the relative pollen diagrams (figures 55 and 56). Concentration diagrams (figures 57 and 58) and charcoal diagrams (figures 59 and 60) are also shown.

Phase NG1A - 4 s 750 - 746.5 mm

The lower two levels of the 2.5 mm diagrams comprise the end of phase NG1A-4 and are defined as of stability type by *Quercus* frequencies of almost 70%. Alnus is low at 30%, Ulmus steady at almost 20% and Corylus/Myrica moderate. Only Gramineae and Sphagnum are important herb and spore types. Concentration values confirm the percentage counts. Charcoal values are low.

Phase NG1A - 5 d 746.5 - 721.5 mm

Defined as a phase of disturbance by low Quercus frequencies of less than 40%. Betula, Corylus/Myrica and Alnus are all greatly increased throughout, while Calluna, Fraxinus and Fagus show peak values near its end and Pinus highest frequencies at the start of the phase. Melampyrum is important throughout except at the end when ruderal taxa, including Plantago lanceolata, Pteridium and Cerealia frequencies rise sharply. Many mire herb types occur. Concentrations rise and charcoal peaks occur.

Phase NG1A - 6 s 721.5 - 710 mm

Defined as a phase of stability by Quercus frequencies of 60%. Pinus and Betula fall sharply, while Alnus and Corylus/Myrica decline to moderate values. Tilia increases and Fraxinus peaks occur. Few open habitat herbs occur, and only Gramineae is significant. Concentrations are moderate and little charcoal occurs.

6.4.2 Interpretation of the 2.5 mm Data

The main interest of the 2.5 mm data lies in their comparability with the pollen record at the 5 mm scale of resolution. Halving the interval between sampled levels has not brought any diminution in the clarity of the pollen phase boundaries, for the oak fall and rise which define the NG1A-5 phase are still extremely clear at this scale of resolution. The agreement between the overall pollen record at both the 2.5 mm and 5 mm levels is very good, and since the two peat profiles sampled are immediately adjacent but not identical, this close similarity of pollen data suggest excellent horizontality of sediment over a few centimetres distance. The presence of organic gyttja sediments suggests a very shallow pool depositionary environment, which would encourage lateral homogeneity of deposition at this micro scale. This will be investigated further below. The shallow water pool environment suggested by the high *limus* component of the sub-strata 6-11 is confirmed by other microfossil types shown by Van Geel (1978) to indicate such environments. *Mougeotia*, *Zygnema* and rotifers are common in these mud-peats, while cladoceran remains and *Spirogyra* also occur. In contrast the *Eriophorum* and monocot peats of sub-strata 5 and 12 do not contain a pool flora and fauna, but instead include taxa like *Amphitrema flavum*, *Assulina* and other mire peat testaceous rhizopods, and *Microthyrium* (Godwin and Andrew 1951). Since these various fungal, algal and animal remains are almost always found *in situ*, their presence in this part of the North Gill 1A profile gives valuable information regarding local environmental conditions of the mire surface and thus conditions of pollen deposition.

The close comparability of the 2.5 and 5 mm diagrams may be clearly seen in the trends of almost all of the pollen curves, and these two pollen records are good evidence of the replicability of the technique, given comparable conditions of pollen deposition. Events such as the late phase 5 *Calluna* peak and its association with *Fraxinus*, *Fagus*, *Pteridium*, *Plantago lanceolata* and Cerealia are faithfully reproduced in both profiles, including the decline in *Melampyrum* pollen which occurs at this point. More subtle trends, like the gradual decline of *Pinus* through phase 5, also correspond between the diagrams. Few differences occur, most interesting perhaps being the twin peak in *Salix* at 5 mm which does not register in the 2.5 mm diagram. Filicales acts similarly.

The comparison of the two pollen records therefore shows that virtually no sediment mixing has occurred, even at the 2.5 m level and that the NG1A-5 record is an accurate sequence of events. That two adjacent microprofiles show the same pollen record in considerable detail suggests that the horizontality of the sediments is extremely high, and thus they are ideal for FRPA sampling. That a small proportion of local pollen taxa like willow and ferns deviate between the two profiles demonstrates that even over distances of only a few centimetres, taphonomic factors may affect individual types. The value of the 2.5 mm diagram, however, is that it confirms the presence of cereal pollen and associated deforestation evidence. The recording of this phenomenon in an adjacent but separate peat column from the NG1A monolith tin, at exactly the analogous level, makes contamination during sampling a most unlikely explanation for the pollen records and confirms their biostratigraphic authenticity.

In broad terms, therefore, the lower part of the 2.5 mm diagram records stable oak-elm forest with alder and hazel subsidiary shrubs and few indications of anything other than densely wooded conditions. A phase of disturbance thus took place at the start of the phase NG1A-5 in which local oakwoods were opened, allowing the expansion of shrubs birch, alder and hazel and the colonisation of the field layer and open ground by Melampyrum, ruderal herbs and bracken. Some relaxation of disturbance took place until late in phase 5 when a major episode of deforestation occurred, apparently for cereal cultivation, which caused the expansion of grassland, broken ground and Calluna heath. In NG1A-6 restoration of closed deciduous forest took place with little evidence of continued disturbance.

6.5 Phase NG1A - 5 FRPA

The pollen and stratigraphic analyses described above have shown that phase NG1A-5 occurs in sediments well suited to fine sampling and that it contains a most interesting pollen record of major environmental disturbance, which also appears to have horizontal integrity. The phase has therefore been subjected to FRPA sampling at the millimetre level. The micro-stratigraphy for the FRPA sampling remains the same as that described above for the 2.5 mm diagram.

6.5.1 FRPA Lateral Sub-Sampling

The first stage in the FRPA study of NG1A-5 was to investigate the horizontality of sedimentation of the pollen stratigraphy at the millimetre level. FRPA work at NG5B and NG1A-3 showed sharp changes at FRPA zone boundaries which seemed to discount the possibility of vertical mixing of pollen in the profile. The 2.5 mm pollen counts also seemed to show lateral integrity of pollen assemblages, with clear-cut changes which mirrored those of the adjacent 5 mm column. The horizontal integrity of each FRPA sample at the millimetre scale remains an assumption, however, for since each FRPA millimetre thick disc of sediment is 2 cm in diameter, even a slight dip in the horizontal plane of deposition could produce a composite assemblage at such a fine vertical sampling interval. This would have implications for the interpretation of the FRPA data and reduce the reliability of the ecological information yielded. The horizontal integrity of the FRPA assemblages was therefore tested by slicing a centimetre of sediment into one millimetre thick discs in the usual way, and then by dividing these 2 cm discs into four quadrants which were prepared separately. The assemblages of the quadrants should reveal any lateral variation in the pollen content of the FRPA disc caused by slight gradients in sedimentation leading to sample mixing. The boundary between NG1A-4 and NG1A-5 was chosen for the test, as any mixture of the two contrasting assemblages would be clearly visible. The resulting pollen assemblages therefore represent both extremely fine spatial and fine temporal pollen data, and they are presented as relative pollen diagrams (figures 61 and 62), concentration diagrams (figures 63 and 64) and charcoal diagrams (figures 65 and 66). Even though sample volumes were very small, high concentrations meant that enough pollen was present to maintain the usual counting sum. As FRPA sampling of NG1A-5 was to be contiguous with that of FRPA at NG1A-3, the system of FRPA zones from phases 3 and 4 are retained and extended into the phase 5 stratigraphy. Later FRPA study (see below) of phase NG1A-5 has shown that the lower five levels of figures 61 and 62 represent FRPA zone G (NG1A-4) and the upper five levels have thus been designated zone H,equivalent to the start of NG1A-5.

The four quadrants of each level vary within zone G and zone H in the expected way; major taxa frequencies are very similar both between quadrants and between levels, since within zone assemblages are by definition comparable. Also as expected, the less common taxa in these situations show more variability, in terms of presence or absence, than the abundant types, for the recording of these rarer types in any particular assemblage is largely a matter of chance, becoming more likely with increased numbers of grains counted. Thus in the stable zone G Hedera, Fraxinus or various herb grains occur in only one or two quadrants out of four, or not at all, because their frequencies are at such low levels that their recording varies in stochastic manner. The percentages of more abundant types like Quercus, Alnus or Gramineae, however, vary little within the homogeneous vegetation types of either zone G or H. The first major observation of these data is that, whether of disturbance or stability type, the four quadrants at any level are very similar, suggesting that horizontality of each level is real. This is critical when levels across the zone G/H transition are compared, for levels on either side which are internally homogeneous differ strongly from each other. Melampyrum is a good example, the four quadrants of level 746 mm being similar at 15%, but with hardly any Melampyrum present at level 747 mm. Pteridium, Salix, Quercus, Pinus and Betula all behave in the same way, there being no blurring of the stability/disturbance distinction with these taxa across the zone boundary. Those which are not indicators of disturbance effects here, such as Ulmus, Alnus, Calluna or Gramineae are similar in both boundary levels.

The evidence, therefore, is that assemblage mixing across the zone boundary had not occurred, so that horizontal stratification seems to be proven. One explanation of this could be that some truncation of the profile may have occurred at this level, causing an hiatus and later deposition of disturbance type assemblages after an interval of time. The behaviour of some critical curves argues against the existence of an hiatus, however, in providing evidence of a more gradual change across the zone boundary. In particular, the level before the boundary, 747 mm, records a small fall in Quercus percentages to 55% from a previous steady 65%, before a major fall to 30% across the boundary. Similarly Corylus/Myrica rises from 50% to 65% before rising across the boundary to 70%. Betula moves from 10% to 15% before rising to 35% across the boundary. Calluna rises from 10% to 15% before maintaining and increasing higher values across the boundary, which is defined by the major fall of oak as at all other diagrams.

With certain taxa, particularly oak, hazel and birch, the final level of zone G appears transitional to the disturbance type assemblages of zone H. This was not apparent at the 2.5 mm level of resolution. Indeed, while the major changes in birch and oak are delayed until the first level of zone H, the major hazel increase is completed in the final level of zone G. This transitional behaviour of oak, birch and hazel can not be interpreted as evidence of pollen mixing, however, firstly because the quadrant assemblages at each level show hardly any difference at all in the percentages for individual taxa, as would be inevitable if lateral variability in deposition or post-depositional mixing were the cause. The main reason why mixing is not a possible factor, however, is that only these three or four major taxa show any signs of transitional frequencies. Important indicator taxa like Melampyrum, Pinus, Salix and Pteridium show no signs of transitional frequencies at all, having very sharp changes across the boundary. The combination of sharp changes, gradual changes of different kinds and within-level quadrant similarity would appear to rule out hiatus, pollen mixing and non-horizontal deposition as significant factors affecting the pollen stratigraphy at the zone G/H (phase NG1A-4/5) boundary. The conclusion must be that the FRPA biostratigraphy, at least at this part of the profile, is both a vertically and horizontally reliable record of vegetation history. It is not practical to check each FRPA profile in the same way, but this test analysis has shown that FRPA spectra, even at this extremely fine scale, can represent accurate ecological records, given ideal sediment type. The fluctuations in oak, birch and hazel prior to the main disturbance changes of NG1A-5 must therefore be regarded as real palaeoecological events and interpreted accordingly.

The above analyses have certainly shown this part of the NG1A profile to be suitable for full FRPA study.

6.5.2 FRPA Pollen Stratigraphy

The FRPA pollen stratigraphy of NG1A-5 has been divided into the following three zones of s or d type which are used to zone the relative pollen diagrams (figures 67 and 68), and are also applied to the concentration (figures 69 and 70) and charcoal (figures 71 and 72) diagrams. The NG1A-5 FRPA record is a continuation of the NG1A-3 record, so the NG1A-3 zonation scheme is retained and extended for the NG1A-5 data.

Zone NG1A - G s 763 - 746.5 mm

This zone is a continuation of the zone G recognised upon figures 49 and 50, the NG1A-3 FRPA diagrams. It is defined as a stability zone by *Quercus* frequencies of 70%. *Alnus* is low at 40%, *Ulmus* steady at 20% and *Corylus*/*Myrica* moderate at 55%. *Tilia* is consistent around 10%. *Betula* and *Calluna* are low. Apart from an isolated *Sphagnum* peak, Gramineae is the only important herb and spore type. Concentrations are low and little charcoal occurs.

Zone NG1A - H d 746.5 - 721.5 mm

Defined as a zone of disturbance by a sharp fall in *Quercus* frequencies to 30%. *Betula* increases sharply to 30%, *Pinus* also rises to peak values, although declining late in the zone, as does *Salix*. *Corylus*/*Myrica* increases to 75%, while *Alnus* is more moderately increased. *Calluna* is increased to 20% until the end of the zone when it rises sharply to 75%. Peak frequencies of *Melampyrum* of up to 20% occur at the start and in mid zone. *Pteridium* is important at the beginning, and a great increase in ruderal weed pollen, particularly *Plantago lanceolata*, occurs near the end of the zone. Cerealia pollen also occurs at this time. Concentration values are high, while charcoal peaks occur at intervals, but particularly in mid zone, with *Neurospora* spores.

Zone NG1A - I s 721.5 - 695 mm

Defined as a zone of stability by an increase in *Quercus* frequencies to 60%. *Ulmus* steady at 20%, while *Tilia* is consistent at 10%. *Corylus/Myrica* continues to decline, while *Alnus* percentages remains low and fluctuate. *Betula*, *Pinus*, *Salix* and *Calluna* are all much reduced in frequency. Occasional ruderal herbs occur, but mainly herb pollen is contributed by Gramineae, which rises late in the zone, and mire herbs. Peaks of *Sphagnum* occur. Concentrations fall and support the percentage data. Charcoal values are low, while peaks of *Gelasinospora reticulata* occur.

6.5.3 Interpretation of NG1A - 5 FRPA

The duplicate analyses and fine spatial analyses described above have supported the validity of the NG1A-5 pollen stratigraphy as a sequential ecological record. The FRPA spectra are contiguous with those of the upper zone G of the NG1A-3 stratigraphy, and the NG1A-5 basal zone G of figures 67 and 68 shows a continuation of its characteristic closed deciduous forest environments. The full FRPA zone G is therefore equivalent to phase NG1A-4. Oak remains the dominant dryland tree during this zone, although it fluctuates a little and seems to have a reciprocal relationship with alder. Natural alterations in the species composition of the woodland at the stream valley edge are suggested here due to edaphic factors or even, at this fine temporal scale, succession due to the demise of individual trees near to the sampling point. Short-term population changes should produce such perturbations in the curves of the established forest taxa given the very local source area of much of the pollen rain to this site at this time. Similar features may be noted in the curves for Corylus/Myrica and Betula which will represent autogenic successional development within the local forest community. The single high Calluna peak of zone G presumably reflects temporary colonisation of land very close to the pollen sampling point by heather plants rather than any significant change in vegetation patterns. Taxa like willow and ash were clearly not locally common, with very low frequencies, and the low pine curve could well represent longer distance transport of grains rather than local populations. Oak-elm woodland with lime and a rich hazel-alder shrub flora seems to have been the stable vegetation in this zone. High grass values probably reflect conditions in the stream valley or upon the mire surface, in association with several mire herb types which occur. The isolated zone G Sphagnum peak probably represents very local mire surface change, although of limited extent as grass percentages are not affected.

The stability of this deciduous forest was shaken by a very substantial episode of disturbance which is reflected by the pollen fluctuations of FRPA zone H, which is equivalent to phase NG1A-5. The consistent low values for Quercus and lack of major changes in the other forest taxa within zone H itself, mean that further sub-zonation of zone H is not attempted. Nevertheless some variability in the behaviour of non-tree and shrub disturbance indicators show that the disturbance zone H is comprised of the results of more than one disturbance impact upon the vegetation.

The first two spectra of zone H record substantial removal of oak from the woodland matrix near to NG1A, with its pollen frequency more than halved. Alder was also caught up in this deforestation to some extent, as a slight fall in alder pollen occurs at this time. Elm, however, rises so that it was presumably growing beyond the area where oak destruction took place, escaping population loss and increasing its pollen count by eased transportation through the disturbed area around NG1A. Ruderal herbs like *Plantago lanceolata*, Cruciferae, Chenopodiaceae, *Senecio*-type and *Artemisia* show that disturbed, bare ground was created, and the inwash of eroded mineral soil into the peat profile shows that it was adjacent to the mire, perhaps on the slopes on the edge of the stream valley. The charcoal peaks and high values for *Melampyrum* and *Pteridium*, with *Epilobium*, show that fire was the main instrument of vegetation change. Pine may well have also responded to local burning, while willow, hazel and birch all expanded to form shrub communities within and at the margins of the burned area. Of particular interest is the behaviour of oak, hazel and birch in the final level of zone G, for there is a fall in oak and a rise in hazel and birch which appears to be transitional between stable zone G and disturbed zone H. This FRPA pollen stratigraphy therefore replicates the changes recorded in the FRPA quadrant spectra (figure 61), which were obtained from the adjacent micro-profile, including the absence of *Melampyrum* and other disturbance indicators from the ultimate level of zone G.

The identical ecological signal from the two FRPA micro-profiles must mean that these are records of real vegetation changes in which oak, hazel and birch were affected in a prelude to the major disturbance manifest as zone H. It also reinforces the excellent lateral integrity of the sediment at this part of the NG1A peat column. These limited changes in a few tree and shrub types are difficult to explain, but it could be that a light canopy burn in the local woodland could have reduced the output of oak pollen and encouraged the flowering of the main understory types, birch and hazel, producing the pollen fluctuations recorded without radically altering tree populations. Such canopy opening might have been a preliminary stage to the main fire disturbance of the forest at the start of zone H.

After the initial two spectra of zone H, some relaxation of disturbance pressure occurred, for many indicators of open conditions are reduced and some tree taxa recover slightly. *Melampyrum* and *Pteridium* almost cease to be recorded at this time, few weed taxa occur, and willow, hazel and pine are reduced. Alder, and also slightly oak, increase in frequencey.

A second disturbance impact occurs in mid zone H and lasts until near to its end. Again oak is particularly badly affected but lime populations were also reduced, its pollen curve becoming discontinuous. Significant deforestation through fire took place, extending from the very edge of the mire into the mature broadleaf forest, for the combination of macro and microcharcoal peaks with those for *Neurospora* suggest very local burning (Van Geel 1978). The abundant *Melampyrum* counts, and lesser evidence of *Pteridium*, *Calluna*, *Epilobium* and *Artemisia* shows that the fire created a major clearing within the previously closed forest. Willow, pine, birch and hazel, all taxa able to survive and expand after forest fire, are present in very high frequencies throughout this second disturbance impact of zone H. A rich complex of regeneration shrubs must have formed the vegetation within the area opened by burning. Heliophyte and secondary trees like *Fraxinus*, *Fagus*, *Crataegus*-type, *Prunus* and *Viburnum* are common in this episode, taking advantage of the opportunities provided for immigration by the distabilisation of the oakwood. Few taxa occur which are of bare ground or grassland type which are not associated with the effects of fire, and the vegetation changes taking place in this episode are entirely consistent with the effects of a major, local forest fire.

The third and final disturbance impact within zone H occupies the final four spectra of the zone and is radically different in kind to the two impacts recorded before it. Oak values remain very low, although a slight recovery does occur, so that the local oakwood remained the scene of the disturbance episode. A slight, but distinct, fall in the *Ulmus* curve occurs, however, which suggests that the area affected by disturbance was extended to include soils carrying elm populations, whether in stands or dispersed through the oakwood. Major changes occur in the response of regeneration, heliophyte shrubs, however. Hazel and pine, taxa adapted to post-fire regimes, both decline to lower, although still substantial, frequencies. Willow, abundant in the post-fire conditions of the previous disturbance impact, is virtually absent during this one. Similarly *Melampyrum*, which previously rivalled willow's abundance, is reduced to low levels in this final stage of zone H. It appears that all taxa promoted by fire are disadvantaged in this episode, and charcoal values themselves, although registering a small peak, do not compare with their previous abundance. Fire was evidently not the major force operating in the final disturbance impact of zone H.

Much the most important aspect of this episode is the recognition of Cerealia grains of *Triticum*-type at more than one level, for these permit the interpretation of the pollen changes of these four spectra in terms of human forest clearance for cereal cultivation. These grains are accompanied by ruderal and grassland weeds which are accredited indicators of clearance and agriculture. *Plantago lanceolata* shows a sustained peak and also present are *Taraxacum*-type, Chenopodiaceae, *Artemisia*, Cruciferae, *Matricaria*-type and *Polygonum aviculare*, a suite of weeds indicative of both pasture and cultivation (Behre 1981). This phase of forest clearance had a major impact upon the forest, resulting in the temporary expansion of areas of grassland and heath, and erosion of soils into the mire. Increased bracken and birch, as well as ribwort plantain show that open heathland was created, but the main indicator is the abundance of heather in this episode. Some degeneration of soils due to real forest clearance, rather than mere disturbance, may have occurred. Even if only of limited duration, this forest clearance clearly had a major impact upon the woodland around North Gill 1A, with vegetation changes of a scale and type hitherto not recorded at the site.

At the end of the zone H cultivation episode the local woodland became re-established, for oak, elm and lime all return to high frequencies and alder remains important as a lesser forest component with the declining hazel. The fall of birch and the gradual decline of heather reflects the reoccupation of the area by deciduous tree cover. It is most interesting therefore that in the first six spectra of zone I, when the tree and shrub pollen curves no longer show open conditions, that cereal-type grains continue to be recorded, and reduced but consistent curves for Plantago lanceolata, Pteridium, Melampyrum and Artemisia still occur. This could be due to contamination from the previous zone, but the fully recovered pollen curves for the deciduous forest trees and shrubs discount this, for contamination by only a few of the rarer herb types without also altering the balance of tree frequencies seems implausible. It seems much more likely that the sporadic weed and cultivation grains in early zone I are at their correct stratigraphic level. It is possible that the woodland canopy had become closed once again after the area cleared for cultivation had been abandoned and left to regenerate, thus restoring the deciduous tree pollen rain to its former abundance. If a fringe of more open ground lay between the forest and the North Gill mire, however, limited cultivation and pasture in that location could transmit low levels of cereal and weed pollen to NG1A, without causing any alterations to the tree cover and thus to the tree pollen rain, in a final, very local stage of cultivation. The still high heather curve at this time might support the existence of valley edge open areas, although breaks in the dryland forest canopy no longer existed.

The rest of zone I reflects a vegetation history dominated by the mixed oak forest, with few non-woody flora which are not involved with the development of the mire. The pool phase of mire history comes to an end in zone I and since the length of time pool conditions existed equates with zone H closely, the wetter mire surface may have been a result of the disturbance impacts of that time.

6.5.4 FRPA Half-Millimetre Samples

Samples from the NG1A-5 part of the profile have been subjected to pollen analysis at increasingly fine sampling intervals from 1 cm to 1 mm, and the FRPA data at the millimetre scale have provided a reliable record of vegetation history. Clearly the FRPA diagram from NG1A-5 does not represent the limits of the technique in these sediments. An attempt was therefore made to explore the limits of the FRPA technique by reducing the sampling interval still further. Thin-sectioning of the mud-peat at the boundary between zones G and H was undertaken at intervals of 0.5 mm. Although frozen, the top and base of the peat column in the microtome chamber failed to section successfully at this extremely small interval. The central part of the column, however, which included the zone boundary area, sampled successfully and the results of the analyses of these 0.5 mm thick samples is shown upon relative pollen diagrams (figures 73 and 74), concentration diagrams (figures 75 and 76) and charcoal diagrams (figures 77 and 78).

As with the millimetre FRPA diagrams, the zone boundary is drawn below 746.5 mm, where the major fall in Quercus pollen frequencies occurs, although a smaller fall from high frequencies occurs in the level below that. This resembles the behaviour of oak in the final millimetre level of zone G, but other transitional features of that millimetre stratigraphy in hazel and birch do not occur, both taxa rising quite sharply at the boundary as in other diagrams. Pinus is more gradual however, a feature not previously recorded.

Within zone H the features of the millimetre curves are preserved at this finer level, and initial peaks in Salix, Melampyrum, Pinus and Pteridium occur which are followed by a period of lower percentages, before peak values return later in the zone. Other, less diagnostic, pollen curves closely resemble the millimetre record. This half-millimetre test analysis has shown that the FRPA sampling technique can function successfully at this most extremely fine interval, and where the pollen record is suitable can provide ecologically sensible results at that scale. This must, however, be approaching the technical limits of the method, as well as the stratigraphic integrity limits of pollen assemblages, depending upon the deposition rates of individual sediments. Furthermore, the quality of the ecological data at this extreme level is hardly an improvement upon the millimetre scale. Nevertheless the feasibility of using FRPA at this extreme level in exceptional circumstances has been demonstrated by the results of this test analysis.

6.6. Conclusion

This chapter has investigated the sensitivity and replicability of the FRPA technique by testing the NG1A pollen record across the full range of degrees of resolution and at fine spatial scales. FRPA has been shown to be an effective research technique. Although each decrease in sampling interval improved the quality of the data yielded, it seems that initial sampling at the one centimetre interval was sufficient to detect the presence of disturbance phases within the pollen stratigraphy and to define their limits. Fine sampling at the one millimetre level was then the optimum scale at which to extract highly detailed and reliable ecological data. This strategy, used at NG5B, will therefore be retained in the FRPA study of other pollen profiles at North Gill.

CHAPTER SEVEN

OTHER FRPA PROFILES

7.1 Introduction

After the effectiveness and reliability of the FRPA method had been tested at NG5 and NG1A and shown to be successful, further profiles were chosen for detailed analysis. After pollen analysis at the one centimetre level of a further six profiles, three were selected as being in suitable locations and containing satisfactory pollen stratigraphies for FRPA work. These three are designated NG4, NG6 and NG7 and their locations are shown on figure 6.

7.2 North Gill 4

This profile is located just north of lateral boring transect N and on site transect 4 in a small sector of low gradient in the stream valley. It is intermediate between NG1A and NG5, and was chosen to investigate ecological conditions between the lower and central section of the North Gill study transect. Sampling was undertaken at a point where stratigraphic units seemed most horizontal and a wood layer in the lower profile was fragmentary, to allow sub-sampling for pollen. The basal metre of organic and minero-organic sediments were recovered in monolith tins.

7.2.1 Lithostratigraphy

After field and laboratory investigation, the following lithostratigraphy was recorded.

Stratum 1 Below 96 cm

Gs4

Nig.1, strf.0, elas.0, sicc.2, lim.sup.1

Coarse, yellow sand.

Stratum 2 96 - 94 cm

Gs3, Ag1, Sh^4++

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Coarse sand and silt with high organic fraction.

Stratum 3 94 - 92 cm

Sh^{4}2, Ag1, anth.1, Gs+

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Amorphous minero-organic peat with charcoal.

Stratum 4 92 - 86 cm

Sh^{4}3, Ag1, Th^2+

Nig.3+, strf.0, elas.0, sicc.2, lim.sup.0

Brown amorphous peat with slight silt fraction.

Stratum 5 86 - 71 cm

Th^{3}2, Dl2, Sh^4++

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Brown herbaceous peat with many wood fragments. Alnus branch at 74 cm.

Stratum 6 71 - 69 cm

Th^{2}4

Nig2+, strf.1, elas.1, sicc.2, lim.sup.1

Humified herbaceous peat with high turfa macrofossil content.

Stratum 7 69 - 67 cm

$Sh^4 2$, Ag1, anth.1, Ld^4++

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Amorphous peat with detrital mud. Major silt and charcoal content. Stronger silt band and 68 cm.

Stratum 8 67 - 62 cm

$Th^3 4$, Sh^4+, Th(vagi)^3+

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Well humified amorphous herbaceous peat with slight Eriophorum presence.

Stratum 9 62 - 50 cm

$Th^3 2$, Th(vagi)^{2}2

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Mid humified Eriophorum and herbaceous peat.

7.2.2 Pollen Stratigraphy

Samples for pollen analysis were removed from the NG4 profile at one centimetre intervals and the resulting relative pollen diagrams are shown as figures 79 and 80. These have been sub-divided into seven phases characterised as of disturbance (d) or stability (s) type. These phases are also applied to the pollen concentration diagrams (figures 81 and 82) and the charcoal diagrams (figures 83 and 84). Quoted concentration figures are 10^3 grains cm^{-3} and percentages are of AP+G. The local phases are described as follows.

NG4 - 1 d 95 - 92.5 cm

The lowermost phase is defined as one of d character by low Quercus values (40%). Alnus frequencies are also depressed at <60%, while those taxa considered indicative of disturbed and regeneration habitats are well represented. Corylus/Myrica (70%), Betula (30%), Salix (30%) and Fraxinus are very significant. Pinus is higher than average for the diagram, but not a major factor at only a little over 10%. Potentilla, Melampyrum, Rumex and Pteridium are in high percentages while other ruderals , like Artemisia, also occur Filicales values are high, as are those of Gramineae (40%). The percentage figures are supported by the concentration data in general, although total concentrations are quite low. Some taxa, like Betula and Pinus, do not match percentage peaks with high concentrations. Charcoal data confirm the d status of the phase, however, with all size classes and Neurospora present in peak frequencies.

NG4 - 2 s 92.5 - 69.5 cm

Defined by high Quercus frequencies of over 50%. Single levels occur towards the end of the phase where oak frequencies are less high, but not sufficiently to warrant their separation as d phases. Alnus percentages are very high at 80%, steady in the majority of the phase but fluctuating near the end. Corylus/Myrica is significant throughout but reduced from the basal phase, while Salix gradually fades from its maxima at the start of the phase. Other woody taxa are consistently moderate throughout. N.A.P. values are generally low, contributed mainly by Gramineae. Despite isolated peaks of Pteridium and sporadic ruderals (Plantago lanceolata at one level) indications of disturbance are equivocal. Peak frequencies for Rumex of 20% late in the phase are an important feature. Alnus concentrations fall near the end of the phase, but total concentrations are also falling. Microcharcoal frequencies, but not concentrations, rise late in the phase, and Gelasinospora and G. reticulata increase.

NG4 - 3 d 69.5 - 67.5 cm

Defined by a sharp fall in Quercus percentages to <30%. Alnus also falls to <40% and Tilia is greatly reduced. Peak frequencies are recorded for Salix, Corylus/Myrica, Pinus and Betula, which reaches almost 40%. A peak of Melampyrum occurs, but few other indicators of disturbance are present except moderate Pteridium. Total concentrations rise, but Corylus/Myrica is superabundant, rising to 85. Gramineae concentration rises to 20. Peak values for microcharcoal and Neurospora occur.

NG4 - 4 s 67.5 - 63.5 cm

Defined by a rise in Quercus pollen frequencies, reaching 70%. Alnus recovers slightly but reaches only 40%. Corylus/Myrica, Salix, Betula and Pinus all fall, although the first of these remains significant. Calluna is very poorly represented, but Fraxinus shows peak values. Gramineae is the only significant herb pollen recorded, while Sphagnum rises sharply to 70%. Pollen concentrations confirm the percentage evidence. Very little charcoal is present.

NG4 - 5 d 63.5 - 59.5 cm

Defined by a sharp fall in Quercus frequencies to 40%. Alnus also declines, but recovers late in the phase to 50%. Betula, Pinus and Calluna show peak values, while Corylus/Myrica is also increased and the Salix curve begins to rise. Tilia frequencies fall and Fraxinus increases. Gramineae frequencies rise to 70% with Filicales and, especially, Sphagnum expanding also. A moderate Melampyrum peak is the only significant disturbance type in the herbaceous pollen record, although a continuous Pteridium curve begins. The concentration evidence confirms these data, with Sphagnum very high at 43. A peak in microcharcoal values occurs and Neurospora also rises.

NG4 - 6 s 59.5 - 55.5 cm

Defined by a rise in Quercus frequencies to 60%. Alnus, Tilia and, as throughout, Ulmus are relatively unchanged. Betula, Pinus, Corylus/Myrica and Calluna fall to low values, but Salix and Fraxinus remain present, as is Fagus. Gramineae and Sphagnum remain important, but little else of the N.A.P. types is significant, although Rumex and Pteridium rise late in the phase. Total concentration is low, and the curves do not fluctuate. Little charcoal is recorded.

NG4 - 7 d 55.5 - 51 cm

Defined by a sharp fall in Ulmus pollen frequencies from 20% to 10%. Quercus remains high, while Alnus increases to 50%. After an initial rise Corylus/Myrica declines gradually, while Pinus is very low. Betula increases while Calluna expands to peak values of over 40%. N.A.P. percentages decline due to a sharp fall in Gramineae to 20%, although Cyperaceae rises in frequency. Pteridium and Sphagnum remain important but most significant are peak frequencies of Plantago lanceolata, although ruderal types are otherwise low. Pollen concentrations are generally low, and largely confirm the percentage data. Charcoal frequencies are low. Gelasinospora reticulata is increased.

7.2.3 Vegetation History at NG4

The decline of elm at the NG4-6/NG4-7 boundary is interpreted as representing the Ulmus decline at the Flandrian II-III transition. The lack of change in the Quercus pollen curve marks this horizon out as different to the pollen phase boundaries which preceded it at NG4 and the great increase in Plantago lanceolata rather than Melampyrum which accompanies it is analogous to events at the radiocarbon dated profile of NG5B. This level is therefore correlated with that dated Ulmus decline of 4730±80BP (HAR-6620). The three disturbance phases which occur beneath it at NG4 are therefore of Flandrian II age, the considerable alder frequencies of NG4-1 showing that the base of the profile cannot antedate the start of Flandrian II. Peat inception was coincident with a phase of fire disturbance of woodland, with oak and alder well below their optimum values at the site, and the expansion of a range of heliophyte woody taxa encouraged by opening of the forest canopy to form heterogeneous successional communities as the disturbed area regenerated. Willow, birch, hazel, and ash were encouraged to spread during this period, and perhaps pine also was locally present. That open ground was created is shown by the presence of ruderal taxa and herbs increased after burning of woodland, like Melampyrum. The presence of a range of mire or marshy ground herbs may well indicate a degree of paludification which led to peat inception at the site. The abundance of willow may reflect the establishment of carr vegetation around the lower end of the stream valley, a response to increased wetness, as well as any Salix populations in the general post fire seral scrubland. Although this earliest phase of forest recession was clearly of major impact within the landscape, the area around NG4 was still well wooded, and this is much more so the case when regeneration succession led to the restoration of forest cover in phase NG4-2. The superabundant alder values must mean that alder carr, or at least streamside stands of the shrub, fringed the stream at NG4, perhaps supplanting the willow carr, which gradually fades from the ecological record. Oak expanded to dominate the dryland forest, in which hazel, elm and some alder acted as subsidiary components. Consistent birch and heather curves may record areas of more acid soils where relict heathland survived. The stable vegetation was deciduous woodland of varying type, however, and no open ground seems to have remained to break the forest cover. Herb types point to marshy or streamside habitats only.

Pollen fluctuations which occur towards the end of this phase are suggestive of slight disturbance but the fall in oak frequencies is too small to be interpreted in that way with any certainty. Coincident falls in alder pollen occur, however, and taxa such as hazel and pine have inconsistent curves which may be the faint reflections of disturbance too far from NG4 to be recorded clearly in the pollen record. The Rumex peak of this time is likely to be an artifact of very local Rumex growth in a wetland context, rather than a disturbance effect. Clumps of Rumex pollen point to its very local source. No ruderal weed pollen occurs to support the designation of this part of phase NG4-2 as one of disturbance.

The ecological changes which characterise phase NG4-3 are clearly a record of major forest recession, however. Both oak and alder were removed and replaced by the familiar range of post disturbance seral types; birch, pine, hazel, willow and Melampyrum. Hazel is particularly abundant, and the presence of both silt and charcoal in the profile point to considerable soil erosion resulting from this removal of local woodland. No matter how severe were the effects of disturbance, the oak populations of the affected area were fully restored upon regeneration and the open condition indicators show by their absence that reforestation was complete. The exception to this is alder and the reduced levels of alder from NG4-3 onwards show that the alder carr which hitherto occupied the stream valley at this site was absent after this disturbance. Alder wood is no longer present in the profile, but the Sphagnum curve increases greatly from this time so that the end of abundant local alder growth may result from changes in the bog hydrology and acidity rather than direct destruction, although the input of exogenous material into the mire shows that changes in the catchment were likely to have been sufficiently major to have been at least partly instrumental in the process. Low concentrations point to an increased rate of bog growth after NG4-3.

The third phase of reduced oak values may be interpreted as a further example of deforestation around NG4. Although the extent of the decline in oak cover seems less than in the previous d phase, it was still a major event, with birch and pine the taxa which respond most vigorously to the opening of the oak canopy. Hazel hardly increases at all, so that perhaps soil changes had given birch an advantage in the regeneration communities. Most herbs are of wetland type and the bog continued to grow rapidly with Sphagnum and Eriophorum abundant. Some weed types do record ruderal habitats, but are not plentiful.

The final phase of stable vegetation prior to the elm decline was a time of closed canopy deciduous forest, with oak and elm most common but with an important admixture of lime and alder, and some remaining hazel understory. There are no indications of breaks in this forest cover, other than the mire itself, with sporadic weed grains of little significance. The elm decline itself is ecologically similar to that at NG5, with oak, alder, birch and hazel all expanding their representation in response to the removal of elm populations. The greatest expansion is in heather, however, reflecting some heath establishment in the deforested areas, with some grassland areas shown by the Pteridium and Plantago lanceolata curves. A change in the type rather than the extent of woodland cover may have been the result of disturbance in this early Flandrian III phase, with the more open kinds of vegetation swiftly becoming recolonised by woodland trees.

7.3 NG4 FRPA

The one centimetre analysis at NG4 proved that a well defined series of pollen phases existed of which three were of disturbance type prior to the elm decline. As at NG5B and NG1A, the second of these phases was chosen for FRPA, being of suitable sediment structure and of reasonable size for sampling. Only two centimetre spectra were included within the d phase NG4-3, but it was noted that for up to seven centimetres before the start of NG4-3 much smaller perturbations of the pollen curves sensitive to disturbance had occurred, including the oak and alder curves, the origins of which were problematical. It was concluded that it was exactly this kind of small scale evidence that FRPA could best elucidate, and so both NG4-3 and this end phase of NG4-2 were included within the FRPA, a total of ten centimetres. A point was chosen where the wood fragments in the stratigraphy could be avoided, although some very tiny pieces were still present but did not hamper freezing and thin sectioning at the millimetre scale. No major refinement could be seen in the lithostratigraphy, which was as follows.

Sub-Stratum 1 780 - 710 mm

$Th^3 2$, Dl2, Sh^4++

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Brown herbaceous peat with tiny wood fragments.

Sub-Stratum 2 710 - 690 mm

$Th^3 4$

Nig.2+, strf.0, elas.0, sicc.2, lim.sup.1

Humified herbaceous peat.

Sub-Stratum 3 690 - 682 mm

Sh^{4}2, Ag2, anth.+. Ld^{4}+

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Amorphous silty peat with charcoal and organic mud.

Sub-Stratum 4 682 - 670 mm

Th^{3}4

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Humified herbaceous peat.

7.3.1 *FRPA Pollen Stratigarphy*

The FRPA pollen stratigraphy at NG4 has been divided into seven zones of s or d type and are used to zone the relative pollen diagrams (figures 85 and 86) and are also applied to the concentration diagrams (figures 87 and 88) and the charcoal diagrams (figures 89 and 90).

Zone NG4 - A s 770 - 765.5 mm

Defined as a zone of stability by high *Quercus* frequencies. *Alnus* is also very high at 75% and *Ulmus* steady at 50%. *Corylus*/*Myrica* is over 50%. Gramineae is the main herb taxon at 30%. Concentration values confirm the percentage counts and tree and shrub types are by far the most abundant. There is very little charcoal.

Zone NG4 - B d 765.5 - 757.5 mm

Defined as a zone of disturbance by a sharp fall in *Quercus* frequencies to 45%. *Ulmus* and *Tilia* rise by 10%, but *Alnus* is unchanged. *Pinus*, initially, and *Betula* increase to peak values and *Corylus*/*Myrica* is only slightly enhanced. *Pteridium* and *Rumex* frequencies increase greatly, but other open habitat types are very poorly represented. All other pollen curves are relatively stable. Concentration values peak twice within the zone, although not all taxa increase on both occasions. Concentrations of Alnus (204) and Corylus/Myrica (150) are extremely high. Charcoal and Gelasinospora reticulata are present but low.

Zone NG4 - C s 757.5 - 729.5 mm

Defined as a zone of stability by a sharp increase in Quercus frequencies which fluctuate around 60%. Alnus is unchanged at 70% until suffering a slight decline at the end of the zone. Corylus/Myrica remains high at about 60% while Betula, Ulmus and other major taxa also remain stable. Apart from Gramineae at 30%, most notable feature is Rumex which fluctuates around 20%. Concentrations are reduced from the maxima of the previous zone and remain steady. Little charcoal is recorded.

Zone NG4 - D d 729.5 - 718.5 mm

Defined as a zone of disturbance by a fall in Quercus values to 45%. Alnus is also slightly reduced (50%) while Betula and Corylus/Myrica are marginally increased. Ulmus rises to over 30%. A consistent Erica curve is present. A slight presence of Melampyrum and other disturbance herbs like Plantago lanceolata and Artemisia occurs, while Rumex ceases to be recorded in mid zone. A steady Potentilla curve is present. Concentration values fluctuate widely but do not contradict the percentage figures. Charcoal remains low.

Zone NG4 - E s 718.5 - 697.5 mm

Defined as a zone of stability by the rise of Quercus frequencies to 60%. Alnus frequencies remain depressed at 50% but rise to 70% in late zone and a peak of 90% at its end. Ulmus is reduced from its peak of the previous zone to 20% and other taxa change very little. Concentrations show occasional peaks but in general are stable. Charcoal remains low.

Zone NG4 - F d 697.5 - 678.5 mm

Defined as a zone of disturbance by a sharp fall in *Quercus* percentages which reach only 30% in late zone. *Alnus* falls also, then recovers slightly, then falls to as little as 25% late in the zone when *Ulmus* is also slightly reduced. *Betula* and *Fraxinus* increase in the initial period of *Quercus* and *Alnus* decline, but at the time of their major decline there are great increases in *Betula*, *Pinus*, *Corylus*/*Myrica*, *Salix* and *Calluna*. Many heliophyte shrubs occur. *Melampyrum* is consistently near 10%, and several other ruderal herbs are recorded. *Pteridium* is important throughout. Concentration evidence confirms this evidence, although the fall in *Quercus* concentrations is much less pronounced than in the percentage data, while *Corylus*/*Myrica* is particularly abundant (168). Peaks in small charcoal, microcharcoal and *Neurospora* occur.

Zone NG4 - G s 678.5 - 671 mm

Defined as a zone of stability by the rise of *Quercus* frequencies to 60%. *Betula*, *Pinus*, *Corylus*/*Myrica*, *Salix* and *Calluna* all fall sharply from their maxima of the previous zone. A peak of *Fraxinus* occurs. *Alnus* increases only slightly to about 40%. Ruderal herb types are almost absent. Only *Sphagnum* increases greatly, to around 80%. Concentrations uniformly fall very sharply, except for *Sphagnum* which is increased. Charcoal falls to very low values.

7.3.2 Interpretation of NG4 FRPA

As with the results from NG5B and NG1A, the FRPA data from NG4 seem to represent a sequential and sensitive record of palaeoecological change at the micro scale. There is no clear evidence of biostratigraphic mixing in either the percentage or concentration data, and so the FRPA diagram may be interpreted as a reliable record of events.

The minor and equivocal fluctuations in major pollen taxa which occurred late in the NG4-2 centimetre phase have been resolved by FRPA into two small but quite discrete episodes of disturbance in the oak woodland around NG4. The same criteria are used to define these two minor zones of disturbance as for the more obvious disturbance episodes and so their recognition would appear to be equally valid. The lack of any lithostratigraphic evidence of forest removal, not even increases in the microcharcoal input, suggests that these do not represent major local impacts on the vegetation and the absence of any indicators of open ground creation, or even of substantial canopy opening, confirms this view. The pollen curves suggest that some displacement of oak took place in zone B, but that the alder carr which the abundant alder pollen suggests surrounded NG4 remained undisturbed. The filtering effects of this dense screen of carr woodland (Tauber 1967) would probably have muted considerably the pollen record of oak removal on the drier ground further from the NG4 mire. It is possible that the fall by windthrow of a few oak trees tens of metres from NG4 would produce a small open space which would take about three decades to regenerate to woodland, a period of time in line with the several FRPA levels which zone B covers. Regeneration took place mainly through birch with increased wind influx of pine pollen during the more open conditions of the earlier stages of the event. Alternatively a larger episode of disturbance taking place at a greater distance might produce very similar pollen fluctuations, the open ground herb and heliophyte taxa failing to register clearly in the pollen diagram due to transport deficiencies over the greater distance. This problem in the interpretation of FRPA data is discussed in more detail in chapter ten. Whatever the cause or spatial location of this small disturbance of oak populations, however, the FRPA investigation has not only been sensitive enough to define it clearly, but has been able to recognise the pattern of ecological changes within it, despite their extremely ephemeral nature.

The second zone of slight disturbance, zone D, is very similar in this respect for progressive changes in the ecological information yielded may be discerned in the kind of temporal detail impossible at the coarser degree of resolution. Thus oak is generally replaced by elm in zone D, reflecting a change in the proportions of the local deciduous forest trees due to temporary oak removal. At a finer scale, however, it seems that ash was favoured in the early stages of the zone, whereas birch and hazel were more important near its end. Hazel also seems to profit from a limited removal of alder towards the end of the zone, so perhaps the drier edges of the alder carr were included within the oakwood disturbance of this time. It could be that the initial flowering advantage given to understory ash trees by oak canopy opening was lost when more intense disturbance, <u>Pteridium</u>, <u>Melampyrum</u> and microcharcoal increase slightly and <u>Tilia</u> also falls, caused actual removal of alder, oak and ash populations after which regeneration through willow, hazel and birch took place. Whatever the ecological history of zone D, distinct changes are recognisable within it by FRPA which were insufficiently clear at the coarser level of resolution to warrant its description as a d phase. Whether the cause was very minor or not very local, zone D is a clearly defined zone of disturbance at the FRPA level. The intervening zones of stable woodland and the changes in mire taxa have also been clarified by the FRPA investigation, so that natural processes registered only broadly at the centimetre level of resolution are much more clearly defined. Natural periodic fluctuations in the relative taxa composition of the stable broadleaf woodland occur. Most interestingly periodic peaks in the oak curve occur in zone C approximately every eight pollen spectra, which may represent an interval of about 25 years if an average FRPA interval of about three years per sample is accepted. Rhythmic natural cycles in tree populations may be recorded here, and these are echoed mainly in the elm, lime and alder curves, perhaps reflecting the natural population dynamics of the undisturbed mid Flandrian II mixed oakwood.

It is interesting that the start of curves for Potentilla, Melampyrum and Pteridium coincide with the end of the major Rumex curve in mid zone D. The rise of Rumex in the disturbance zone B to exceptional levels for a herb taxon must have meant the growth of individual plants very close to the sampling point of NG4 and its increase and persistence in zone C suggests that it must be regarded as a highly local component of the mire flora, there being several Rumex species which are of mire habitat. If disturbance were the cause of the demise of Rumex in the same way that ash and alder decline, then its effects must have been felt upon the mire surface, either directly or by proxy in hydrological changes. Since charcoal values hardly change, the latter is more likely and a direct link between the end of Rumex and the rising Gramineae and Erica curves may be probable, particularly if of Erica tetralix, due to increased wetness of the local mire surface. The intermittent nature of the Erica curve and the fluctuations which occur in the alder curve in zone E must document fluctuating hydrological conditions at the mire edge, for the absence of any disturbance of dryland communities at this time would suggest that an unstable hydrological regime occurred in zone E with alder unable to re-establish itself in its dominant carr form. That alder was eventually successful is demonstrated by its superabundance at the end of zone E when it must have completely dominated the mire edge vegetation. An interesting feature of the FRPA stability zones, as with the stability phases at the centimetre level, is the appearance of Fagus. Beech was clearly encouraged to immigrate into the oakwood during the recurrent disturbance in Flandrian II around NG4.

The foregoing vegetation changes are all referable to the latter part of phase NG4-2, but the more obvious disturbance impacts of phase NG4-3 are very clearly defined upon the FRPA diagram as the events of zone F. As in the previous d zone, a short, fainter episode of disturbance occurs at the start of zone F where ash, birch and pine replace oak , alder and hazel although other indications of disturbance, aside from the start of higher bracken values, are very few indeed. Again it may be that an initial episode of canopy destruction preceded a more intense deforestation. The FRPA data show that this low scale change in canopy composition, not recorded at all at coarser resolution, is separated from the main disturbance event of zone F by a short period of restored oak and alder levels. The FRPA data show very clear evidence of destruction of oak and alder woodland in the second half of the zone, however, when deforestation took place very close to NG4, destroying the local alder carr and some of the adjacent dryland oakwood and creating enough bare and destabilised soils to allow the inwash of soil and charcoal into the mire from devegetated slopes. The regeneration of the cleared area through a ground flora of Melampyrum, bracken and a range of ruderals including grassland weeds like Plantago lanceolata and then the familiar suite of successional shrubs and trees is very similar to the evidence of centimetre phase NG4-3. Differences are revealed by FRPA however. Increased *Calluna* occurs in zone F but is not present in phase NG4-3, for example. The greatest contrast is in the quality of data yielded, however. In particular, the curves for taxa such as *Melampyrum*, *Pteridium*, *Pinus* and *Quercus* seem to have a double peak, and so an even greater degree of understanding of the changes taking place during this major disturbance episode may be possible. Some of the FRPA changes at the end of zone F, for example the curves for *Melampyrum*, *Salix*, *Pinus* and *Fraxinus*, are quite sudden, although some curves do show more gradual changes. Some degree of discontinuity may be present here, although perhaps only a natural time delay prior to the resumption of deposition may be involved, of a length rather greater than intervals within the d zone. The FRPA data match the centimetre data very closely in these changes, however, and the withdrawal of clearance pressure could well be expressed in quite rapid alternations in local vegetation. The rise of *Sphagnum* across this boundary is a further point of agreement between the two scales of resolution. Certainly the FRPA data also show the major restoration of a densly forested environment, balanced by the failure of locally abundant alder carr to reoccupy the locality of the site itself, where a more oligotrophic type of flora had become established due to changed edaphic and hydrological conditions.

7.4 North Gill 6

This profile is located just north of lateral transect F and between longitudinal site transects 4 and 5. It is intermediate between NG5 and NG7, within the first area of shallow gradient below the confluence of the North Gill headwaters. It is thus the most northerly profile within the stream valley proper, and was chosen to investigate ecological conditions at the point where the stream valley is most adjacent to the upland plateau edge. Sampling was carried out at a point where the sediments were most amorphous and horizontal. There were few wood remains in the stratigraphy. The basal metre of organic and minero-organic sediments were recovered in monolith tins.

7.4.1 Lithostratigraphy

After field and laboratory investigation the following lithostratigraphy was recorded.

Stratum 1 Below 100 cm

Gs4

Nig.1, strf.0, elas.0, sicc.2, lim.sup.1

Coarse yellow sand.

Stratum 2 100 - 92 cm

$Sh^4 2$, Gs2, anth.+

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Amorphous, minero-organic peat with a little charcoal.

Stratum 3 92 - 90 cm

anth.4, Sh^4++

Nig.4, strf.0, elas.0, sicc.2, lim.sup.0

Charcoal band, with amorphous organic material.

Stratum 4 90 - 82 cm

$Sh^4 3$, Dl1

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Brown amorphous peat with small wood fragments.

Stratum 5 82 - 79 cm

$Sh^4 2$, Ag1, anth.1, Ld^4++

Nig.2+, strf.0, elas.0, sicc.2, lim.sup.0

Dark amorphous clayey peat, with some charcoal and silt.

Stratum 6 79 - 72 cm

$Th^3 2$, Th(vagi)^{3}2

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Well humified herbaceous peat with Eriophorum

Stratum 7 72 - 70 cm

Th(vagi)^{2}4

Nig.2, strf.1, elas.1, sicc.2, lim.sup.0

Band of fresher Eriophorum peat.

Stratum 8 70 - 62 cm

Th(vagi)^{3}2, $Th^3 2$

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Humified Eriophorum and monocot peat.

Stratum 9 62 - 60 cm

Th(vagi)^{2}4

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Fresher Eriophorum peat.

Stratum 10 60 - 50 cm

Th(*vagi*)^{3}2, Th^{3}2, Dl+

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Humified *Eriophorum* and monocot peat, some *Calluna* twigs.

7.4.2 Pollen Stratigraphy

Samples for pollen analysis were removed from the NG6 profile at one centimetre intervals and the resulting relative pollen diagrams are shown as figures 91 and 92. These have been subdivided into seven phases of stability or disturbance type. These phases are also applied to the pollen concentration diagrams (figures 93 and 94) and the charcoal diagrams (figures 95 and 96). Units for quoted figures are as for previous profiles. The local phases are described as follows.

NG6 -1 d 99 - 90.5 cm

Defined as a d phase by generally low, although fluctuating, *Quercus* frequencies. *Alnus* frequencies are very low (35%) while *Ulmus* is steady at 20%. *Betula*, *Pinus* and *Corylus*/*Myrica* are high, and *Calluna* (30%) is also important. Open habitat types *Pteridium* and *Melampyrum* show peak values and other ruderal taxa occur. Gramineae dominates the N.A.P. assemblage. Overall concentrations are very high, particularly for *Corylus*/*Myrica* (105). *Neurospora* occurs, but charcoal percentages are not very high, except at the end of the phase.

NG6 - 2 s 90.5 - 82.5 cm

Defined as of s type by increased *Quercus* frequencies (55%). *Alnus* is abundant (75%) while *Betula*, *Pinus*, *Corylus*/*Myrica* and *Calluna* all fall to moderate frequencies. *Salix* (20%) becomes important. Gramineae declines in value and other herb pollen types are very low. Concentration values are low, only *Alnus* (30) being abundant. Little charcoal occurs. Gelasinospora reticulata increases.

NG6 - 3 d 82.5 - 79.5 cm

Defined as a d phase by reduced Quercus frequencies (40%). Alnus is slightly reduced initially then recovers. Pinus, Corylus/Myrica and Salix increase, as do Gramineae, Pteridium, Melampyrum, Rumex and other herbs. Concentration values support the percentage data. Charcoal of all size classes increases, and microcharcoal concentration is high. A peak of Neurospora occurs.

NG6 - 4 s 79.5 - 73.5 cm

Defined as of s type by high Quercus frequencies, reaching 70% at the end of the phase. Alnus declines gradually but is still very high, but Salix falls from high values to 10%. Betula and Ulmus are unchanged at 20%, but Pinus is very low. Gramineae remains high, but other herb types are poorly represented. Total concentrations are low, but Alnus in particular falls sharply at the end of the phase. Charcoal values are low, but Gelasinospora reticulata peaks occur.

NG6 - 5 d 73.5 - 72.5 cm

Defined as a d phase by a very sharp fall in Quercus frequencies to 40%. Major peaks occur in Corylus/Myrica, Betula, Pinus, Salix and Calluna. Tilia declines while Fraxinus increases. Peaks occur in Melampyrum, Pteridium and Filicales. Concentration figures support the percentage data closely except that Quercus concentration does not fall. Charcoal increases significantly, but only to moderate levels.

NG6 - 6 s 72.5 - 59.5 cm

Defined as an s phase by high Quercus frequencies (60%). Ulmus and Tilia are consistent and Fraxinus increases late in the phase. Alnus gradually declines to 30%, while other tree and shrub taxa also are reduced in frequency, Salix being almost absent. Sphagnum rises to recurrent peak values, but herb types are low, only Gramineae being a major contributor, although Rumex is significant early in the phase. Except for Sphagnum, concentrations are low. Little charcoal is recorded.

NG6 - 7 d 59.5 - 50 cm

Defined as a d phase by a major fall in Ulmus pollen values, from 20% to 8%. After a slight initial decline, Quercus remains high. Betula, Alnus, Corylus/Myrica and especially Calluna increase in frequency. Gramineae declines but Cyperaceae is increased in value, while Sphagnum falls to low percentages. Plantago lanceolata and Pteridium curves show major peaks. The concentration figures support the percentage data. Charcoal is virtually absent.

7.4.3 Vegetation History at NG6

The decline of elm at the NG6-6/NG6-7 boundary is interpreted as the Ulmus decline at the Flandrian II-III transition, for the pollen changes are similar to the radiocarbon dated elm decline at NG5B, with Quercus not subject to change and a consistent Plantago lanceolata curve occurring from the level of the elm fall. Three phases of disturbance below this level are therefore of Flandrian II age.

The basal disturbance phase coincides with the start of peat formation at NG6 and both alder and oak were apparently adversely affected by disturbance, although the latter fluctuates strongly in abundance. The replacement of oak and alder woodland by birch, pine and hazel scrub seems to have followed local burning of the vegetation, the fire response herb Melampyrum being prominent in the early stages of regeneration and expansion of heather dominated heathland also occurring. Ruderal herb types like Plantago lanceolata point to the creation of open grassy areas, with bracken present within and at the edge of the open area. Immigration of woodland taxa ash, hawthorn and surprisingly in Flandrian II, hornbeam was probably aided by the destabilisation of the primary mixed oak woodland. High overall concentration suggests that peat growth was relatively slow, added perhaps to high pollen productivity in more open vegetation.

Local regeneration, within the stream valley and at the stream edge, caused the creation of dense local alder and willow carr with an oak-hazel woodland upon the drier areas beyond containing lesser amounts of elm and alder. Wood remains in the peat derive from the local carr vegetation. Restoration of the forest after disturbance was almost complete, with no indications of persisting open areas. Renewed fire disturbance of the surrounding oakwood which took place in NG6-3 gave ash, hazel and lime the chance to increase representation among the tree cover during regeneration, and the range of ruderal herbs which accompany this second episode of deforestation shows that open ground was created around the site. Although the impact of fire disturbance in the oakwood was very strong, however, it appears that the local carr vegetation was unaffected, and some expansion of willow took place. Detrital mud and microfossils which indicate open water, such as Zygnema and Mougeotia (Van Geel 1978), point to pools existing here, although aquatic pollen is absent. Conditions for the maintenance of carr communities existed, and these were either undisturbed or survived so close by that their pollen was recorded in the profile in great abundance. Inwash of charcoal of large size into the profile still occurred, so that very dense carr did not obstruct the input of material into the sediment, whether growth of carr was in situ or adjacent to the site.

That part of the willow expansion of NG6-3 was as a result of the burning of the oakwood is shown by the gradual reduction in the abundance of willow in the next phase when oakwood regeneration took place and the successional communities brought about by disturbance were no longer part of the vegetation. Dense tree canopies in this restored forest cover caused a reduction in hazel abundance as well as in willow, but alder remained largely unchanged, its maximal values probably still caused by abundant local growth, although the conversion of the profile to a cotton-grass peat shows that any local pool phase had been superseded by more acid bog growth, which perhaps contributed to the local demise of willow. Perhaps a willow, alder and oak gradient from mire to dry ground existed upslope from the stream, for the mire hydrology change appears not to have affected alder populations.

The third phase of deforestation is confined to a single pollen level but is of great clarity, with major removal of oak from around NG6 and the great expansion of the familiar series of secondary trees and shrubs like birch, hazel, willow, pine and ash. Alder is also much less abundant but its reduction starts at the end of the previous phase and whether due to local hydrology or actual removal of alder populations by disturbance impacts remains conjectural. These impacts were sufficient to create ruderal and heathland vegetation in place of woodland around the site. The fall of alder is closely linked to the rise of the Sphagnum curve, however, and the decline of alder is thus more likely an autogenic process, although perhaps accelerated by the effects of deforestation in encouraging hydrological change. Bog growth certainly accelerated from this point onwards.

The long period of woodland stability represented by NG6-6 reflects the full development of deciduous mixed oakwood with dominant oak and subsidiary components of elm, lime and alder, the latter now reduced to its level of abundance in the wider forest after the end of its local carr stage. Correction of the pollen curves to take account of differential pollen productivity of these taxa would modify the relative proportions of these deciduous woodland components, but would not affect the overall forest dominance of this late Flandrian II landscape.

Woodland stability and composition is disturbed at NG6 at the time of the elm decline, however, as the secondary trees birch and hazel, with heather and bracken heath, increase in response to the opening of the forest which occurs due to the apparently differential removal of elm populations from the nearby forest. Oak is not affected and alder is actually encouraged at this time. Consistent Plantago lanceolata points to the establishment of grassland as part of this process. Fire seems not to have been involved in disturbance as the taxa which indicate burning, as well as those representing broken ground communities, are almost absent. The landscape of early Flandrian III around NG6 remained well wooded despite this disturbance.

7.5 NG6 FRPA

The pollen analyses at one centimetre intervals showed that three disturbance phases occurred prior to the Elm Decline at NG6, and the second of these, NG6-3, was selected for FRPA. This was carried out at a point where the silt fraction was not high enough to hinder effective thin-sectioning, and a slightly increased detrital mud component existed. The micro-stratigraphy was as follows.

Sub-Stratum 1 835 - 823 mm

Sh^{4}4

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Amorphous peat.

Sub-Stratum 2 823 - 819 mm

anth.3, Sh^{4}1

Nig.4, strf.0, elas.0, sicc.2, lim.sup.0

Charcoal rich peat.

Sub-Stratum 3 819 - 790 mm

Sh^{4}2, Ag1, Ld^{4}1, anth.++

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Amorphous clayey, silty peat with some charcoal.

Sub-Stratum 4 790 - 780 mm

Sh^{4}2, Th^{3}2, Th(vagi)^{2}+

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Well humified herbaceous peat.

7.5.1 FRPA Pollen Stratigraphy

The FRPA pollen stratigraphy at NG6 has been divided into seven zones of s or d type which are used to zone the relative pollen diagrams (figures 97 and 98) and are also applied to the concentration diagrams (figures 99 and 100) and the charcoal diagrams (figures 101 and 102).

Zone NG6 - A s 835 - 824.5 mm

Defined as a zone of stability by high Quercus values of almost 60%, with Alnus also high at 75% and Ulmus consistently over 20%. Corylus/Myrica is most significant at 60% and Salix is steady at 20%. Herb pollen is most infrequent, only Gramineae of significance at 40%. Concentration values are moderate, with Alnus highest (50). Little charcoal is present.

Zone NG6 - B d 824.5 - 818.5 mm

Defined as a zone of disturbance by a fall of Quercus frequencies to 40%. Alnus is also slightly reduced at the start of the zone, but recovers. Pinus is most increased in value and Salix and Betula also rise. Corylus/Myrica is only slightly increased. Fraxinus and Fagus appear at the end of the zone. Peak values occur in several weed types, including Melampyrum, Rumex, Ranunculus and Pteridium, and several ruderals like Plantago lanceolata, Chenopodiaceae and Artemisia are recorded. These changes are reflected in concentration levels, which are as a whole higher late in the zone. Neurospora and high charcoal levels occur.

Zone NG6 - C s 818.5 - 812.5 mm

Defined as a zone of stability by increased Quercus values (55%). Pinus is almost absent and Betula and Corylus/Myrica show a small fall. Alnus is increased to almost 80%. Other tree curves change little. Herb pollen, both mire and ruderal, is almost absent. Concentration values confirm these percentage data, but are little changed in total. Little charcoal occurs, but Gelasinospora reticulata shows peak values.

Zone NG6 - D d 812.5 - 807.5 mm

Defined as a zone of disturbance by a marked fall in Quercus frequencies to 40%. Alnus, Ulmus and Betula are unaffected. Pinus, Salix and *Corylus/Myrica* all increase sharply, while weed taxa are present in peak values, especially *Rumex*, *Melampyrum* and *Pteridium*, and mire herbs also rise. Concentrations are high, particularly for *Alnus* and *Corylus/Myrica*, and support the percentage data. Charcoal is present in moderate amounts.

Zone NG6 - E s 807.5 - 802.5 mm

Defined as a zone of stability by a sharp increase in *Quercus* percentages. *Alnus* and *Ulmus* are unchanged. *Corylus/Myrica*, *Salix* and *Pinus* all fall markedly. *Fraxinus* is significant. Herb pollen is provided almost exclusively by Gramineae and Cyperaceae, few other types occurring. Concentrations confirm this pattern, while little charcoal occurs.

Zone NG6 - F d 802.5 - 794.5 mm

Defined as a zone of disturbance by a small decline of *Quercus* frequencies to 45%. *Alnus* is unaffected. *Corylus/Myrica*, *Salix* and *Pinus* all rise to peak frequencies. Open habitat taxa *Melampyrum*, *Rumex* *Pteridium* and several other ruderal weed types occur. Many wetland herbs are recorded. Concentration values remain stable, although *Alnus* is reduced considerably. Charcoal values are increased.

Zone NG6 - G s 794.5 - 780 mm

Defined as a zone of stability by an increase in *Quercus* frequencies, reaching 60%. *Ulmus* remains consistent while *Alnus* increases gradually to around 75%. *Pinus* is reduced to very low values and *Betula*, *Corylus/Myrica* and *Salix* percentages fall sharply. Herb pollen values fall, and open habitat types are present in low frequencies only. Concentration figures confirm the percentage values. Charcoal is almost absent, while *Gelasinospora reticulata* rises to peak values.

7.5.2 Interpretation of NG6 FRPA

The FRPA pollen stratigraphy from NG6 gives every indication of being a sequential body of data unaffected by factors of post depositional mixing or deformation. The fluctuations are relatively low-scale but are well marked and have an internal integrity that suggests that they represent real changes in the vegetation. Although smoother than in other profiles, the changes in curves between zones make good ecological sense, agree well with the trends of the centimetre scale pollen record and reveal the familiar post-disturbance type of vegetation change that would be expected from this level of the profile. Differences between NG6 and other profiles may therefore be regarded as reflecting reality, rather than as any artifact of sampling or deposition.

Of first significance is that this section of the profile contains three distinct disturbance zones at the FRPA scale and is therefore analogous to the situation at other profiles at North Gill within the second of the Flandrian II d phases. Prior to the first of these FRPA d zones, the vegetation in the immediate vicinity of NG6 was that of dense carr vegetation comprising alder and willow, with lesser components like hawthorn and ivy, surrounded by a closed mixed broadleaf forest of oak, elm and lime. The high Corylus/Myrica frequencies would suggest that some forest edge abundance of hazel took place, or that pollen was carried to NG6 from more open terrain, perhaps nearer the plateau edge. The consistent heather record could also be interpreted in this way, although some suitable local environments around NG6 itself is probably more likely, perhaps in the more diverse communities at the carr-forest ecotone, where birch could also have found conditions suitable for the population suggested by its curve of 20%. Mesotrophic conditions of high water tables in this area, lying near the head of the stream valley in a low gradient position would have restricted non-woody vegetation to grasses, ferns and herbs associated with the carr environments. A high component of Limus gyttja at this level of the profile, and fragments of detrital wood below it, indicate the incipient ponding of stream waters in this section of the valley.

The vegetation disturbance which took place in zone B appears to have been located within the dryland forest adjacent to the stream valley rather than impacting upon the carr woodland itself , except perhaps at its fringes. Only a minor perturbation of the alder curve occurs, while the replacement of oak by pine, hazel and willow and the creation of habitats for ruderal, dry ground weeds points to deforestation away from the wetland itself. There are few indications of burning of the mire surface itself. The survival almost unscathed of the alder-willow carr could well have muted the effects of what seems to have been a disturbance of some magnitude, causing a lessening of the scale of the pollen evidence due to screening effects of dense local foliage. Willow in fact was promoted by the change in vegetation, perhaps expanding at the fringes of the carr woodland at the edge of the burned area. Any removal of alder must have been temporary for it quickly re-established itself in its previous abundance. This is continued into the following period of vegetation stability in zone C, when alder values of 80% must represent the occupation of NG6's immediate environs by dense alder carr. Again non tree or shrub pollen are confined to those which are at home as part of damp, shady carr environments. Closed oak woodland was fully restored around the site during this period.

The second episode of oakwood disturbance is markedly similar to the first, the only appreciable change being that alder seems to have been entirely unaffected this time, and so the vegetation within the stream valley was not subject to the disturbance which caused replacement of oak by pine, hazel and willow, and the expansion of open ground weeds. The fluctuations are clearer than previously, willow being particularly favoured. That only small amounts of charcoal reached the peat surface suggests that the alder screen remained intact and so the disturbance was perhaps a little further removed from the sampling point than upon the earlier occasion, although still clearly quite close to NG6. For the pollen of so many ruderal weed types to be recorded, the creation of a substantial area of open ground must have occurred. Increased input of water into the mire may have been a result, for some silt is present in the profile and gyttja comprises a significant part of the sediment, indicating some open water deposition. Wetland taxa are also more common in the pollen record.

This hydrological change is the only real lasting effect of this disturbance zone, for the deciduous forest which is established in the following stability zone shows no signs of residual open areas, and an unbroken stand of alder and willow carr within closed forest continues to characterise the NG6 environment at this stage. This alder dominance is continued in the third episode of disturbance and the reduction in oak is also rather slight. The incidence of disturbance indicators is rather high, however, with Plantago major-media, Plantago lanceolata and a range of ruderal herbs. Several herbs of damp grassland occur which suggest that open grassy areas were maintained, as well as the more usual evidence of Melampyrum and Pteridium. True aquatic taxa like Myriophyllum spicatum, Peplis and Caltha reflect the development of pool environments at the site, and the rising importance of willow also points to this type of community. That the aquatic character of the local environment may have been at least partly the result of the nearby disturbance at the edge of the stream valley is shown by the deposition of a more turfa type sediment and the absence of aquatic pollen after the end of this period. Carr vegetation continued to survive locally. Indeed, no lasting vegetation change seems to have resulted from this sequence of disturbances, for closed forest again was restored to dominance around NG6, and indications of open areas are very few, restricted to sporadic weed grains.

7.6 North Gill 7

This profile is located just north of lateral transect C and just west of site transect 5, at a point where the main spring of the North Gill incises to the level of the sub-peat soil for the first time, thus forming the most upstream example of the full range of organic deposits to be exposed in section at the site. It is the closest FRPA site to the plateau of the Watershed, and lies about 25 metres below the older profile of North Gill Head (Innes 1981). No wood remains occurred at this altitude, but a large charcoal layer was present and sampling took place at a point where it appeared to be most horizontal. The basal metre of organic and minero-organic sediments was recovered in monolith tins.

7.6.1 Lithostratigraphy

After field and laboratory investigation the following lithostratigraphy was recorded.

Stratum 1 Below 94 cm

Gs4, Sh^4+

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Coarse yellow sand, very slightly organic near the top.

Stratum 2 94 - 82 cm

Gs2, $Sh^4$2

Nig.2+, strf.0, elas.0, sicc.2, lim.sup.0

Amorphous minero-organic peat.

Stratum 3 82 - 76 cm

As2, $Sh^4$2, Ld^4++

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Amorphous peaty clay with some detrital mud.

Stratum 4 76 - 73 cm

$Sh^4$2, anth.2, Ld^4+

Nig.3+, strf.0, elas.0, sicc.2, lim.sup.0

Charcoal rich peat and mud.

Stratum 5 73 - 60 cm

$Sh^4$4

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Well humified amorphous peat.

Stratum 6 60 - 47 cm

$Sh^4 2$, $Th^3 1$, $Th(\underline{vagi})^2 1$

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Humified *Eriophorum* peat.

Stratum 7 47 - 40 cm

$Th(\underline{vagi})^2 4$

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Fresh *Eriophorum* peat.

7.6.2 Pollen Stratigraphy

Samples for pollen analysis were removed from the NG7 profile at centimetre intervals and the resulting relative pollen diagrams are shown as figures 103 and 104. These have been sub-divided into seven phases characterised as of stability or disturbance type. These phases are also applied to the pollen concentration diagrams (figures 105 and 106) and the charcoal diagrams (figures 107 and 108). Quoted units are as in previous profiles.

NG7 - 1 d 93 - 83.5 cm

Defined as a phase of disturbance by low *Quercus* frequencies (30%). *Alnus* percentages are also depressed, although rising at the end of the phase, while *Ulmus* is consistent at 20%. *Betula* and *Pinus* are very high, while *Corylus*/*Myrica* approaches 80%. Salix is low, but *Calluna* frequencies are high at 50%. N.A.P. values are high, with Gramineae, Filicales and *Sphagnum* most important. Disturbance indicators are dominated by *Pteridium* and *Melampyrum*, both of which have curves within which twin peaks occur. *Melampyrum* reaches 20% in the later maximum. Pollen concentrations are high and confirm the percentage data. Charcoal values are moderate, but a significant Gelasinospora reticulata curve occurs.

NG7 - 2 s 83.5 - 81.5 cm

Defined as a phase of stability by greatly increased Quercus percentages. Alnus is also high (40%). Corylus/Myrica remains abundant (80%) and Tilia increases. Pinus frequencies fall, but Betula is only slightly reduced. Calluna is maintained around 50%. Sphagnum is increased and Gramineae also rises initially, but indicators of disturbance are very low. Concentrations increase overall, while charcoal values remain low.

NG7 - 3 d 81.5 - 78.5 cm

Defined as a d phase by a sharp fall in Quercus frequencies. Alnus is also initially low but Ulmus increases to almost 30%. Betula, Pinus and Corylus/Myrica all rise sharply in value, but Calluna is reduced from its previous level to only 40%. Filicales and Sphagnum increase, and peak frequencies are recorded for Succisa, Melampyrum and Pteridium. Concentrations are similar to those of the previous phase, except for Corylus/Myrica (104) which is superabundant. Charcoal frequencies remain low.

NG7 - 4 s 78.5 - 76.5 cm

Defined as a phase of stability by a major increase in Quercus frequencies to more than 50%. Alnus and Ulmus frequencies are also high. Betula, Pinus and Salix percentages are very low, although Corylus/Myrica is not greatly reduced and Calluna rises to 70%. Gramineae, Cyperaceae and Rosaceae increase markedly, while Sphagnum and Filicales fall and weed types are almost absent. Concentrations are uniformly high, but are in accord with the percentage figures. Charcoal values remain low.

NG7 - 5 d 76.5 - 71.5 cm

Defined as a phase of disturbance by a marked decline in Quercus frequencies. Ulmus (30%) is very high and Alnus remains well represented at over 50%. Pinus, Betula, Tilia and Salix are all increased in value. Gramineae, Cyperaceae, and Rosaceae all remain high, but both Melampyrum and Pteridium are greatly increased in value. Concentrations are high with Calluna (60) most increased. Charcoal, especially microcharcoal, is abundant with Neurospora and Gelasinospora reticulata in high values.

NG7 - 6 s 71.5 - 67.5 cm

Defined as a phase of stability by a marked increase in Quercus values. Ulmus remains high although declining slightly near the end of the phase, as do Alnus, Corylus/Myrica and Calluna. Tilia and Betula remain important but Pinus is greatly reduced. Apart from Gramineae, herb pollen types are very low. The pollen concentration data support the percentage figures very closely. Charcoal values are much reduced although Gelasinospora reticulata remains in high values.

NG7 - 7 d 67.5 - 50 cm

Defined as a phase of disturbance by a decline in Ulmus frequencies to around 9%, although elm is almost absent at one level. Quercus increases to nearly 70%, while Corylus/Myrica and Calluna expand greatly in frequency. Betula and Tilia remain unchanged, but a major Fraxinus curve occurs after the early part of the phase. Great increases in Cyperaceae and, initially, Gramineae take place while Sphagnum rises and an intermittent Plantago lanceolata curve occurs. Few other herb types are present. Gelasinospora reticulata remains important.

7.6.3 Vegetation History at NG7

The decline of elm at the NG7-6/NG7-7 boundary appears to represent the Ulmus decline of the Flandrian II-III transition. As with the other profiles, the pollen fluctuations at this level in the diagram are very similar to the *Ulmus* decline level at NG5B which is supported by radiocarbon dating, with *Quercus* increasing, statistically at least, as elm falls and *Plantago lanceolata* characteristic of the ruderal component of the disturbance rather than *Melampyrum*. The three disturbance phases which antedate the *Ulmus* decline are therefore of Flandrian II age, and they are biostratigraphically very clearly defined.

The earliest disturbance event is associated with the beginning of peat formation in this part of North Gill and the vegetation of NG7-1 was dominated by a diverse, post-disturbance, successional range of plant communities. There are indications in the ruderal curves especially, but also in alder, willow and pine, that more than a single disturbance impact is recorded. The second half of the phase records a renewed increase in *Melampyrum*, bracken, pine and willow and a decline in alder from already low levels at the start of the phase. The distinction of local oak and alder woodland and the encouragement of secondary shrub and tree taxa after a pioneer ruderal phase seems to have occurred around the springhead area where NG7 is located. The range of weed types is very restricted however, with only *Melampyrum* present in any quantity, particularly in the late phase renewal of impact. The post disturbance ground cover was largely achieved by heather rather than ruderal weeds and it may be that local burning and a diversification of woodland composition took place which did not involve the creation of a significant amount of bare or broken ground. The massive response of *Melampyrum* reflects a lack of competition from ruderal types which suggests that fire may have been limited to the burning of the woodland vegetation without the exposure and destabilisation of soil profiles. This would explain the lack of major soil and charcoal erosion into the mire which is a feature of post fire conditions in other profiles. This would favour taxa encouraged by fire rather than merely open conditions, and the expansion of Melampyrum, bracken, heather and pine may be a response to this factor, as well as to the very small size of the NG7 area of deposition at this time and less pronounced slopes than lower in the stream valley. The high heather, and to a lesser degree birch and bracken, curves suggests that the creation of local heathland vegetation was a result of the removal of deciduous woodland. This deforestation evidently did not extend to soils which carried stands of elm, and so presumably was restricted to local oak-alder woodland at and around the stream head.

The levels to which the oak and alder pollen curves rise upon the creation of this disturbance influence are a good indication that the local deforestation of the basal phase had indeed had a major ecological impact, for in phase NG7-2 a very densely canopied forest cover developed. This was mainly of mixed oakwood type being dominated by oak and alder with a considerable hazel component which shows that thick shrub or understory hazel growth continued as part of the forest mosaic. That this forest ecosystem still included much birch-heather heathland is clear, unless such plant communities were associated with conditions on or around the developing mire itself. Increasing Sphagnum counts may support more acid conditions but this need not necessarily be the case.

The pollen fluctuations of phase NG7-3 are clear indication of the return of disturbance to the local woodland with oak and alder being reduced in equal measure and replaced by a varied vegetation cover consisting of post fire weed associations with Succisa, Melampyrum and Epilobium and successional birch, pine and hazel scrub, of which the latter was most abundant. The ground cover of heather fell at this time, perhaps being supressed in drier areas by hazel and being unsuited to the increased wetness of the mire, with the development of Sphagnum moss and pool areas on site shown by the record of gyttja in the stratigraphy. Regeneration of woodland following this period of disturbance was most successful, with oak and alder woods containing much hazel and increasing amounts of lime being established around the site. No indications remain that open areas still existed, and even the secondary woodland taxa like birch and pine are of limited significance, and willow and ash, which might represent less well developed forest, hardly present. No minor heliophyte shrubs are recorded, confirming the stability of closed forest across the site. A drier period in mire history occurred with heather becoming abundant while wet mire and pool taxa decline. Drier mire surfaces would also favour grasses and other herb types. Peat accumulation was very slow during this drier, undisturbed mire phase, with very high microfossil concentrations overall and very well humified organic sediments.

The major forest disturbance of phase NG7-5 seems not to have greatly altered the hydrology of the mire, the extent of which could well have remained very limited indeed, but had a significant impact upon the local non-mire woodland vegetation. That fire was directly involved in the area of NG7 is shown by the heavy charcoal layer in the mire sediments at this level, although significantly increased input of drainage water from cleared slopes is not evidenced by either soil inwash or raised water levels in the mire. Burning may well have taken place across the site itself, or at least at its very edges, to produce such a discrete charcoal band without associated inwash phenomena. The presence of all size classes of charcoal would support on-site burning, and the peak of *Neurospora* spores would tend to confirm this (Van Geel 1978). Non of the pollen data suggest an hiatus in the biostratigraphy which might be caused by mire surface burning, for no very sharp discontinuities occur in the pollen curves. It may well be that the NG7 sampling point remained a shallow mire pool at this time which allowed the continuous deposition of both charcoal and microfossils and prevented sediment being consumed by local fire. Massive expansion of local heather growth, or at least flowering, occurred and oak alone seems to have been removed during the period of burning. Alder is hardly affected, and so may well not have been present at NG7 prior to the burn but distributed generally in th surrounding oakwood. Other pollen changes are also quite muted, although the *Melampyrum* record responds as usual, and willow and lime seem to have been more encouraged by the disturbance than the more usual hazel and pine. The small scale effects upon the forest of a very local fire may have favoured the less common individuals already present in the stable woodland rather than creating open areas suitable for the expansion of taxa more encouraged by higher intensity deforestation. Heather may well have assumed the role of main response taxon at this plateau edge location which was normally that of hazel, the latter perhaps more of a canopy co-dominant here than an understory shrub, if canopies were already less dense than at lower altitudes.

Restoration of woodland after this local disturbance took place very successfully in NG7-6 with few indications of anything other than stable forest around the site. Oak, elm and lime were major components, with alder and hazel important but declining as canopy closure progressed. A major reduction in the ground cover of heather, or at least its supression through shading, resulted from the reafforestation, and other dryland open ground plants are very rare, bracken persisting as a woodland edge plant and grasses abundant on the mire.

Restored woodland conditions are again disturbed in phase NG7-7, but only elm trees appear to have been affected by it, with lime perhaps also slightly reduced. The expansion of the other woodland tree taxa may well be an artifact of the percentage data, for oak concentration shows a slight fall although percentages rise. Concentrations as a whole fall, however, as a result of greatly increased rates of bog growth, particularly later in the phase when Cyperaceae and Sphagnum become locally common as the bog surface grew wetter. Some real woodland changes occurred, however, for ash becomes very important, presumably as a result of the disturbance of tree cover on the better soils where elm and lime would have grown (Gordon 1958). With the mire area wetter, the expanion of heather which takes place must have been located in dryland areas, probably linked with the creation of grassland indicated by the consistent presence of Plantago lanceolata. The general decrease in woodland density is supported by the continuing importance of hazel, although it never reaches the local abundance in this Flandrian III deforestation that it achieved in the Flandrian II d phases. Oak had become the primary constituent of the local deciduous forest by this stage and quite stable, if secondary, woodland remained the dominant vegetation, with some heathland, throughout this post elm decline phase.

7.7 NG7 FRPA

The one centimetre analyses showed that three disturbance phases occurred prior to the elm decline at NG7, and as at previous profiles the second of these was selected for FRPA. The amorphous, clayey sediment of this part of the profile proved to be very suitable for fine resolution sampling at millimetre intervals. No additions to the lithostratigraphy were noted at the micro scale, which was as follows.

Sub-Stratum 1 840 - 828 mm

Gs2, $Sh^4 2$

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Amorphous minero-organic peat.

Sub-Stratum 2 828 - 770 mm

As2, $Sh^4 2$, Ld^4++

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Amorphous, peaty clay with some detrital mud.

7.7.1 FRPA Pollen Stratigraphy

The FRPA pollen stratigraphy at NG7 has been divided into seven zones of s or d type which are used to zone the relative pollen diagrams (figures 109 and 110) and are also applied to the concentration diagrams (figures 111 and 112) and the charcoal diagrams (figures 113 and 114).

Zone NG7 - A s 828 - 820.5 mm

Defined as a zone of stability by high Quercus frequencies of 50%. Ulmus is steady at 20%, but Alnus is low at only 40%. Calluna is very significant at 50%. Few herb pollen types occur, only Gramineae present in high frequencies although Sphagnum is steady at 20%. Concentrations are high, especially for Corylus/Myrica (130). Little charcoal is recorded.

Zone NG7 - B d 820.5 - 817.5 mm

Defined as a phase of disturbance by a sharp fall in Quercus frequencies to 30%. Alnus is also slightly reduced. Pinus is greatly increased, and Betula rather less so. Corylus/Myrica is unchanged, while Calluna and Gramineae fall. A sharp Melampyrum peak occurs, but other herb pollen frequencies are unaffected, as are concentration values for most taxa, Quercus declining however. A small increase in microcharcoal occurs.

Zone NG7 - C s 817.5 - 812.5 mm

Defined as an s zone by a small but distinct rise in Quercus frequencies, Alnus and Salix also increasing slightly. Pinus is clearly reduced in value but Betula rises to 30%. Corylus/Myrica is unchanged. Herb taxa are almost all unaffected, except Melampyrum which declines to low values. Concentration data confirm the percentage data. Charcoal values are low, but Gelasinospora reticulata rises to peak frequencies.

Zone NG7 - D d 812.5 - 795.5 mm

Defined as a zone of disturbance by a fall in Quercus frequencies to about 30%. Alnus is also reduced, while Pinus rises sharply and Betula and Corylus/Myrica are more slightly increased in value. Calluna remains steady at 30%. Melampyrum forms a consistent curve of over 10% and several ruderal weed types occur. Succisa and Rumex are prominent, while Filicales and Sphagnum rise. The Gramineae curve fluctuates in frequency. Overall concentrations are high, particularly for Corylus/Myrica, and support the percentage data. Large amounts of microcharcoal occur, with peaks of Neurospora and Gelasinospora reticulata.

Zone NG7 - E s 795.5 - 792.5 mm

Defined as a zone of stability by a very sharp rise in Quercus frequencies to 50%. Alnus and Ulmus percentages also increase, whereas Pinus and Betula are sharply reduced. Corylus/Myrica falls only slightly. Gramineae values rise, but all other herb taxa are much reduced in frequency. Little change occurs in total concentrations and these agree with the percentage figures. Charcoal values are low.

Zone NG7 - F d 792.5 - 786.5 mm

Defined as a zone of disturbance by a fall in *Quercus* frequencies to 30%. *Betula* and *Pinus* percentages are increased, but all other tree and shrub pollen curves remain stable. Peak *Melampyrum* values occur and other herb types also expand in frequency, while Filicales and *Sphagnum* remain low. Concentrations are steady, and little charcoal occurs.

Zone NG7 - G s 786.5 - 775 mm

Defined as a zone of stability by a return of *Quercus* frequencies to 50%. *Pinus*, *Betula* and *Corylus*/*Myrica* decline slowly, the latter temporarily. *Calluna* rises to almost 60%. Gramineae and *Melampyrum* frequencies decline and other herb types do not change. The concentration evidence mirrors the percentage changes, while charcoal frequencies remain low.

7.7.2 Interpretation of NG7 FRPA

The nature of the pollen fluctuations at the FRPA level at NG7 resembles that of the other FRPA profiles in that there is no evidence of other than undisturbed, sequential pollen deposition. While some pollen curves are relatively smooth and show few features, like *Corylus*/*Myrica*, most pollen taxa's curves show a series of fluctuations which reflect real vegetation successions, and which are ecologically conformable with the curves for other pollen types. Sharp pollen changes occur and allow the recognition of pollen zones which are based upon the dominance of disturbed or stable conditions. NG7 FRPA may therefore be considered, like the other FRPA profiles, as an interpretable record of vegetation history, there having been no discernable hiatus or mixing effects in the pollen stratigraphy. It is of interest that three periods of reduced oak pollen percentages, designated as three zones of disturbance, occur in the profile, although without coincident lithostratigraphic evidence of environmental destabilisation in the form of charcoal or mineral bands. The clay-organic nature of the sediment at this level suggests steady, probably sub-aquatic deposition in a pool or mineral flush environment around the spring-head.

The local vegetation during zone A, prior to disturbance, was of a dense shrub woodland, although its composition differs from the other FRPA profiles in that standard deciduous forest trees seem to have been less dominant than elsewhere. Mixed oak-elm-lime forest existed nearby, but the relatively low alder and most abundant hazel frequencies suggest a drier, lower canopied variety of woodland around NG7. Hazel must have played more than an understory role at this profile, with dense hazel scrub woodland present as thickets rather than with hazel dispersed in the woodland matrix, since hazel contributes more than half of all tree and shrub pollen recorded at this time. Heather also was common, perhaps favoured by drier soil conditions in this area.

With hazel so locally abundant, it is not surprising that it seems to have lost some ground during the first zone of disturbance at NG7, although as usual oak , with lime and alder, was the major casualty. Heather and willow were also temporarily reduced, although the paucity of charcoal at this level might suggest that the source of the disturbance was not immediately nearby. Epilobium and Melampyrum values do implicate burning as the mechanism involved, however. Regeneration processes after disturbacne led to the restoration of some oak populations, but birch appears to have assumed a measure of co-dominance in the forest, with hazel once more locally abundant. There are few indications of herb communities which are not of wetland type and while the character of the restabilised woodland had changed, it was still of closed canopy type.

Zone D represents by far the most severe impact upon the woodland ecosystem around NG7 during phase NG7-3, with a major reduction in the cover of the deciduous forest trees, primarily oak and alder but with lesser effects upon lime and elm. The high charcoal values cite fire as the major cause of this oakwood recession and some Neurospora spores suggest that it may have been quite close by, although with no inwash of extraneous material. Slope gradients are much lower in this area, reducing the potential for transport of eroded material. Much more open conditions resulted from this disturbance, with grassland herbs like Plantago lanceolata and a range of pyrophytes and ruderals like Artemisia, Cruciferae, Rumex, Succisa and Epilobium present. Hazel's superabundance in this zone suggests that it was locally very dominant indeed, probably suppressing heather which might have been expected to respond favourably to woodland recession. Birch and pine were also very important members of the post disturbance woodland. Although dominant, these successional associations give way in zone E to an almost complete restoration of the oakwood, so that the severe disturbance impact of zone D wrought few lasting changes to the landscape. Continued high hazel representation was a natural feature of the woodland around NG7, while birch and pine could not sustain their local populations once fire pressure had been removed as a factor.

The third disturbance event, zone F, is quite distinct but limited in its effects, bringing about much less severe changes than the impact of zone D. They are similar in kind, however, with the replacement of oak by pine and birch via a Melampyrum dominated herb community the main result. The final removal of disturbance from NG7 in this phase allowed the re-establishment of a full deciduous forest ecosystem with oak populations fully restored and elm, lime and alder also important. Hazel, and to a lesser degree birch, remained significant local species and heather expanded to colonise favourable habitats close to NG7. Absence of significant non-wetland herbs suggests that this restoration of closed oakwood was virtually complete.

CHAPTER EIGHT

OTHER PROFILES

8.1 Introduction

In addition to those profiles at which FRPA work was undertaken a number of sediment columns were recovered from other points along the North Gill stream where peat sections occurred and where the stratigraphy had appeared to be sufficiently consistent to warrant their further investigation in the laboratory. Although the pollen analysis of these profiles at the one centimetre interval showed their pollen stratigraphies to be unsuitable for closer investigation by FRPA, for reasons explained below, their pollen diagrams are most useful for the purpose of ecological reconstruction at the centimetre level of resolution, and these are presented in this chapter. The location of these four profiles is shown on figure 6, and they are designated NG8, NG9, NG9A and NG10.

8.2 North Gill 8

The site of NG8 is located on site transect 4, within the centre of the stream valley, where it intersects with lateral site transect P. It is intermediate between FRPA profiles NG1A and NG4. Unusually for the lower part of the stream valley, no significant macrofossil wood remains were visible in the section, although faint charcoal layers occurred at intervals in the peat, most clearly at the base. The basal metre of organic sediments and the upper part of the underlying sandy soil were removed to the laboratory in monolith tins.

8.2.1 Lithostratigraphy

After field and laboratory investigation the following lithostratigraphy was recorded.

Stratum 1 Below 94 cm

Gs4

Nig.1, strf.0, elas.0, sicc.2, lim.sup.1

Coarse yellow sand.

Stratum 2 94 - 91 cm

$Sh^{4}2$, anth.1

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Amorphous peat with charcoal.

Stratum 3 91 - 86 cm

$Sh^{4}4$

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Amorphous dark brown peat.

Stratum 4 86 - 84 cm

$Sh^{4}2$, anth.2

Nig.3+, strf.0, elas.0, sicc.2, lim.sup.0

Amorphous black peat with charcoal.

Stratum 5 84 - 79 cm

$Sh^{4}4$

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Amorphous dark brown peat.

Stratum 6 79 - 77 cm

$Sh^4 2$, anth.2

Nig.3+, strf.0, elas.0, sicc.2, lim.sup.0

Amorphous dark brown peat with charcoal.

Stratum 7 77 - 66 cm

$Sh^4 2$, $Th^3 2$, Ag+

Nig.2, strf.1, elas.0, sicc.2, lim.sup.0

Well humified herbaceous peat with slight silt fraction.

Stratum 8 66 - 50 cm

$Th^3 4$, $Sh^4 +$

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Well humified herbaceous peat.

8.2.3 Pollen Stratigraphy

Samples for pollen analysis were removed from the NG8 profile at one centimetre intervals and the resulting relative pollen diagrams are shown as figures 115 and 116. These have been subdivided into eight phases characterised as of d or s type. These are applied to the pollen concentration (figures 117 and 118) and charcoal (figures 119 and 120) diagrams. Quoted units in this chapter are as presented for previous diagrams. The local phases are described as follows.

NG8 - 1 s 124 - 123.5 cm

The basal phase comprises one level which is defined as being of stability type due to high Quercus values of almost 60%. Alnus (75%) and Corylus/Myrica (60%) are also high, while peak Salix figures of over 40% occur. Betula and Ulmus are moderate at 20%, but Pinus is almost absent.

N.A.P. values are low except for Gramineae and Filicales. Concentration figures show Alnus to be most abundant at 30, although Corylus/Myrica and Salix are important. Very little charcoal is recorded.

NG8-2 d 123.5 - 121.5 cm

Defined as a phase of disturbance by a small fall in Quercus to under 50%. Alnus is maintained, but Corylus/Myrica and Salix fall. Pinus is sharply increased. Potentilla and Melampyrum increase, but little else of importance occurs. Alnus shows a fall in concentration not apparent from the percentage data. Significant charcoal readings for all size classes occur, but the incidence of charcoal is not high.

NG8 - 3 s 121.5 - 119.5 cm

Defined as a phase of stability by increased Quercus frequencies. Alnus and Corylus/Myrica also rise, although Betula is reduced. N.A.P. values are low, with Gramineae and Filicales reduced and wetland herbs almost absent. Alnus concentrations are very high at 60, and in general concentrations confirm the percentage data. Only moderate amounts of micro-charcoal occur. N.A.P. values are low except for Gramineae and Filicales. Concentration figures show Alnus to be most abundant at 30, although Corylus/Myrica and Salix are important. Very little charcoal is recorded.

NG8 - 4 d 119.5 - 114.5 cm

Defined as a disturbance phase by the sharp decline in Quercus percentages, although recovering late in the phase. Pinus is initially high, then declines, while Alnus falls steadily throughout the phase. Corylus/Myrica behaves very like Quercus while the Salix curve resembles that of Alnus, but falling to very low values by the end of the phase. A slight Calluna peak occurs at the start of the phase, and

Rumex, Melampyrum, Pteridium and Filicales are all periodically increased. A Galium peak of almost 20% is a feature of the final level. A very sharp fall in total concentration occurs in mid phase, coincident with increased values for all size classes of charcoal.

NG8 - 5 s 114.5 - 108.5 cm

Defined as a phase of stable vegetation by peak Quercus values of 80%, although falling later. Betula and Pinus are very low, and Tilia is initially very low but then recovers, as does Alnus. Corylus/Myrica and Calluna peak at the end of the phase after initially low values. Gramineae frequencies are less high but Rumex, Potentilla and Ranunculus are consistently high, while Sphagnum becomes abundant (40% in the later part of the phase. Concentration values support the percentage data, while charcoal values are low.

NG8 - 6 d 108.5 - 107.5 cm

Defined as a phase of disturbance by a marked fall in Quercus frequencies at this level. Peak Ulmus values of 30% occur, while Corylus/Myrica declines. Other taxa remain unchanged except for Gramineae and Sphagnum which increase. Quercus concentrations do not correspond with the percentage fall, although increased charcoal values do occur.

NG8 - 7 s

Defined as a phase of stability due to restored Quercus percentages. Other tree taxa show little change, although Alnus is slightly reduced and Fraxinus more common. Salix and Calluna increase slightly. Gramineae and Sphagnum are the other N.A.P. types in high frequencies. Total concentrations are high at first, but fall greatly late in the phase. Very little charcoal occurs.

NG8 - 8 d

Defined by a fall in *Ulmus* pollen values, slow at first but reaching as low as 5%. *Quercus*, *Alnus* and *Corylus/Myrica* fluctuate but are not much changed from the previous phase. Increases in *Pinus* and *Fraxinus* occur, and *Calluna* rises to very high values of almost 50%. Gramineae is replaced by Cyperaceae, *Sphagnum* increases and *Plantago lanceolata* and other ruderals occur. Concentrations are initially very low, but rise later. Very little charcoal occurs.

8.2.3. Vegetation History at NG8

The decline of *Ulmus* at the NG8-7/NG8-8 boundary is correlated with the elm decline at the Flandrian II/III transition. The profile is of interest because the basal pollen level reflects a period of stable deciduous woodland with 'disturbed' flora elements very poorly represented. *Corylus/Myrica* appears, as it does throughout much of this diagram, to behave as part of the woodland canopy taxa rather than as a regeneration or heliophyte type of shrub. A fairly open tree canopy seems likely, although the absence of pine, ash and minor secondary types suggests it was largely undisturbed. Very dense alder and willow communities, presumably mainly of carr form, existed nearby but the lack of stratigraphic wood might suggest that NG8 was not situated at a point where detrital wood could become incorporated into the sediment, nor was it directly beneath carr vegetation. NG8 may not have been adjacent to the streamside carr, for the alder curve is unaffected when the woodland canopy is broken by disturbance in the first d phase. Oak and hazel seem to have been most reduced, and pine most increased, so that a location away from the main stream channel may be supposed. The stability of the alder-willow vegetation which may well have been fringing the North Gill stream remained undisturbed until NG8-4 and then not until the end of the disturbance phase. Opening up of the vegetation again seems to have been confined to oak-hazel woodland, and the synchroneity of the curves for these two taxa suggest that they were equally adversely affected by any woodland recession which took place. The role of hazel here seems rather different to that elsewhere at North Gill, where it was a major member of the successional shrub community. The disturbance which reduced oak and hazel in NG8-4 seems to have removed the alder-willow carr from this part of the stream valley, but this may have been less a result of their direct removal than of changed, and rather wetter, hydrological conditions. Increases in grasses and then Sphagnum following this disturbance, and evidence of increased bog growth rate and acidity, may point to this cause for the demise of carr woodland, and the presence of wet acid indicator microfossils like Amphitrema flavum, Microthyrium and Assulina may support this. The coincidence of abundant Galium, with Equisetum and Typha angustifolia may reflect the passage through fen stages as carr changed to more acid bog flora. A lowpoint in the heather curve may reflect the absence of drier habitats on the bog margins during this transition.

It may be that the decline of streamside carr taxa was the result of their removal by fire, for charcoal occurs in limited amounts near the end of NG8-4, but Melampyrum and other weed types are only sparsely present. The Rumex curve, which starts at this time, continues through d and s phases alike and, as at NG4 and NG1A, may be an indicator of wetland vegetation rather than of ruderal weed types. The disturbance phase NG8-6 is characterised as a d phase by little more than the low Quercus values which define it. These could in any case be a statistical artefact caused by a random high value for the Ulmus curve at that level, for little supporting evidence is present to confirm disturbance conditions, except perhaps a fall in hazel frequencies which would be consistent with earlier vegetation relationships at the site, and a little charcoal.

The vegetation of late Flandrian II at NG8 is consistent with that of the other North Gill profiles of the mid and lower valley, and in many respects with that of the upper part of the site also. Oak, hazel, and alder woodland was dominant, with some elm and lime also, with a grass and Sphagnum oligotrophic bog flora upon the mire itself. The changes which took place within this landscape at the time of the elm decline were significant, but confined to a relatively few taxa. Within the mire system itself sedges replaced grasses as co-dominant with Sphagnum as bog growth accelerated and evidence of acid conditions increased. The fall of elm is balanced by rises in pine, ash and birch, although the more abundant oak, hazel and alder are largely unchanged. Calluna does expand greatly, but whether this represents heathland associations or drier peat margins is uncertain, although the data from other mire vegetation would favour the former. Weed types are very low and even Plantago lanceolata is only sporadically recorded.

The interpretation of the NG8 pollen record must be that it conforms in its general features to the other profiles of this part of North Gill. The elm decline is reliably present and phases of disturbance occur below it, while a high alder-willow episode is part of its earlier history. In general, however, the characteristics familiar from other profiles in the disturbance phases are not well marked, indicator taxa being low or absent. Also the profile is very compacted, having only twenty centimetres of Flandrian II peat. The sequence of d and s phases is not sufficiently clearly defined, and the scale of the disturbance phase vegetation changes insufficiently high, for the profile to be used for FRPA work. The ecological data from NG8 are valuable at the coarser scale of resolution, however, and there is no reason to suspect that the pollen stratigraphy is other than an accurate record of vegetation change at that level. Pollen counts were made for several levels above those shown on the pollen diagrams, but these are not shown or discussed as they are not relevant to the present study. They do, however, confirm the later occurrence of further episodes of forest disturbance in post elm decline times in this part of the site.

8.3 North Gill 9

The site of NG9 is located between site transects 4 and 5, where it intersects with lateral site transect E. It was selected for the amorphous nature of the lower profile and for the major bands of charcoal and silt which were present. Its position was selected so as to be intermediate between the central and upper parts of the stream valley. The lower metre of sediment, including a considerable depth of minero-organic material at the base, was removed to the laboratory in monolith tins.

8.3.1 Lithostratigraphy

After field and laboratory investigation, the following lithostratigraphy was recorded.

Stratum 1 Below 98 cm

Gs 4

Nig.1, strf.0, elas.0, sicc.2, lim.sup.1

Coarse yellow sand.

Stratum 2   98 - 95 cm

$Sh^4 2$, Gs 1, anth.1

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Sandy, amorphous peat with charcoal.

Stratum 3   95 - 88 cm

$Sh^4 4$

Nig.3+. strf.0, elas.0, sicc.2, lim.sup.0

Black amorphous peat.

Stratum 4   88 - 86 cm

$Sh^4 2$, Ga 1, anth.1

Nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Sandy amorphous peat with charcoal.

Stratum 5   86 - 79 cm

$Sh^4 4$

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Dark brown amorphous peat.

Stratum 6   79 - 76 cm

$Th^3 2$, Th(vagi)$^3 2$

Nig.2+, strf.0, elas.0, sicc.2, lim.sup.0

Herbaceous peat with Eriophorum.

Stratum 7 76 - 74 cm

Th(vagi)^{2}4

Nig.2, strf.1, elas.1, sicc.2, lim.sup.0

Fresh Eriophorum peat.

Stratum 8 74 - 50 cm

Th^{3}4

Nig.2+, strf.0, elas.0, sicc.2, lim.sup.0

Humified herbaceous peat.

8.3.3 Pollen Stratigraphy

Samples for pollen analysis were removed from the NG9 profile at one centimetre intervals and the resulting relative pollen diagrams are shown as figures 121 and 122. These have been sub-divided into three s and d phases which have been applied to the concentration (figures 123 and 124) and charcoal (figures 125 and 126) diagrams. The local phases are described as follows.

NG9 - 1 d

Defined as a disturbance phase by very low frequencies of Quercus, which fluctuate between 20% and 40%. A slight recovery of oak values in mid phase occurs, but percentages are again low after this slight peak. Alnus is also low at 30%, with a very low count in the basal phase. Pinus, Betula, Corylus/Myrica and Salix are present in high frequencies, and Calluna has occasional peak values. Gramineae (40%) is common and Sphagnum and Filicales are also prominent. A consistent Melampyrum curve of about 10% is the main feature of the N.A.P. assemblage, however, as well as high values for Pteridium. Plantago lanceolata and a range of other weed types occur. The concentration data support the percentage curves. Abundant charcoal of all size classes occurs as well as *Neurospora* and *Gelasinospora reticulata*.

NG9 - 2 s

Defined as a phase of stability by high *Quercus* frequencies of up to 60%. *Ulmus* begins to decline towards the end of the phase, while *Alnus* is slightly increased and *Corylus*/*Myrica* slightly decreased in frequency. *Betula* is also reduced, while *Salix* and *Pinus* are very low indeed. *Calluna* is also low with the exception of a single peak level of 60% near the end of the phase. *Tilia* becomes significant. Gramineae, Cyperaceae and *Sphagnum* all rise but indicators of disturbance are almost absent. Concentration figures confirm the percentage curves and charcoal counts are very low.

NG9 - 3 d

Defined as a disturbance phase by a sharp fall in *Ulmus* pollen percentages. All other tree curves are stable, although *Alnus* and *Quercus* do increase slightly. Peak values are recorded for *Plantago lanceolata* and *Pteridium* but other N.A.P. types are unchanged. Concentrations generally increase and support the percentage data. Very little charcoal occurs.

8.3.4 Profile NG9A

In order further to clarify the character of the basal d phase at NG9, a subsidiary peat column was taken from a point one metre to the north of NG9 and was designated NG9A. The subsidiary profile contained a greater inorganic fraction than at NG9, and the following basal lithostratigraphy was recorded, above which it resembled NG9.

Stratum 1 Below 100 cm

Gs4

Nig.2, strf.0, elas.0, sicc.2, lim.sup.1

Coarse yellow sand.

Stratum 2 100 - 90 cm

$Sh^4 2$, Gs 1, anth.1

Nig.3, strf.0, elas.0, sicc.2, lim.sup.0

Amorphous peat with sand and charcoal.

Stratum 3 90 - 85 cm

$Th^3 4$

Nig.2+, strf.0, elas.0, sicc.2, lim.sup.0

Humified herbaceous peat.

A more detailed pollen analysis was made of this short profile, and samples were removed at intervals of five millimetres. The resulting relative pollen diagrams are shown as figures 127 and 128. These have been subdivided into two local s and d phases, which have been applied to the pollen concentration (figures 129 and 130) and the charcoal (figures 131 and 132) diagrams. The local phases are described as follows.

<u>NG9A - 1 d</u> 1000mm - 897.5 mm

The basal phase is defined as of disturbance type by very low frequencies for <u>Quercus</u>, at 25%. <u>Alnus</u> is also low at 30%, while <u>Corylus</u>/<u>Myrica</u> (70%), <u>Betula</u> (50%) and <u>Pinus</u> (20%) are very high. <u>Salix</u> and <u>Calluna</u> are moderate. Although a range of ruderal herbs occurs, including Rumex and Plantago lanceolata, the high Melampyrum curve, at up to 20%, is most significant. Although fading in mid phase, it recovers near the end. Pteridium and Gramineae behave similarly. The concentration evidence confirms the percentage data. Charcoal is most abundant and is accompanied by Neurospora.

NG9A - 2 s 897.5 - 890 mm

Defined by a very sharp rise in Quercus frequency to 60%. Alnus decreases slightly and Corylus/Myrica rises slightly. Betula falls sharply to 20%, while Pinus almost ceases to be recorded. Although isolated ruderal grains occur, indicators of disturbance, primarily Melampyrum, are almost absent. N.A.P. is contributed almost completely by Gramineae and Cyperaceae, Filicales being very low. Concentrations are low. A little charcoal is still present.

8.3.5 Vegetation History at NG9 and NG9A

The fall in elm pollen at the beginning of phase NG9-3 is considered to represent the Flandrian II/III transition, falling to 3% AP+G from a mean of around 20%, although a gradual diminution in elm occurs in the last few levels of the previous zone. The actual fall in elm values is thus not as clear-cut as in other profiles, but is placed at 67.5 cm because the fall is proportionally greatest there, elm percentages are lowest directly afterwards, and supporting evidence such as the start of a high Plantago lanceolata curve occurs at that point. The basal phase, NG9-1, is thus a Flandrian II disturbance phase, during which the pollen and stratigraphic evidence records the effects of major forest fire within the vicinity, leading to the inwash of considerable quantities of charcoal, particularly at the base of the profile and in mid phase where a strong layer of sand shows that the burning of the stabilising vegetation led to significant erosion of mineral soils. The creation of bare ground and post fire herb communities is shown by the high *Melampyrum* percentages, as well as a range of ruderal types. The reciprocal nature of the oak curve and the group of seral tree and shrub taxa like hazel, pine, willow and birch is very clear and agrees with the familiar process of regeneration to closed deciduous woodland canopy via these successional communities. Alder is present in consistent values not much less than those of the post disturbance phase NG9-2, and so may not have been greatly affected by the fire which caused the other pollen fluctuations. The particularly low alder count of the basal level corresponds with the lowest oak frequency, so that the most extreme deforestation of oak and alder woodland may have preceded the inception of organic accumulation, the basal pollen phase reflecting some measure of successful post fire regeneration. If so, the original burn must have been close enough to eradicate local alder carr growth as well as making serious inroads into the surrounding oakwood. The pattern of the charcoal inwash and pollen distributions suggests that phase NG9-1 records a two-fold disturbance event, for a partial regeneration of oak woodland and reduction in disturbance pollen occurs between 88 and 90 cm, after which the charcoal and sand layer points to renewed disturbance and increases in the pollen curves of disturbance taxa. *Melampyrum*, *Pinus*, *Betula* and *Salix* show this very well, with *Quercus*, *Tilia*, *Fraxinus* and *Calluna* encouraged during the pause in disturbance in mid phase.

This two-fold character of the basal phase points to the pollen assemblage of NG9-1 being in stratigraphic sequence, and not a mixed assemblage as a deposit inwashed *en masse* would be. It also points to phase NG9-1 being analogous with the latest pre elm decline phase at NG1A, within which a similar binary distribution of disturbance evidence exists. That these two phases record the same sequence of events seems likely, although over such a distance their correlation cannot be assumed. There are no grounds for believing that an hiatus exists in the NG9 profile, although the changes in the pollen curves at the end of NG9-1 are quite sharp. It seems likely therefore that peat did not begin to form in the NG9 area until late in Flandrian II, the earlier Flandrian II disturbance phases never having been recorded there. The area of North Gill around the confluence of the stream's headwaters, within which NG9 and NG10 are situated, is not one which contained microbasin areas suitable as foci of early sediment accumulation and its relatively steep gradients and water-shedding topography may have kept it free from peat accumulation until the latest episode of Flandrian II disturbance at North Gill. At NG5B that phase is dated to between about 5400BP and 5000BP, a late date for peat inception relative to the lower parts of the stream valley. NG9 was therefore not selected for FRPA.

The vegetation history revealed by the more detailed analysis at five millimetre intervals at NG9A confirms the character of the vegetation changes of the basal phase, although the binary nature of the disturbance event is less clear. The _Pinus_, _Melampyrum_ and _Pteridium_ curves do tend to support that contention, although the more sandy nature of the sediment may suggest a more mixed assemblage than at adjacent NG9. The phase NG9A-1 may well represent only the latter half of the vegetation record of phase NG9-1.

The vegetation around NG9 between the end of phase NG9-1 and the elm decline seems to have been formed by an almost totally restored mixed woodland dominated by oak and with lesser proportions of alder and hazel, presumably in their respective understory roles as regulated by edaphic factors. Elm and birch also contributed, but taxa requiring more open conditions are poorly recorded, except for those likely to be associated with the mire or its margins such as grasses, sedges and Sphagnum. Calluna is very low, suggesting no significant development of heathland soils or dry bog surfaces, with the exception of a single level at which heather abundance occurs just prior to the elm decline. That this level is coincident with the beginnings of the decline of the elm curve may show it to be involved ecologically with that event. Interestingly, brief Calluna peaks associated with the start of the Ulmus decline is a feature also recorded at other North Gill profiles, as at NG5. Elsewhere, Calluna dominance is maintained into Flandrian III. The other changes in the vegetation associated with Ulmus decline disturbance are of the familiar kind witnessed at other profiles. Other tree taxa are unaffected, except perhaps for a brief reduction in lime populations, and the appearance of beech. Weed types are few and characterised by Plantago lanceolata rather than Melampyrum, with the presence of Plantago coronopus quite notable. The spread of grassland rather than the opening of woodland by burning is a very evident dichotomy between Ulmus decline events and those which preceded it, and a pattern repeated at all North Gill profiles. At NG9 the elm decline took place within the context of a still heavily wooded landscape, although one which had been subject to very heavy disturbance pressure during Flandrian II.

8.4 North Gill 10

The site of North Gill 10 is located just to the east of site transect 3 and south of lateral site transect D. It lies within the valley of the main easterly tributary of the North Gill stream, and was selected to represent conditions between the middle and upper parts of North Gill, replacing NG9 which analysis had shown not to represent the full range of Flandrian II peats present elsewhere in the study area. NG10 was selected because a discrete band of silt and sand appeared twenty-five centimetres above the base of the peat profile and the stratigraphy thus appeared analogous to that recorded in the lower and middle North Gill valley. The lower metre of organic sediment was removed to the laboratory in monolith tins.

8.4.1 Lithostratigraphy

After field and laboratory investigation, the following lithostratigraphy was recorded.

Stratum 1 Below 100 cm

Gs4

Nig.1+, strf.0, elas.0, sicc.2, lim.sup.3

Coarse yellow-white sand, very sharp transition to the next stratum.

Stratum 2 100 - 76 cm

$Sh^4 2$, $Th^3 2$

Nig.3, strf.0, elas.0, sicc. 2, lim.sup.1

Well humified and amorphous herbaceous peat.

Stratum 3 76 - 74 cm

Ga2, Ag2, Sh^{4}++

Nig.1, strf.0, elas.0, sicc.2, lim.sup.1

Mineral band with sand, silt and a high organic content.

Stratum 4 74 - 50 cm

Th^{3}2, Th(*vagi*)^{3}2

Nig.2+, strf.0, elas.0, sicc.2, lim.sup.0

Well humified *Eriophorum* and monocot peats.

8.4.2 Pollen Stratigraphy

Samples for pollen analysis were removed from the NG10 profile at one centimetre intervals and the resulting relative pollen diagrams are shown as figures 133 and 134. These have been subdivided into six local s and d phases which have been applied to the pollen concentration (figures 135 and 136) and charcoal (figures 137 and 138) diagrams. The local phases are described as follows.

NG10 - 1 d 100 - 98.5 cm

Defined as a phase of disturbance by low *Quercus* percentages, especially in the basal level, while *Ulmus* reaches almost 30%. *Corylus*/*Myrica*, *Alnus*, *Pinus* and *Salix* are all present in high values. Gramineae, Rosaceae, Filicales and *Sphagnum* are high, while disturbance indicators *Melampyrum* and *Pteridium* show peak values, and *Plantago lanceolata* and Cerealia occur. Concentrations are generally low, while peaks for charcoal and *Neurospora* occur.

NG10 - 2 s 98.5 - 92.5 cm

Defined as a phase of stability by generally higher *Quercus* percentages, although isolated levels are not much increased from the previous phase. Ulmus and Betula are both steady at around 20%, while Tilia, Fraxinus and, at a single level, Fagus are prominent. Alnus and Corylus/Myrica fall slightly, but Pinus and Salix are much reduced. Calluna frequencies expand to reach 50%. All N.A.P. types except Cyperaceae are greatly reduced, and only sporadic single ruderal grains occur. Concentration values fall, and confirm the percentage data, while charcoal values are reduced, although Gelasinospora reticulata increases.

NG10 - 3 d 92.5 - 87.5 cm

Defined by a sharp fall in Ulmus pollen frequency from 20% to 5%. Fraxinus and Tilia also decline, while Quercus (70%), Alnus (55%) and Corylus/Myrica (70%) rise sharply, and Betula less so. Ulmus recovers somewhat near the end of the phase, when Calluna becomes abundant at 70%. N.A.P. values remain relatively low, most significant being a gradual increase in Gramineae, a major peak in Sphagnum and a low but consistent curve for Plantago lanceolata. Concentration falls markedly toward the end of the phase. Little charcoal is recorded.

NG10 - 4 s 87.5 - 75.5 cm

Defined as phase of stability by high Quercus frequencies, Ulmus remaining low. Corylus/Myrica, Alnus and Calluna are the other dominant taxa. Occasional herb types occur, but Gramineae and Cyperaceae are the most abundant N.A.P. types except for a single Sphagnum peak. Concentrations are moderate and fall further at the end of the phase. Little charcoal occurs but Gelasinospora reticulata is common.

NG10 - 5 d 75.5 - 73.5 cm

Defined as a d phase by a sharp fall in Quercus percentages, with Ulmus, Betula, Corylus/Myrica and Calluna rising to peak values. Non tree pollen frequencies are low, although Plantago lanceolata, Pteridium and Cerealia are significant indicators. Concentration is very low. Charcoal is almost absent.

NG10 - 6 s 73.5 - 70 cm

Defined as an s phase by markedly increased *Quercus* frequencies, while *Ulmus* is reduced but steady at 10%. *Corylus*/*Myrica* declines while *Calluna* rises and *Alnus* and *Betula* are unchanged. N.A.P. types remain very low, with very few taxa recorded. Concentrations are low and little charcoal occurs.

8.4.3 Vegetation History at NG10

The very sharp fall in elm pollen at the NG10-2/NG10-3 boundary must represent the *Ulmus* decline of the Flandrian II/III transition, with elm frequencies of at least 20% AP+G below that horizon consistent with the proportion of elm pollen present in Flandrian II levels from other profiles at North Gill, including the radiocarbon dated profile from NG5B. It follows that only a single pre elm decline phase of disturbance, phase NG10-1, is present at NG10 and that the Flandrian II profile resembles that at NG9 in lacking much of the record of Flandrian II vegetational history known to exist at most areas of North Gill. The basal phase NG10-1 is typical in that it records a reduction in the oak woodland cover and the expansion of those elements of the shrub flora - hazel, willow, pine and heather - which are usually involved in post disturbance seral regeneration in mixed deciduous woodland. It is not a very major period of forest recession, however, for the pollen fluctuations involved are not of great scale, and are quite gradual in nature. Also, no charcoal evidence of any abundance supports the pollen evidence. It seems that the levels which form NG10-1 may well represent the culminating stages of a disturbance - regeneration cycle in which readjustment of the vegetation to stable conditions is well advanced.

The more secure vegetation changes consequent upon initial ecosystem disruption are not present. This is in contrast to the compelling evidence of burning and widespread creation of broken ground habitats created at NG9. Deposition appears not to have commenced at NG10 until the processes of regeneration to woodland in the vicinity was well advanced. Whether NG10-1 represents the first accumulation of organic sediments at this location, or whether earlier deposits were removed in the process of disturbance or post disturbance erosion remains conjectural. It is possible that the fairly concave local topography (Edwards and Hirons 1982, Taylor and Smith 1980) of this part of the North Gill hillslope had acted in a water shedding manner which had not been conducive to sediment accumulation during previous periods of vegetation disturbance. It is also possible, although less likely, that this area of the site had not previously been directly subject to such perturbations. The question of peat inception and mire growth is considered further below. The presence of Cerealia pollen and of three accredited disturbance indicators in _Melampyrum_, _Plantago lanceolata_ and _Pteridium_, albeit in low frequencies, makes the disturbance context of this basal phase unequivocal, however. That pollen of cereal type is present, and that _Alnus_ appears not to have been affected by the disturbance, points to the correlation of this basal phase with that of the latest phase of pre-elm decline disturbance noted in other, longer Flandrian II profiles. This is supported by the lack of any indication of an hiatus between this phase and the elm decline, as curve changes appear to be gradual and smooth. The Flandrian II profile at NG10 appears to be late in inception, like that of NG9, by comparison with the sediment of the lower North Gill valley, rather than to be truncated in any way by post-inception processes. Since no complete Flandrian II disturbance cycle of events is preserved at NG10, its use for FRPA was not considered.

In terms of vegetation change the results of the disturbance at NG10 resemble those at NG7 rather than those of the stream valley profiles. Deposition of disturbance evidence during this phase is much clearer at NG9 both in range and quantity of indicators, except for Cerealia pollen, and accumulation of sediment rich in charcoal and pollen evidence of severe deforestation took place there when post disturbance conditions were at their environmentally most severe. Sediment accumulation at the steeper gradient location of NG10 was apparently only possible when recovery after disturbance was almost complete, and processes of paludification and acidification had begun. Thus high Calluna frequencies in the disturbance phase and particularly in the phase of stability succeeding it are more akin to the situation at NG7 than at the valley profiles, including NG9. The expansion of Calluna heathland which followed this late Flandrian II opening of the forest was presumably local to the spring head and hillslopes surrounding it, although some heathland maintaining itself upon the upland plateau proper seems a real possibility (Simmons and Cundill 1974). Some degree of change in the character of the post disturbance woodland is also likely, however, for while deciduous woodland was successfully restored around this location, the high Fraxinus presence and peak values at single levels for Fagus and Ilex attest some change in its composition.

The spread of grassland and heathland accompanies the vegetation changes at the time of the Ulmus decline of phase NG10-3 with increased hazel, alder and birch and a fall in elm, lime and ash also suggesting some local acidification of the environment and loss of soil quality.

Increased wetness of the local environment is shown by an increased rate of mire growth reflected in low pollen concentrations in this part of the profile and above, and most clearly shown by the abundance of *Sphagnum* spores. Other microfossil types recorded in the NG10 post elm decline peats also point to a very wet and acid local bog surface at this time. *Amphitrema flavum* and *Assulina sp*. are common and other types present include *Microthyrium*, *Mougeotia* and rotifers (van Geel 1978) the hydrological affinities of which have been discussed above. It is likely that, as in other profiles, the hydrological effects of forest disturbance at the elm decline which include cereal cultivation, gave an impetus to bog development in this location. A mixture of oak, alder and hazel woodland and heather heathland seems to have dominated the landscape as Flandrian III progressed, with oligotrophic bog vegetation occupying the mire area. Reciprocal fluctuations in *Calluna*, *Sphagnum*, Gramineae and Cyperaceae curves will reflect the degree of wetness of the mire at different times. Little major variation in this pattern of Flandrian III vegetational history, which is in any case beyond the aims of this thesis, occurs in the upper profile of NG10. Phase NG10-5 is of interest, however, for it records cereal cultivation, as at the *Ulmus* decline, with major inwash of eroded mineral soil but with no concomitant evidence of local burning in the form of charcoal or fire promoted taxa like *Melampyrum*. Although in other ways the vegetation responses to disturbance of woodland in phase NG10-5 are akin to those of the Flandrian II events under study, the absence of any indication that fire had a role in disturbances of the elm decline and later marks them out as different in kind to the Flandrian II examples.

CHAPTER NINE

SPATIAL COMPARISON AND INTERPRETATION

9.1 Fine Spatial Analysis at North Gill

In the preceding four chapters the results of highly detailed pollen analyses from several North Gill peat profiles have been presented and analysed, and together these comprise an extremely complex set of palaeovegetational and palaeoecological data. The use of centimetre sampling intervals in all profiles, and especially the extensive use of millimetre intervals in five of them, makes the North Gill pollen record of major importance for the study of fine temporal vegetation change, particularly with respect to woodland plant successions in response to disturbance influences but also regarding natural pattern and process in woodland ecosystems. These fine temporal aspects of the North Gill data will be discussed further in chapter ten.

Of equal importance, however, is the potential of the North Gill evidence to be interpreted in terms of fine spatial vegetation changes, and it is this element of the research data which will be considered in this chapter. The character of the North Gill site itself, and the nature of the sampling strategy adopted, mean that the fine spatial interpretation of the North Gill pollen record may be achieved in two different ways. Firstly the potential exists to compare the vegetation histories of different parts of North Gill using the multi-profile approach discussed by Edwards (1983), in an attempt to reconstruct a 'three dimensional' picture of contemporaneous vegetation patterns across the site as a whole, and to monitor and explain the changes in these through time. Fundamental to the success of this approach is the ability to establish secure points of temporal correlation between pollen profiles, so that contemporaneous vegetation conditions in different spatial areas may be studied. This may be relatively easy where pollen features occur which are recognisable at a regional, or at least extra-local scale. At the Flandrian Chronozone scale of temporal resolution for example, major biostratigraphical features such as the Ulmus decline or the Alnus rise can serve as acceptable correlative temporal markers for a regional study area such as the central North York Moors, which has broadly standard environmental parameters such as altitude and soils, despite their wider dichroneity (Smith and Pilcher 1973, Bennett 1988). At this coarser temporal scale such three-dimensional work has been accomplished quite successfully (Smith and Cloutman 1988). If the resolution of the temporal scale is refined, however, so that pollen stratigraphic features which represent events of relatively short duration are to be studied, then their secure temporal correlation becomes much less certain. With features which may be entirely local in origin (Jacobson and Bradshaw 1981) and which may last for only a few centuries or even a few decades, such as minor episodes of vegetation disturbance within closed forest, it may not be possible to assume correlation across even very short distances, such as those which separate the sampled profiles at North Gill, on the grounds of pollen assemblage similarities alone. The extremely fine temporal resolution of the North Gill pollen stratigraphies, at the centimetre scale and so much more so at the FRPA millimetre scale, means that in the absence of comprehensive radiocarbon dating the correlation of pollen data between profiles even 40 m apart must be very circumspect. This three-dimensional correlation aspect of fine spatial interpretation at North Gill is considered in detail below.

Those factors of poor pollen dispersal within closed woodland which may compromise inter-profile correlation at North Gill, however, also act to make possible very precise fine spatial pollen interpretation of the individual North Gill profiles when they are regarded as separate pollen data sets. In this context each North Gill profile will have had a spatially restricted and thus well definable pollen source area for most of its pollen rain. Although periodically subject to quite severe disturbance, the vegetation of the second half of Flandrian II around North Gill comprised forest of varying degrees of canopy closure. Unlike pollen data sets from large sized lake or bog basins which recruit and integrate pollen from wide areas and thus ill-defined and mixed sources, pollen sampling sites from within wooded environments have very local source areas (Jacobson and Bradshaw 1981, Prentice 1985, 1988, Bradshaw 1988). Indeed, within forests empirical work in linking modern pollen spectra to tree abundances in the surrounding vegetation (Andersen 1970, 1973, Bradshaw 1981a, 1981b, Heide and Bradshaw 1982) shows that most pollen deposited at a point beneath a closed tree canopy is derived from tree populations growing within 20 - 30 m of it. This is because most pollen transport in these situations is inferred to be by gravity fall from the canopy (Andersen 1967, 1974b), with pollen transmission through the trunk space (Tauber 1965, 1977) of relatively little importance. Such empirical modern pollen studies have employed moss polsters as sampling media which effectively act as points of only a few centimetres radius (Bradshaw 1981a) but it is assumed that other types of sampling suite such as forest floor humus or small hollows (Bradshaw 1988) will function in the same way as long as they are beneath the tree canopy. Small hollows, the sediments of which are typically humus or peat, are regarded as closed canopy pollen sites if they have a diameter of up to 20 or 30 m (Andersen 1970), i.e. an area of about 0.1 ha, within which depths of sediment of up to a metre are usual. Several authors (Bradshaw

1988) have on this basis interpreted the pollen record of such sites mostly in terms of 'local' changes in tree cover, occurring less than 30 m from the edge of the basin, and Prentice (1985) has recommended that the term local be reserved for this restricted vegetation zone. Pollen input from beyond this local zone should be regarded as extra-local up to a distance of several hundred metres, beyond which it comprises the regional pollen rain.

Such a limited and well defined local pollen source area clearly offers tremendous potential to the palaeoecologist interested in studying woodland dynamics and succession at the scale of the forest stand (Vuorela 1977), for the pollen percentages should be referable directly to local tree populations, in the absence of complicating extra-local pollen, by using pollen representation factors (Andersen 1970, Bradshaw 1981a). Local events such as small fires or windthrow should thus be able to be interpreted in a highly spatially precise way. The numerous pollen profiles which have been studied from small forest hollows or mor humus deposits have mostly tended to realise this theoretical potential for fine spatial sensitivity, and there are some of particular relevance to the research at North Gill and thus worthy of close attention here. Most have been reviewed by Bradshaw (1988).

At Slish Wood, Sligo, Ireland, Dodson and Bradshaw (1987) investigated a small area of mor humus half a metre deep which commenced accumulating about 1,900BP, adjacent to a small lake also sampled for pollen. The two pollen stratigraphies were radically different and hard to correlate, the humus profile containing a stronger record of disturbance, with much charcoal, than the lake core, although the latter had a broader range of taxa recorded. Fire induced successions, including replacement of woodland by heathland, at the humus profile were not apparent in the lake core. The humus profile evidently recorded very local impacts upon the vegetation in comparison to the core from the small lake.

A small association of humus and charcoal was recorded at Breen Wood, Antrim by Cruickshank and Cruickshank (1981) who analysed three humus profiles within 20 m of each other and were able to correlate pollen assemblages between the profiles on the grounds of disturbance activity, with forest being temporarily replaced by heathland. Again very local vegetation change seems to be represented here.

A closer temporal analogue to the North Gill data is the work of Iversen (1964) at Draved Forest, Denmark, where a metre of mor humus contained a 6000 year pollen and charcoal record which suggested highly local human activity. In the same woodland Aaby (1983) demonstrated that spatial differences could be considerable over very small distances, for two near-recent humus profiles less than 10 m apart showed differences in the percentages of Quercus, Fagus and Tilia almost certainly due to patterning of the populations of the trees around the sites during the last few centuries.

Work in small, peat-filled hollows has produced results likely to be even more germane to the kind of evidence recovered at North Gill. Bradshaw (1981b) investigated the 3 m deep sediment column of an enclosed depression only 10 m in diameter within Oxborough Wood, Norfolk, comparing the pollen sequence to that from the nearby regional site of Hockham Mere. It was found that vegetation patterns not apparent from the regional site dominated the small hollow assemblage, due to very local woodland successions. Birks (1982) sampled a 3 m peat profile at Roudsea Wood, Cumbria, which was radiocarbon dated between 6680BP and the Elm Decline, a Flandrian II sequence analogous to the North Gill data. The sampling site was a small hollow 25 m in diameter within a wood noted for its present day ecological diversity. The fossil pollen record showed that this diversity had been a feature of the local woodland populations in Flandrian II also, for many rare shrubs and woodland herbs with very low pollen dispersal properties were recorded which must have been growing very close to the hollow. The pollen record was evidently of very local origin.

The work of Andersen (1984) in Eldrup Forest, Denmark was intended to use the local pollen rain properties of small hollows to investigate local woodland successions and compare them to changes recorded at a regional scale from a peat bog core. The small hollow sites yielded detailed data about tree successions and times of immigration which were at variance to the regional diagram, particularly regarding individual species. Tilia for example, was habitually more abundant within the forest than in regional terms, whereas Corylus/Myrica was a late immigrant to the forest compared to the wider landscape. Andersen studied the records from three small hollows, and comparison of pollen spectra from hollows 100 m apart revealed pattern in the structure of the forest, composition being similar until disturbance near one of the hollows caused a replacement of Tilia by Fagus which did not occur at the other site until much later.

Mitchell (1988) has completed a detailed study of two small hollows in woodland in Killarney, Ireland which were 30 x 10 m and 30 x 40 m in size. Pollen percentage, pollen concentration and charcoal analyses were applied to the 3 m deep sediments in each case, which radiocarbon dating showed to cover the last 5000 years. Two major disturbance events were recorded in the forest hollow diagrams which were not visible in pollen diagrams with a more regional pollen source area. The first included a sharp fall in Pinus and Betula and an expansion of Quercus, the latter two taxa increasing in subsequent regeneration of forest. Charcoal frequencies were very high and a temporary peak of weeds, including Plantago lanceolata, Melampyrum and Pteridium. The second disturbance was similar except that Quercus was the tree reduced, and most interestingly the post disturbance regeneration comprised an easily visible succession through Betula back to Quercus. This kind of local succession detail was visible only in the small hollow profiles.

A similarly instructive example is the pollen profile from Elstead Bog, Surrey (Carpenter and Woodcock 1981), where a detrital mud and peat deposit 30 m in diameter and 3 m deep occupied a small steep-sided depression identified as having a periglacial pingo origin. These dimensions conform with the small hollow, closed canopy category, and a highly detailed local vegetation history was recovered from the site which covered Flandrian I and the start of Flandrian II. Mineral inwash layers confirmed local soil instability, but the clearest evidence of local disturbance was a charcoal layer which coincided with the Pinus fall, Alnus rise and the Flandrian I-II transition. Ruderal weeds were present, including Artemisia, Cruciferae and Plantago lanceolata, and Salix showed a temporary peak, followed by increases in Corylus/Myrica and Betula, and finally Quercus expanded. Whether or not the fire aided the rise of alder, a clear woodland succession followed the disturbance event, with weeds and willow followed by seral birch and hazel, and finally the establishment of oak with lime increasingly important. Low pollen dispersers like Fagus, Carpinus, Ilex, Fraxinus and Sambucus were recorded in the profile, and the evidence suggests that the small peat deposit was functioning as a closed canopy site, recording very local forest taxa and the consequences of very local disturbance including forest stand succession.

The character of the disturbance - regeneration evidence at the Killarney and Elstead sites is most strikingly similar to many of the North Gill examples of this ecological process. Other small hollow studies are cited by Bradshaw (1988) but the above examples are sufficient to demonstrate the value of fine spatial resolution pollen data for the study of spatially precise woodland patterns, such as post disturbance succession. The interpretation of fine spatial pollen profiles is clearly of direct relevance to the North Gill situation for, given the above definition of a closed canopy site, each of the individual North Gill profiles may be placed in this category, being peat-forming hollows within woodland, and thus with a local closed canopy pollen source. Basin size is clearly a most critical factor, for as basin size increases so the tree canopy tends to open above the site and the extra-local and even regional pollen rain becomes of increasing importance. There is a particularly significant increase in source area upon the change from small hollow sites to 'small basin' sites of greater than c. 0.1 ha (Bradshaw 1981b, Bradshaw and Webb 1985), for such sites can no longer be considered to be fully beneath a tree canopy, although of course local pollen will still be of great importance in such cases. Unless they are very clearly topographically confined (Hulme 1980) like the Elstead Bog example, the dimensions of mire basins at different stages of their development are not always easy to deduce, although a trend towards increased surface area as peat growth and spreading takes place may be surmised.

In this context the earliest periods of organic sedimentation at North Gill, which occurred within small depressions in the stream valley, almost certainly can be compared directly with the above examples of forest humus accumulation, waterlogging promoting them into incipient peat forming hollows. The greasy minero-organic sediment which forms many of the basal pollen profile horizons in these situations could well comprise mor humus material. The association of this basal organic sediment with much charcoal in several North Gill locations, as well as at other similar sites in the North York Moors (Simmons and Cundill 1974), is a feature common to other mor humus deposits (Mitchell and Bradshaw 1984, Smith and Cloutman 1988). At this stage the North Gill profiles certainly functioned as closed canopy sites. The amorphous peat, lithostratigraphic unit NG-L5, at North Gill was a more spatially extensive deposit but from the wood remains of various species found within its lower levels, it still had shrub growth upon it and at its edge. Some approximation of the lateral diameter of the North Gill mire near the end of this sedimentary unit may be gained from the maximum extent of the upper charcoal layer (figure 6) which was presumably laid down upon the waterlogged mire surface and may roughly delimit its edges, although probably not as a single event. This suggest that the width of the peat forming area at North Gill averaged about 40 m at this time. At some places it is greater, but since the age of the upper charcoal may not everywhere be similar it would be unsafe to base firm conclusions upon this. With this proviso, and since the North Gill mire, containing detrital wood in places, may still have had its shallower parts colonised by scrub, and seems to have been surrounded by often very dense woodland, it appears reasonable to regard the various North Gill profiles as representing within-forest, closed canopy sites, even though the 40 m diameter of the mire is at the upper limit of the basin size defined by Andersen (1970), Bradshaw (1981b) and Prentice (1985).

The size of the North Gill peat basin as the Elm Decline approached is much harder to estimate.

The acceptance that each of the North Gill profiles should be regarded as a closed canopy site, with a very limited source area for the great majority of its pollen rain, has major implications for the interpretation of their individual pollen records. The first is that vegetation changes at one profile may not be capable of relation to those at any other, and certainly not those at extreme ends of the sampling transect. The relationship of the pollen record from the several profiles is discussed in section 9.2.

That each profile is reflecting the vegetation changes going on within a few tens of metres of it, however, is in itself of great value when each profile is interpreted independently. These pollen diagrams allow the study of *in situ* late Flandrian II woodland composition at an altitude very near the summit plateau of the North York Moors and perhaps the putative tree-line for the upland (Simmons 1975a), with no great weighting of the pollen spectra by transmision of pollen from beyond the local area. The pollen records may be made even more representative of actual local tree abundances by the application of pollen correction factors to the data. This has not been done routinely in this thesis since no definitive factors have yet been accepted from modern pollen studies, but those of Andersen (1970) and Bradshaw (1981a) are probably germane to the North Gill environment.

Differences in pollen production and dispersal ability still act to weight the pollen data, but in the fine spatial spectra from North Gill these will not be extreme, so that a reliable record of the abundance of rare taxa, or those which are poorly dispersed due to heavy pollen grains, may be more reliably gauged. *Tilia* for example, is shown to have been a significant component of this high altitude woodland, particularly since usually very under-represented in more regional pollen diagrams (Iversen 1973, Moore 1977, Greig 1982). The consistency of Ulmus at around 20% in Flandrian II in all North Gill profiles suggests its even distribution through the local forest stands, rather than its population being concentrated in areas of better soils further away. The recognition of many poorly dispersed or entomophilous taxa in the North Gill assemblages will be due directly to the spatially precise nature of the profiles, these hardly ever being recorded in regional diagrams in Flandrian II. Thus Fagus is repeatedly recorded, although usually as single grains, in most profiles even though its heavy pollen grains are transported a few metres at most (Prentice 1985), and so beech must have been a ubiquitous, if uncommon, element of the Flandrian II upland woods of this area. Even if only promoted by disturbance and regeneration, this recurrent presence denies its usually assumed absence from northern forests at this early date. Taxus and Ilex are other taxa very rarely present in pollen spectra of such antiquity, but their occurrence at North Gill, with holly present in several levels, suggests that they were locally a part of the woodland community. The richness of the shrub pollen flora at North Gill is also a direct consequence of the local pollen source area, within which rare taxa like Rubus, Euonymus, Rhamnus and Frangula are shown to have been present, while taxa such as Viburnum, Crataegus, Sorbus and Lonicera were relatively common. The record for Carpinus at North Gill 6 in mid Flandrian II is most unusual, but given the fine resolution character of the data could represent a very early local presence. Like Sorbus, Fraxinus is heavily under-represented, and its significant values at North Gill must imply a substantial local population, expanding when edaphic or disturbance factors were suitable. The corollary of the much improved representation of poor pollen dispersal shrub types in the very local pollen rain is that those taxa which are not represented, such as Sambucus or Acer, are much more likely to be actually absent from the local forest stand. The recognition of these several woodland taxa which Prentice 1988) describes as 'silent' due to poor dispersal, means that a much more complete ecological knowledge is gained of the woodland communities under study. The Flandrian II upland forests of the North York Moors was clearly of greater richness and diversity than may be gauged from the rather bland and homogeneous assemblages of more regional pollen diagrams. The absence of regional pollen inputs in the North Gill profiles also seems to obviate the problems of natural fluctuations in local pollen production producing erratic curves for local taxa, noted by Janssen (1973). In the absence of disturbance effects, the local nature of all the taxa seems to have produced a smoothing effect on individual curves.

The fine spatial pollen rain also seems to have increased the recognition of pollen of woodland herbs or open ground herbs which may not travel more than a few metres (Moore 1976). However, taller herbs may disperse further in woodland, especially through woodland (Andersen 1970) which may account for the consistently present curves of Rosaceae and Filipendula, and partly so for Rumex, at North Gill profiles. Opening of the woodland, increases the dispersal abilities of herb taxa (Moore 1976b) which partly accounts for the increased abundance and variety of herb types in phases of disturbance. Even in phases of stability, however, the North Gill profiles contain pollen records of many herb types, too numerous to list here but several like Cannabaceae, Ononis-type, Trifolium, Hypericum perforatum and Jasione for example not usually recorded in Flandrian II, due largely to the local nature of the pollen rain. They provide a far clearer indication of the members of the ground flora and field layer of the upland woods, as well as the mire and woodland edge taxa. A more rich and varied herb flora than had been hitherto appreciated seems to have been present.

In summary, the individual North Gill profiles show that the upland Flandrian II forest was dense but, at the spatial level of the forest stand of a few tens of metres diameter, perhaps surprisingly diverse and taxa-rich in all life-form groups. As stressed by Innes and Simmons (1988), this diversity was encouraged and perhaps maintained by woodland disturbance, and improved pollen transmission as well as actual vegetation change have combined to make the effects of disturbance very clear in the North Gill pollen profiles. The acceptance of a within-forest local pollen source area for each profile means that these disturbance phases must reflect events within the local woodland populations at the fine spatial scale. If they occurred in areas more than a few tens of metres from any particular profile, then they could well not be recorded there at all, and certainly not in anything but a very ephemeral way . It is quite possible that at this scale of precision, a disturbance noted at one North Gill profile could avoid detection in the next one 40 m away. The initial interpretation of vegetation history from the pollen record of each individual North Gill profile was therefore made in purely local terms in chapters 5 to 8, independent of pollen data recorded in the other North Gill profiles. Each profile's pollen diagrams have thus also been zoned internally, based upon the criteria defined previously in this thesis as denoting the presence or absence of disturbance, with a series of s and d phases unique to that particular pollen stratigraphy. The more detailed ecological interpretations made in the rest of this chapter from particular pollen diagrams are also made in the realisation that they may only have relevance at the local, fine spatial scale.

9.2 Multi-Profile Comparison at North Gill

The initial interpretation of the individual North Gill pollen profiles has been as independent records of spatially precise vegetation history, due to the small size of each peat forming area and its location within closed deciduous woodland. Beyond this fine-spatial stage of interpretation, however, it remains to be seen to what extent, if any, between-profile comparison or even correlations may be possible. Certainly comparison of the pattern and process of ecological change at each site should be achievable, for the local woodland seems to have been quite similar in each case and the effects of disturbance to have wrought basically similar types of vegetation changes within it, with analogous plant associations being formed. Since the North Gill pollen profiles lie only 40 m apart, or 80 m for the FRPA profiles, it is scarcely surprising that the Flandrian II forest communities should resemble one another closely at each site, but it is also to be expected, with each profile having a discrete pollen source area, that differences of detail should emerge. Many environmental factors would have operated at the fine spatial scale to affect the composition of individual forest stands and prevent complete homogeneity of species distribution. There is thus the potential of measuring the variability between individual forest stands, as well as that within them. Jacobson and Bradshaw (1981) and Bradshaw (1988) stress that with such a small area of woodland sampled by a single pollen site, 'vegetation reconstruction from small sites should not be considered in isolation... several sites are required to gain an understanding of the local pattern in the vegetation'. As well as linking fine-spatial records to more regional diagrams, these authors noted the need for the study of several small 'closed-canopy' sites which provided glimpses of individual vegetation units that combine together to provide vegetation history at a wider spatial scale.

Comparison of several vegetation histories in this way is clearly desirable, for it allows the reconstruction of vegetation patterns in three dimensions. Several multiple core studies have now been completed (Edwards 1983), and many of these, and the potential of the method, have already been discussed in chapter one. Only those from small sites in pre Elm Decline forested environments are of direct relevance to the North Gill study, the most successful perhaps being Williams (1985) and Smith and Cloutman (1988). These workers correlated pollen diagrams which were separated by some distance, in both cases from about 100 m to 250 m apart, within woodland subject to disturbance which they interpreted as originating from Mesolithic activity. Time correlation was made possible by their many radiocarbon dates, however, of which the North Gill study has relatively few, so that broadly contemporaneous vegetation patterns could be studied. It needs to be considered, therefore, whether any time correlation may be attempted between the North Gill profiles, other than the very coarse one of 'mid to late Flandrian II and early Flandrian III' which is provided by the radiocarbon dated Ulmus Decline.

The status of the individual North Gill profiles as within-forest sites with a predominantly local, spatially defined pollen source area can not be questioned, the high proportion of tree and shrub pollen to total pollen shows that this must be so. Only at NG7 with relatively much more shrub and dwarf shrub pollen than the other profiles is there any real doubt as to the density of the surrounding tree canopy. Within the closed-canopy site spatial model, however, there are several factors which are worthy of note, and these may be relevant to North Gill since the profiles there are so close together. 40 m is not far beyond the local spatial limits for pollen origin set by the modern pollen work of Andersen (1970) and Bradshaw (1981a), although in the strictest application of the model are enough to have little pollen rain in common. It should be noted, however, that these local source limits of 20-30 m are derived from moss polsters beneath an unbroken forest canopy, and are thus equivalent to basins of zero diameter. Empirical evidence from small hollow sites match the theoretical predictions of this model and so are also regarded as acting as basins of zero diameter (Prentice 1988). Towards the end of the amorphous peat accumulation at North Gill, and certainly after it, the diameter of the North Gill basin approached 40 m (although much less in earlier stages). These sediments also seem to be continuously distributed within the stream valley from NG1A to beyond NG6, so that in later Flandrian II the main North Gill basin may well have had dimensions of about 40 x 250 m, more than small hollow size. The key factor here may be whether the mire basin was merely fringed by trees and shrubs, or whether woody taxa partly colonised or overhung the basin surface. In the latter case the profiles would have continued to function as closed-canopy sites. This may have occurred during the high alder phase at North Gill, with detrital wood in the peat probably not having been carried far. In the former case there could well have been a 250 m long corridor of open space some tens of metres wide along the stream valley mire, along which pollen transmission over greater than 20 to 30 m could have occurred. The stream itself, of course, is another mechanism by which pollen transfer would have taken place, particularly for taxa like Alnus which is in any case very poorly dispersed terrestrially (Bradshaw 1981a, Prentice 1985).

During the later parts of the Flandrian II bog development at North Gill, with no wood remains in the profiles, taxa like alder and willow relatively low and acid bog peats forming, it is likely that there was open space between at least some of the profiles and at least a limited break in the tree canopy over the basin. Thus as the mire grew and the canopy became more open over the basin, so profiles would have had an increasing pollen source area and a higher extra-local component, defined by Prentice (1985) as pollen originating from greater than 20 to 30 m away. Thus at different stages of their development the North Gill profiles would have had changing source areas, from strictly local sensu Prentice (1985) in their early stages to a more mixed local and extra-local area in their later stages.

Of course, canopy opening was also achieved at times of forest disturbance at North Gill which are so clearly recorded by major falls in total tree pollen percentages, and by inwash of eroded soil, that they must have occurred adjacent to the pollen profiles and were local events. The opening of the adjacent tree canopy would have increased the extra-local component of the pollen rain during these periods, so that for each profile the pollen source area would have been rather greater in disturbance phases than in stability phases. The size of the disturbed area would clearly be critical in this case, and would decide whether any two or more profiles shared the same, or overlapping, pollen source areas. Since the 40 m interval between profiles is near the lower spatial limit of the extra-local pollen source area, any disturbance of other than very local size could be expected to impinge upon the source area of the next profile, and thus be recorded there. Disturbances of less than 20 m diameter could, however, still escape notice at the next profile and small disturbances at one end of the North Gill transect almost certainly would go unrecorded at the other end more than 250 m away. The size of individual disturbances in this respect is therefore a critical variable which, unfortunately, can not be estimated from the empirical North Gill data with any certainty. The above factors, however, point out that pollen source areas for this kind of small site are not rigidly fixed, but vary with changing basin size, basin shape and any fluctuations in the vegetation around the basin. The theoretical model of a local pollen source must be interpreted with flexibility.

This is demonstrated by the comments of some of the authors who have carried out pollen analysis from small hollow size basins. At Roudsea Wood for example, Birks (1982) accepts that the tree pollen percentages are derived from canopy composition within 30 m of his 25 m diameter hollow, lateral pollen transport being negligible. He also states, however, that the pollen of some non tree taxa, like Melampyrum, Sphagnum and Calluna, and agricultural taxa , like Plantago lanceolata and Cerealia, have probably been derived by regional pollen transport from beyond the wood. He also suggests that a decline in Ulmus frequencies may well reflect regional changes in elm populations as much as local changes around the hollow. Similarly Mitchell (1988) at Camillan Wood in Killarney suggested that at stages of the pollen record of this 30 m small hollow site, the entire Pinus pollen curve may have originated from a regional pollen source, rather than from around the closed canopy site. Thus although the local pollen source may be dominant, palaeoecologists feel that non-local pollen may be of significance also.

This conforms with current work on the interpretation of pollen transport which to an extent qualifies the local source area model. The importance of local pollen deposition by gravity fall from the canopy at within-forest sites is not challenged, but Prentice (1985), following observations by Andersen (1974a) and Krzywinski (1977), notes that large numbers of airborn pollen grains are intercepted by, and deposited upon, the forest canopy. These are subsequently brought down to the sub-canopy pollen site as part of the gravity fall component, which therefore can include a significant proportion of pollen grains of extra-local origin.

A second relevant factor is that, due to size and weight differences in pollen grains, individual taxa have different pollen dispersal abilities and hence different source areas. The source radus for each pollen type may be radically different, and dispersal bias is most important (Bradshaw and Webb 1985, Prentice 1985, 1988, Prentice *et al*. 1987). Heavy grains like *Tilia* or *Fagus* may travel only a few metres from their point of origin, while lighter grains like *Pinus* or *Quercus* may disperse much more widely. Even in closed canopy situations these lighter pollen grains have a source area larger than the average source area for the assemblage as a whole, especially since some of their pollen is extra-local, having settled upon the canopy and been transported down through it. In addition, as defined by Oldfield (1970) and employed by Jacobson and Bradshaw (1981), the pollen source area of the taxon or site does not represent all of its pollen rain, but only a high fixed percentage. 70% is the figure usually accepted and this has been used by Prentice (1985, 1988) in his calculations of the source areas of several tree pollen types under various conditions. He uses the '70% radius' as a measure of the major source area of the pollen of any particular taxon collected at a point in the canopy, from where gravity fall and downwash takes it to the ground. It appears to depend largely upon the deposition velocity of particular grains in a given windspeed, a variable which has been measured (Prentice 1985) for each taxon for pollen sites of different sizes.

Taking this dispersal bias into account, Prentice (1988) states that for within-forest, closed canopy pollen sites like moss polsters, defined as having negligible basin radius, 70% of the Pinus pollen rain is dispersed from up to 180 m away, 70% of Quercus pollen from 55 m radius, and 70% of Fagus from only a metre or so away. 30% of the pollen rain for these taxa comes from further away than these radii although much of it comes from very close by. As Prentice states, 'The 70% radius for Pinus in forest-floor samples is thus substantially larger than the 20-30 m that gives good correspondences between pollen and tree percentages for most taxa (c.f. Heide and Bradshaw 1982).'

The implications of this for the North Gill data interpretation are considerable, since each North Gill profile is of the small hollow, closed canopy type of pollen site. Of particular interest is the 70% radius pollen source for Quercus, since oak has been used as the basis for individual profile zonation, as an indicator of the presence or absence of disturbance. For within-forest sites like North Gill, Prentice's calculation that 70% of the Quercus pollen rain originates within 55 m of the site, gives an effective pollen source radius for Quercus two to three times greater than the 20-30 m figure. As basin size increases, so the Quercus pollen source area would increase also. Even at the closed canopy 70% source radius of 55 m, however, it is clear that since North Gill profiles are located around 40 m apart, one profile might lie well within the next profile's effective Quercus pollen source area, sharing part of each other's Quercus pollen rain.

Thus even a small disturbance of oak populations around one profile should be recorded within the oak pollen rain of the next profile in the North Gill transect. However, the next profiles beyond this radius, 80 m away or more, could still easily fail to register any change in Quercus frequencies. Also, at North Gill the distribution of suitable sampling points means that the interval between profiles may in places exceed 40 m, in which case the chances of their sharing a pollen source area are reduced.

Two other factors regarding Quercus are important here. The first is that Prentice's figures are most reliable for taxa which are fairly evenly distributed through the forest. Oak is held to be the major canopy component of upland Flandrian II forests (Godwin 1975), without extremely local concentration of its populations in favoured areas, such as is Alnus by watercourses. Its pollen percentages in stability phases throughout the North Gill transect are steady between 60 and 70% AP+G, suggesting some ubiquity of population, perhaps combined with a certain smoothing by the significant proportion of Prentice's extra-local (betweeen 20 and 55 m radius) component. The second factor is that Quercus pollen percentages apparently match woodland oak populations quite well, so major correlation factors are not required to estimate Quercus tree abundance (Hansen 1949, Smith 1972, Bradshaw 1981a).

Not only is Quercus a reliable indicator of disturbance, therefore, but its effective source radius is very convenient for giving some spatial idea of its location, being neither too low like Fagus or Alnus and therefore extremely local, nor too high like Pinus and therefore open to too great a dispersal bias to be interpreted spatially. The Quercus pollen source area radius of 55 m therefore promises to be still of a size small enough to monitor changes within a well defined, spatially precise area, but large enough to offer the possibility of correlation between pollen profiles at North Gill. The spatial relationships of the North Gill profiles in terms of the 20 m highly local pollen source radius, and the 55 m Quercus radius, are compared on figures 139 and 140. It may be seen that it is conceivable for a small disturbance centred near one profile to be recorded in a maximum of three profiles in the Quercus curve, although not in most other curves. The size of the disturbed area is clearly critical in this, much bigger disturbances registering over greater distances.

On the other hand, a disturbance of any size occurring beyond either end of the transect of profiles could easily register only at the end profiles, NG1A or NG7. Feasibly also, very small disturbances of only a few oak trees at a single profile, due to windthrow for example, could register quite strongly at that profile but at no other, for proximity to sampling source is still a very major influence on the pollen signal (Oldfield 1970). Similarly an event at a distance laterally from the North Gill stream could be picked up faintly at one profile but missed at all others.

In conclusion therefore, the ecological interpretation which follows in this chapter has in mind that the disturbance history at North Gill represents an unknowable number of disturbance events of probably various sizes in only broadly known locations. Some disturbances are almost certainly manifest in more than one profile, while some are almost certainly not. The temporal and spatial relationships of the d phases thus can not be known for sure, although some are likely to be contemporaneous. In the light of the above discussion it seems reasonable, if not to correlate the phases recorded in different profiles, at least to compare them in a conspectus way, based upon their strictly comparable zonation criteria (see below). Thus events of similar kind are being compared, and spatial differences in their impacts are being interpreted, without assumption that they are or are not time-comparable at any degree of resolution below that of the Flandrian chronozone. It is inferred that some are indeed correlatives, but that is a model dependant hypothesis which requires to be tested by radiocarbon dating. All are, however, closely comparable in terms of pattern and process in the ecosystem, are spatially well defined individually and invite comparative interpretation on that basis.

9.3 Spatial Comparison Criteria

The behaviour of the Quercus curve has been held to reflect the type of woodland disturbance regime existing around the North Gill site as a whole, with high or low Quercus percentages interpreted as representing the absence or presence of woodland disturbance respectively, in the period prior to the Ulmus decline. Any natural variability in the oak curve due to variation in pollen production and transport may have been smoothed by oak's ubiquitous distribution in the dryland forest. With the same criteria adopted for each site, being the behaviour of the Quercus and Ulmus curves, the s/d phase zonation schemes which have resulted are therefore comparable, and comparison of pollen phases between sites can be attempted. It is unfortunate that relatively few radiocarbon dates are available from the site and so comparison must to a large degree rely upon biostratigraphical features i.e. changes in the pollen assemblages themselves. This is not ideal, since it is the fluctuations in these data which it is intended to observe and compare, and they cannot be used as instruments of correlation for that would prejudice their objective ecological interpretation by introducing circularity of argument. The difficulty of evaluating spatial differences in vegetation communities is compounded by the great complexity of the overall North Gill data set which, even at the centimetre level of resolution at which comparison must begin, now comprises fourteen different pollen profiles, if the work of Simmons (1969a) and Innes (1981) is added to that presented in this thesis. The range of taxa variability over such a large number of profiles will clearly be potentially much larger than that within a single profile or among only a few. In a post disturbance situation, plant community variation over a relatively short distance could well cause high pollen assemblage diversity between diagrams and make comparison of related plant communities very difficult. It follows from these limiting factors that, in the absence of a comprehensive series of radiocarbon dates which covers several pollen profiles, it is not possible to arrive at a reliable correlation of the North Gill pollen diagrams. The most that may be achieved is a conspectus zonation for comparing events which is based upon criteria common to each pollen site, is consistent within the terms of these criteria and does not conflict with any relevant palaeoecological evidence from the site itself or the wider study area. As far as possible, those pollen changes which cannot be interpreted consistently from profile to profile have been avoided in this scheme, for these require too great a measure of premature interpretation. As has been discussed in some detail above, this means that all pollen types which may be recruited from very local taxa concentrations, and which may therefore be heavily over represented in some pollen profiles, should be disregarded for relating pollen stratigraphies. It is logical, as a starting point, to use the criteria which have been employed to zone each individual pollen profile internally as the basis for inter-profile assemblage comparison and so the Ulmus and Quercus curves will be considered first. There are other pollen types however, such as Alnus, Corylus/Myrica and Pinus, which occur in every North Gill pollen profile, have wider significance as Flandrian biostratigraphical markers and which provide possible alternatives. These will also be considered as possible aids to spatial comparison.

The Ulmus Decline

A marked decline in Ulmus pollen values occurs in all of the North Gill pollen profiles presented in this thesis and in those diagrams previously published from the site and this is accepted as the biostratigraphic feature which defines the end of the Flandrian II chronozone on the North York Moors. Although some temporal variation may have occurred at the spatial scale of the forest stand, it is regarded as forming a near synchronous feature in all North Gill diagrams, supported by two chronologically indistinguishable radiocarbon dates of 4767±60BP (BM-426) and 4730±80BP (HAR-6620) from North Gill a (Burleigh et al 1976) and North Gill 5B respectively. Atherden's (1976) date of 4720±90BP (T-1084) from Fen Bogs shows it to be a synchronous event on the regional as well as site scale. The Ulmus decline therefore forms a chronostratigraphic as well as biostratigraphic benchmark horizon for North Gill and is used as the only secure foundation for inter-site temporal correlation.

The Quercus curve

As explained above, Quercus pollen at North Gill is regarded as combining local and extra-local components since oak in the mid Flandrian is considered to have been distributed fairly evenly through the upland forest as the most common dryland canopy component within the relatively stable deciduous woodland biome (Godwin 1975, Simmons and Innes 1982). Unlike other taxa such as Alnus, Betula and Corylus/Myrica, oak was neither successional nor concentrated by localised variations in edaphic, shade or moisture factors. Upon the sandstone soils around the North Gill site, it is likely that the unbroken woodland canopy contained a great deal of Quercus (Simmons and Innes 1982), most probably Quercus petraea. It follows that disturbance of that woodland canopy within the several North Gill pollen catchments would have inevitably involved a reduction in the abundance of oak and thus a fall in the amount of oak pollen in the tree pollen rain. In all of the North Gill pollen diagrams the behaviour of the dryland total tree pollen curve and the oak pollen curve are very closely associated. The percentage representation of Quercus is therefore regarded as a sensitive indicator of the presence or absence of closed canopy conditions, and by implication forest disturbance. The oak curve in the North Gill pollen diagrams reacts to disturbance events in a uniform way, and is the only taxon to do so. Thus, prior to the Ulmus decline, where other indications of disturbance are present Quercus percentages are always reduced, while if other indicators of disturbance are absent, then Quercus percentages remain high. No other taxon is diagnostic in this way, since Quercus was the ubiquitous dryland woodland dominant in the North Gill pollen catchment. This has justified the use of Quercus as the pre Ulmus decline disturbance criterion in individual profiles, and so Quercus forms the logical basis for pre Ulmus decline inter-profile comparison of disturbance events.

The Corylus/Myrica curve

Corylus/Myrica forms the subsidiary component of the upland oak-hazel mixed woodland of the North York Moors in Flandrian II (Simmons and Innes 1982), but it has not been considered for a role in profile correlation. Fluctuations in the Corylus/Myrica pollen curve have not been used to define pollen phase boundaries because *Corylus*/*Myrica* is viewed as an heliophyte 'response' taxon, being interpreted as primarily contributed by hazel to the pollen diagram. It would have been irregularly distributed as an understory shrub within the oak woodland and while forest disturbance may well have encouraged its expansion and stimulated increased flowering, competition from ecologically similar taxa and natural variations in abundance due to edaphic and other factors would make its behaviour an unreliable record of deforestation. If forest regeneration were locally incomplete, for example, individual pollen profiles may record high *Corylus*/*Myrica* values even though forest disturbance no longer occurred. Also *Corylus*/*Myrica* may not respond positively to deforestation in circumstances where other taxa, such as *Calluna* or *Salix*, may be favoured before it due to environmental factors or local community structure. High or low *Corylus*/*Myrica* frequencies cannot in every case be interpreted as representing the presence or absence of forest disturbance, and so the pollen type has not been used as an s or d zonation criterion. Its pollen frequencies are more indicative of local ecological conditions than of forest disturbance.

Pinus

A fall in *Pinus* pollen has traditionally been regarded as occurring at the end of the Boreal period and of chronozone Flandrian I (Smith and Pilcher 1973). This decline in pine frequencies is also recognised at the Boreal-Atlantic Transition in North York Moors pollen diagrams (Simmons and Cundill 1974, Jones *et al* 1979). Some variation occurs in the higher parts of the region, however, for if the *Alnus* rise is regarded as the diagnostic feature of the Boreal-Atlantic transition, in a number of diagrams pine frequencies remain high during the earlier part of Flandrian II (Simmons and Innes 1982, 1988c, Innes and Simmons 1988). This late presence of Pinus, however, varies considerably from site to site and in some cases, as at North Gill, appears to be linked to the presence of charcoal. In Flandrian II on the North York Moors Pinus appears to have persisted where ecological conditions were favourable, often in post-fire regeneration (Heinselman 1973, Ahlgren 1974, Bennett 1984) but perhaps also where siliceous, limestone or thin soils allowed it to compete successfully with other woodland components. In North Gill and other North York Moors diagrams the behaviour of the pine curve in Flandrian II is not determined solely by forest disturbance and can not be used as an s or d zonation criterion on that basis. Opening of the woodland canopy by disturbance may cause the pine curve to rise due to better transport of pine pollen from further away, although pine is not involved in vegetation change itself.

Alnus

Alder deserves detailed consideration as a suitable candidate for use in inter-profile zonation for three main reasons. The first is that Alnus, although varying considerably in range of frequency between the North Gill diagrams, is present in each diagram in significant percentages through most of the analysed profile. The alder curve is therefore capable of comparison from diagram to diagram. The second reason is that Alnus is a major component of the Flandrian II deciduous woodland, being co-diagnostic of the sub-regional pollen assemblage zone at this time (Simmons and Cundill 1974), and would perhaps have existed throughout the regional woodland in locations of suitable microclimate and soils, although secondary to Quercus and Ulmus. Thirdly, a sharp rise of Alnus pollen is the diagnostic feature of the start of Flandrian II and may be considered to be a regionally near synchronous event, at least at the spatial scale of the eastern Central Watershed of the North York Moors. If the rise from very low frequencies to abundance which occurs near the base of several of the North Gill diagrams in fact represents the major biogeographical event of the Flandrian I/II transition Alnus rise, then this feature of the diagrams could be used as an age equivalent biostratigraphical marker horizon in the same way as the later Ulmus decline. It would therefore provide a further secure means of diagram correlation.

There is, however, no compelling evidence that the expansion in alder pollen frequencies in the North Gill pollen profiles is the alder rise of the Flandrian I/II transition, or indeed any regionally significant synchronous feature of value as a correlative datum. Indeed, there are many indications to the contrary. Although few radiocarbon dates exist for the North Gill profiles, or indeed for the North York Moors upland as a whole, there are sufficient to define the high Alnus phase in some North Gill diagrams and thus, if a synchronous feature, across the site as a whole. The pre high alder date of 6316±55 (BM-425) from North Gill b (Simmons 1969a, Burleigh et al. 1976) provides a maximum date for the Alnus rise at that profile. The date of 5945±90BP (Gu-1072) predates the rise in Alnus frequencies at North Gill 2 (Innes 1981), however, and so this could more accurately date the feature at North Gill. A date of around 6000BP for the Flandrian I/II transition is feasible in the English uplands, although the only other available date for it in the upland North York Moors is considerably earlier at 6650±290BP (Gak-2706) at West House Moss (Jones 1977), although its high standard deviation value reduces its usefulness as a regional standard. It is supported, however, by a date of 6680±90BP (CAR-894) from Seamer Carr in the Vale of Pickering on the southern edge of the upland

(Cloutman 1988). That these two Alnus rise dates are indistinguishable may suggest that there is no altitudinal gradient in the timing of the alder rise in the North York Moors of the kind recognisable from other upland regions such as the Pennines (Simmons and Innes 1987). In fact, dates for the Alnus rise from high altitude in the Pennines are comparable with the North York Moors dates, for example 6779±75BP (SRR-95) at Valley Bog in Upper Teesdale (Chambers 1978), while dates from the intermediate lowland are not considerably older, for example 6962±90BP (SRR-103) at Neasham Fen in the Tees Valley (Bartley et al. 1976). A few very high north Pennine sites do have anomalously late dates, such as 5300±40BP (SRR-1412) from Pow Hill (Turner and Hodgson 1981), but it is much more likely that this date results from atypical local environmental conditions than that it is evidence of any altitudinal trend. It is just possible, therefore, that the North Gill increase in Alnus represents the Flandrian I/II transition dated at about 6000BP, but the bulk of the evidence would suggest a regional Alnus rise several centuries prior to that date. The North York Moors plateau is a relatively low altitude upland in comparison to the Pennines, and the specialised environmental conditions required to produce extremely late Alnus immigration are unlikely to have occurred. In fact, as a streamside site, North Gill is more likely to have witnessed alder colonisation earlier rather than later. This question is further complicated by the presence of disturbance phenomena immediately prior to the increase in alder at several of the North Gill profiles, for example in phase 1 at NG4, NG5 and NG6. Many sites in northern England show forest disturbance, often with charcoal, at the Alnus rise horizon (Simmons and Innes 1987) and it is quite possible that fire disturbance of woodland may provide the trigger for local alder expansion within the overall trend of regional alder immigration. Alnus establishment could not be safely regarded as even a sub-regionally synchronous event if cultural factors were involved in providing conditions suitable for Alnus colonisation at the site scale (Smith 1984). Furthermore, the pre Alnus, disturbance dominated phases of the central area of North Gill occupy the basal levels of the pollen diagrams, so that the status of Alnus prior to peat inception at those sites cannot be known. Whether these basal disturbance phases represent pre Alnus rise conditions (i.e. Flandrian I) or merely a period of low alder frequencies during Flandrian II remains conjectural. The comparative radiocarbon evidence and the coincidental clearance evidence would point to the latter, however, particularly when some of the basal 'low alder' phases do contain substantial amounts of Alnus, although low compared to the ensuing period of Alnus abundance, for example at North Gill 5A and 5B where the alder frequencies at the base of the pollen diagrams are as high as in later Flandrian II.

Corroborative evidence that the pre alder abundance basal pollen phases at North Gill are of Flandrian II age comes from North Gill Head (Innes 1981) and North Gill 7, where alder frequencies never attain the very high values of the sites downstream, but approximate throughout Flandrian II the low frequencies shown at North Gill 5 outside the abundant Alnus phase. Similarly other sites on the Central Watershed at Bluewath Beck Head (Innes 1981) and Glaisdale Moor and Loose Howe (Simmons and Cundill 1974) show Flandrian II Alnus histories in keeping with the North Gill 7 evidence. The massive alder abundance of the lower North Gill profiles would appear to be an event of local significance rather than a regional biostratigraphic marker such as the start of Flandrian II.

It remains a possibility, however, that in strictly North Gill terms the high Alnus phase is a near synchronous feature in Flandrian II vegetational history, and thus of value as a correlative marker at least for profiles NG1A to NG6. It has already been shown that radiocarbon evidence from North Gill 2, supported by Simmons' (1969a) date from North Gill b, dates the Alnus rise there at around 5945BP. The radiocarbon dates from North Gill 5B show the end of the high Alnus phase there to have occurred at 5760±90BP (HAR-6615). Thus if the high alder phase at North Gill represents a single event it seems to have lasted for about two centuries. (If the North Gill 2 date were to be disregarded, the North Gill b date of 6316BP would provide a maximum duration for the feature of five centuries.)

Pre high Alnus pollen spectra are only found in the central part of the site, between North Gill 4 and North Gill 6. At North Gill 1A and North Gill 8 all of the lower profile sequences of disturbance and stability phases occur in association with high alder values, as do the second disturbance phases at North Gill 6 and North Gill 3. However, there is no evidence of disturbance during high Alnus times at the intermediate sites at North Gill 4 and 5. The centimetre sampling interval at NG4 and NG5 is too narrow to have allowed local disturbance around these sites to go undetected and it would follow that the high alder phase disturbances around North Gill 3 and 6 and those around North Gill 1A and 8 must represent distinct and local events. The data from North Gill 7 cannot be considered in relation to any of the other profiles in regard to the high alder phase, for no such phase exists at North Gill 7 to provide a comparative marker.

If the interpretation of the North Gill data is based upon the premise that the high Alnus phase is a synchronous feature, so that its limits may be regarded as time correlatives from site to site, it follows that peat formation occurred at markedly different times at different sites in the North Gill valley. This is a quite reasonable, and even quite likely, possibility. It also follows that at least six distinct episodes of disturbance are represented in the North Gill profiles, and perhaps many more, with no disturbances represented at all pollen sites and the sequence of disturbances at North Gill 7 unable to be compared with the other profiles on the basis of the Alnus curve. This is also quite possible, even though the pollen sampling sites are only 40 m apart, for ephemeral, short-lived and small scale forest disturbances (caused by Mesolithic populations or even by natural events such as windthrow) within dense woodland might only be recorded within a few tens of metres of their location (Jacobson and Bradshaw 1981, Bradshaw 1988). A very localised break in the woodland cover could feasibly go unnoticed in the pollen rain of a site only forty metres away, as in the North Gill situation, in these circumstances. If the high alder phase is used as a marker horizon at North Gill although it would not be possible to correlate individual pollen disturbance phases from profile to profile, a broad spatial assessment of the vegetation mosaic around North Gill before, during and after forest disturbance could still be attempted.

The conclusion drawn from an assessment of the evidence is that it is not valid to use Alnus as either a zonation criterion or biostratigraphical marker for inter profile correlation at North Gill. While the period of high alder frequencies at most profiles probably overlaps chronologically to some extent, neither the start nor the end of the high Alnus phase can be demonstrated to be a synchronous event across all or part of the overall site. It is considered far more likely that the representation of Alnus pollen in each profile is determined by site-specific environmental factors; by local responses to changes in edaphic conditions, hydrology, pollen production or transport, and to the timing, location and character of vegetation disturbance in different parts of the site. This accords with the highly local character of alder pollen frequencies as proposed by Janssen (1986) and discussed in detail in chapter two above. Tinsley and Smith (1974) record modern Alnus as showing very poor local pollen production and transport. It would be quite possible for the high Alnus phase at North Gill to be a correlative event, although this would have required a single factor to be operative at all sites from NG6 to NG1A, and the existence of this has not been demonstrated. At North Gill, therefore, both the establishment and decline of Alnus are considered to be probably time-transgressive, and its distribution and relative abundance are believed to be strongly spatially variable. It has therefore not been adopted as a means of profile zonation or correlation, but interpreted as an indicator of local palaeoecological change. From this point of view it may be very useful for inter-profile comparisons.

9.4 Inter-Profile Conspectus

The s and d sequence of pollen phases recognised at each North Gill pollen profile on the basis of fluctuations in the frequencies of Ulmus and Quercus, and interpreted as reflecting the presence or absence of human activity, are shown upon figure 141. The Ulmus decline is present in every case and is used to provide a benchmark for initial profile correlation. Three disturbance (d) phases of reduced oak frequencies are recognised at each profile except for North Gill 9 and North Gill 10, where only a single d phase occurs prior to the Ulmus decline probably due to late peat inception. As well as being recognised subjectively in each diagram on pollen stratigraphic grounds, the triple phase sequence was recognised numerically by PCA at North Gill 3 and North Gill 1969 (NGa and NGb), by DECORANA at North Gill 5B and shown at the latter to be chronologically distinct by radiocarbon dating. As the sampling interval used in Flandrian II peats in this thesis does not exceed one centimetre, it is believed that all disturbance phases present in the sampled profiles will have been recorded, since the time span represented by this sampling interval will probably be a few decades. A major cycle of disturbance and regeneration of woodland could not be completed in so short a time. As discussed above for the individual profile analyses, there is no convincing evidence for any hiatus due to peat erosion or growth standstill in the North Gill diagrams where FRPA has been applied, although it may have occurred at North Gill 2 (Innes 1981), and possibly at North Gill 9. In the diagrams with triple disturbance sequences, the behaviour of the pollen curves themselves suggests no breaks in the sediment profile, and so the number of disturbance phases in each profile is considered to be an accurate record of the sequence of events at each site.

Although three d phases occur in each of the major profiles, however, it is not possible to show that these can be correlated directly between diagrams; to show that the same three disturbance events were responsible for the creation of the sequence of d phases at each profile at the North Gill site. That could only be achieved by the radiocarbon dating of every d phase in every profile and even then, given the vagaries of the radiocarbon method, unequivocal correlation may not be gained. It is conceivable that a combination of (a) disparity in the start and duration of peat accumulation in the different profiles, and (b) several local forest disturbances at a distance from one another, could produce the effect of three d phases in each profile but which in reality resulted from a higher number of events. Such an explanation perhaps is the most likely hypothesis, but there is no evidence to confirm it. The close proximity of the North Gill profiles makes it probable,given oak's source area radius, that some disturbances did in fact leave their mark in more than one profile, since with some variation due to topographical features, the pollen profiles at North Gill are only between 40 and 60 metres apart. All of the d phases at North Gill contain pollen fluctuations which indicate substantial canopy opening, and often incorporate charcoal and inwash evidence of soil erosion. They represent substantial, local impacts upon the woodland, involving the creation of significant open areas, and are not merely the fading pollen signal of distant canopy opening. It does not seem probable that all such major vegetation impacts would fail to be recorded in an adjacent profile. The distance decay function (Edwards 1982) of ruderal herb grains, being produced in low numbers and easily filtered out by a woodland screen, is very high, so that the rich ruderal pollen flora in many of the North Gill d phases means that their point of origin was very close to the sampling site. They could represent local disturbance only. The fall in oak pollen values caused by such disturbance could well, however, be registered at the next profile or further, depending on the size of the disturbed area.

The pollen evidence shows that each profile at North Gill was locally affected by disturbance, although some variation in intensity exists. That three d phases exist at each site makes it possible that three single large disturbances, or clusters of disturbances could be sufficient to explain this evidence. This triple sequence could be coincidental, for a larger number of diachronous smaller disturbances could produce the same pattern, of a maximum number the same as the total number of phases recorded at North Gill. In the light of the above discussions on Quercus pollen dispersal and local pollen source areas, a reasonable working hypothesis for interpreting the North Gill data spatially is that the reality probably lies somewhere between these extreme figures.

Even if, however, we are observing the effects of a large number of separate disturbances, it is possible that, rather than these occurring at unrelated intervals during Flandrian II, there were broad periods of time during which disturbance occurred with some regularity at North Gill, and intervening periods when disturbance was not such a regular occurrence. This could explain why the same number of disturbances occur in each long profile. This balance could be coincidental, but a large number of chronologically unrelated disturbance impacts would surely have produced a less evenly distributed pattern of d phases. This model would mean that many of the d phases would be of broadly comparable age.

Such evidence is circumstantial, however, and it has been decided not to attempt any model-dependant chronological correlations for the North Gill s and d phases prior to the Elm Decline. Phases are therefore compared spatially in terms of ecological changes, but are not correlated.

The disturbance phases from all of the individual pollen profiles have therefore been compared sequentially (figure 141), and conspectus S and D phases established for North Gill as an aid to spatial interpretation. These are not regarded as chronozones, but only as summary biostratigraphic units and they conform with the zonation system of woodland s/d phases established for the North Gill 3 area in chapter four and by Simmons and Innes (1988a). This is used as a basis for data comparison. The *Ulmus* Decline is regarded as a fourth D phase, while a period of high *Quercus* values which predates phase D1 at both North Gill 8 and North Gill 1969 is regarded as site phase S1, although not represented at most profiles. The summary S/D phase sequence is used as the framework for the following interpretation of the spatial changes in vegetation communities occurring at North Gill as a consequence of Flandrian II woodland disturbance.

9.5 Spatial Comparison of the North Gill Data

In this section the environmental data from North Gill are interpreted in terms of the spatial changes in vegetation communities occurring on, at the margins of, and around the North Gill mire, using the combined lithostratigraphic and microfossil data assemblages from the several analysed profiles. Both mire development and woodland history are considered together, as the development of the overall North Gill landscape occurred as an integrated whole, with many points of interaction between the wetland and dryland systems, and between autogenic and allogenic stimuli.

9.5.1. Phase NG-S1

This phase in environmental history at the site predates the first major disturbance phase at NG8 and NG1969 and represents a time of vegetation stability. Organic sediments of this age have a very limited distribution (figure 141) being restricted to North Gill 8 and North Gill 1969, and incorporating few pollen spectra, although such pre-disturbance sediments could be present at other unanalysed points at the site. The two profiles with S1 pollen phases are located in the lower and central area of the site, however, so a spatial comparison is possible and, since they may represent early peat inception at North Gill, they provide important information regarding the pre-peat vegetation at elsewhere at the site. This appears to have been fairly homogeneous closed woodland at both profiles, with tree and shrub pollen accounting for about 90% of total pollen in both cases, with consistent amounts of Ulmus, Betula, Tilia and Quercus with the latter dominant. Pinus values are very low and almost nil at NG8 suggesting that pine did not find suitable habitats in the North Gill woodland. The slightly higher frequencies at NG1969 may reflect pollen transport from populations on the higher sandstone plateau. Some disparities occur within the shrub pollen types, however, indicating perhaps some localised community differences along the North Gill transect within a similar oakwood matrix. Corylus/Myrica is rather higher at the lower site, perhaps due to differences in substrate, NG8 being on limestone while NG1969 is on sandstone. Alnus values are higher at NG8, so perhaps the stream valley supported a denser stand of alder in its lower part than higher up, although herbs of streamside habitat, like Filipendula, occur at both. A major difference, however, is that Salix is abundant at NG8 but almost absent at NG1969. Since willow pollen production and transport are both poor (Bradshaw 1981a) such high values must mean very local dense willow stands (Caseldine and Gordon 1978) around the lower part of the North Gill stream at this time. Marsh grasses, perhaps Molinia, seem to have provided the peat forming vegetation at NG8, whereas mosses occupied the area around NG1969, where Sphagnum values are very high and the basal peat is formed from the moss Polytrichum commune. Abundant Sphagnum spores do not necessarily mean a great expansion of bog moss, for sporing is very variable (Tinsley 1972), but they are conventionally assumed to represent wetter conditions (Tallis 1964c) and high values during a phase of peat inception make sense.

Increased acidity is not implied, however, for other acid-tolerant types, such as Calluna, are poorly represented.

Dickson (1973) has pointed out that base-tolerant Sphagna can be found in carr or wet woodland habitats and this may be the case at North Gill. Johnson and Dunham (1963) have noted that Polytrichum moss is favoured by running water, so that the Polytrichum moss peat at NG1969 may be the result of natural paludification within wet woodland, although much charcoal is present.

Polytrichum is also considered, however, to be an efficient coloniser of burned areas (Ahlgren 1974), in which case Polytrichum moss growth, and perhaps peat inception, may have followed a period of burning at the North Gill stream. If so, this would account for some ruderal herb pollen grains found during S1 at both NG8 and NG1969. Artemisia, Rumex and Chenopodiaceae occur during this phase. Some more open areas within the forest, perhaps at the stream edge, may testify to a pre-peat burning event. The role of forest disturbance in peat inception is considered below. The reason why early peat formation took place at these two sites is not clear but, whatever processes were involved in the start of organic accumulation, microtopography may be presumed to be critical regarding its actual location (Edwards and Hirons 1982). Minor variations in the pre-peat topography would account for the occurrence of early centres of peat inception, in micro basin features of perhaps very limited extent indeed. Sediment formation rates in such situations could be extremely slow (Chambers 1981, 1984) particularly if initially of mor humus, although the concentration evidence from NG8 does not particularly suggest this. Factors of pollen influx and preservation make this equivocal evidence however. Both sites are in areas of low gradient in the North Gill valley. It is possible that such areas represent shallow hollows within the stream valley, but not affected by the actual stream course where moving water prevented material accumulating. Paludification within very localised, confined microdepressions via wet moss, rush and sedge floras could be responsible for this phenomenon. It is interesting that no aquatic taxa occur in this phase at either site.

9.5.2. Phase NG-D1

The second phase in vegetation history at North Gill is one of woodland disturbance, and consequently vegetation diversity, and is recognised at all profiles except NG9 and NG10. It can be correlated stratigraphically with the lower charcoal rich peat which forms the basal organic deposit over much of the site, except NG8 and NG1969. The considerable extent of this lower charcoal peat unit (figure 6) suggests that the fire which created it was coincident with a major expansion in the ground surface area upon which organic accumulation occurred at North Gill, and very probably the cause of it (Moore 1975). Peat growth may have been encouraged by the waterlogging of the stream valley, and perhaps by its choking by inwashed material, following clearance of surrounding slopes. The deposit varies considerably in thickness and consistency, being several centimetres thick in microbasin areas and rather thinner at points of slightly steeper gradient. The moss peats of NG-S1 were by now buried, although Simmons (1969a, 1969b) found Polytrichum peat superior to the charcoal rich organic stratum near NG1969, presumably resulting from colonisation of post-fire, wet areas.

The spread of waterlogged environments throughout most of the stream valley allowed the creation of a mosaic of wetland plant communities across the site. Obligate aquatic pollen appears only at NG1A and NG3, so that areas of deeper water may have been quite restricted. A reedswamp and fen type of herb flora is present in quantity at all profiles from NG6 downstream however, with taxa such as Filipendula, Potentilla, Ranunculus and Galium prominent. Holdgate (1955) has reported modern upland fen associations including these taxa. Some wetland taxa show great spatial variability, however. Sphagnum is present in high frequencies at NG6 and NG7, and quite significant values at NGHead and NG5. It is hardly present however, at NG4 and downstream. The opposite distribution occurs with the carr taxa Alnus and Salix, important local components of the stream valley vegetation. Alder in particular shows a clear gradient in frequencies from NG1A to NG7. Between NG1A and NG4 it declines from 70% - 60% of AP + G, around NG5, NG1969 and NG3 it falls to very low values of 10% before recovering to around 40%, at NG6 and NG7 it is at 25%, while at NGHead it reaches barely 10% of AP + G. Salix also shows such variability with high values between NG1A and NG4, moderate frequencies in mid transect around NG5, but low values from NG6 upstream. At NG1969, however, willow rises to these moderate values from a very low base in NG-S1 and so the Alnus - Salix record shows a clear spatial gradient in the distribution of carr vegetation in NG-D1. It appears possible that this arrangement of taxa is a response to the localised fire disturbance at the site. Thus at NG1A to NG4, the alder-willow carr maintains its values and thus was presumably not actually removed during the burn, although close enough to record ruderal communities on drier areas adjacent to it. In mid site, from NG2 to NG6, there is clear evidence of actual removal of local adler in the very low frequencies at NG1969, falling from high values in NG-S1. In contrast, Salix increases across this phase boundary. This may be explained by the replacement of fire-cleared alder by willow in the carr habitat, Salix being strongly encouraged by burning to assume local dominance (Iversen 1973). At NG6 and above, however, both alder an willow are poorly represented, and fen-carr seems not to have been the local wetland flora. Instead Sphagnum is present in high values at thise sites, although low elsewhere, and so shallow moss-filled depressions seem to have existed in the upper part of the site rather than fen carr. Two factors may account for this, (a) generally less well developed wetlands near the plateau edge and perhaps also (b) that NG6 to NG7 was upstream of the most severe disturbances during phase NG-D1. Indeed, since the area around NG9 and NG10 sems not to have started accumulating peat at all at this time, it may be that the NG7 and NGHead sites began accumulation as flush deposits around the spring-head rather than as a direct response to other forms of paludification, although their well humified character may deny this. That NG7 was peripheral to fire disturbance is supported by the charcoal evidence, for while there is abundant microcharcoal, macroscopic charcoal is lacking. It is possible that all macrocharcoal would have been washed away downstream from NG7, but perhaps it was not directly influenced by disturbance, although clearly well within pollen rain influence. The curves of Gramineae and Cyperaceae in this phase are noteworthy for their lack of spatial diversity, for at virtually every profile they are very similar with grasses at 30% of AP + G and Cyperaceae at 10%. Such consistent representation suggests a very even distribution in all parts of the site, probably as mire taxa. Some of the Cyperaceae could be from non-mire taxa, but as it is often under-represented in the pollen rain (Rybnickova and Rybnicek 1971) it may have rivalled Gramineae in terms of ground area covered.

In addition to the spatial differentiation of wetland plant communities at this time, the fire disturbances of phase NG-D1 clearly also greatly diversified the dryland vegetation surrounding the wetland site itself. As tree pollen values fall sharply, it would seem that quite substantial deforestation took place, although there is considerable variation in the fall of tree pollen from profile to profile. Oak and alder are the taxa most subject to removal, the former present in NG-D1 at an average value of 40% everywhere, slightly less at NG7. This suggests oak's even local and extra-local distribution in the North Gill forest. Minimum oak values during D1 are more instructive, however, being 40% at NG1A to NG4, 20% at NG5 and 30% at NG6 and NG7. This is further evidence that the most severe disturbances may have been around the central part of the site, with the extremities of the transect, particularly the lower end, less closely affected. A similar pattern emerges if alder is added to oak and calculated as a percentage of total land pollen; 45% (NG1A), 40% (NG4), 25% (NG5B), 30% (NG6), 20% (NG7). The latter low value reflects natural paucity of Alnus at the head of the stream. The pollen assemblages during D1 (and indeed in all of the disturbance phases) contain elements from contrasting types of community.

Three types may be recognised; regenerating communities from within the disturbed area, woodland edge ecotone communities from its margins, and homogeneous, or at least undisturbed, woodland communities from beyond it. The relative proportions of these three components will have been determined by the proximity of each pollen profile to the centre of each disturbed area, and the resulting differences in detail will show the spatial variations in the post disturbance changes in vegetation, determined by the distance decay effect on pollen transport and taphonomy.

The deciduous dryland tree pollen in this phase, dominated by oak, will have come from the undisturbed woodland. The evidence in the Quercus minimum values around NG5 that this area was close to the centre of a disturbed area is generally supported by the ruderal herb pollen identifications. Although ruderals occur at every profile, their quantity and diversity are greatest in the central part of the site, between NG4 and NG6. Melampyrum, likely to be Melampyrum pratense, achieves highest values of 20% around NG5 and so must have been growing very close by (Moore et al. 1986), although it is present in every profile at North Gill in D1, usually around the 10% level. These peak Melampyrum frequencies are of a similar magnitude to the very high values after fire clearance recorded by other authors in the uplands of Flandrian II (Tinsley 1975, Chambers 1982, 1983, Simmons and Innes 1981, 1988c). Simmons (1969a) recorded frequencies of over 80% of AP at Moss Swang in the North York Moors. Although Melampyrum is so abundant at NG5, it is unaccompanied by other 'weed' types, whereas lower values of Melampyrum occur in association with a wide range of weeds in adjacent profiles, at NG4, NG2, NG1969, NG3 and NG6. At the latter three profiles, this includes Plantago lanceolata, while all contain several broken ground or grassland weeds like Artemisia, Cruciferae, Taraxacum and Chenopodiaceae. These ruderals are much less in evidence at the profiles which the AP values suggest were not so heavily disturbed, although Melampyrum is still present in high values. The ubiquity of Melampyrum may well be due to its ability to respond to a variety of disturbed habitats. Thus the Melampyrum values at NG1A, NG4 and NG7 may reflect its tendency to dominate the field layer in lightly burned woodland (Iversen 1949, Berglund 1966) where open ground conditions have not been created. In the central part of the site, however, where severe disturbance occurred, Melampyrum would share the habitat of post disturbance damp grassland with taxa like Plantago lanceolata, Succisa and Potentilla. The association of the latter two taxa with Melampyrum in post disturbance grassland is not uncommon, and it has been observed by several authors including Mamakowa (1968), Turner and Hodgson (1983), and Williams (1985). The latter author considers that Succisa may be a good indicator of adjacent grassland, since it occurs in wet grassland and pasture (Vuorela 1973, Behre 1981), often post clearance, but its grains are very poorly transported indeed. It certainly reflects open conditions (Adams 1955). At North Gill it occurs in significant values at NG5 and adjacent profiles, in small amounts at NG4 and NG6, and not at all at NG1A and NG7. Succisa frequencies at North Gill may thus very sensitively indicate the location of open conditions in mid transect, less open conditions around NG4 and NG6 and only lightlu disturbed woodland at the extremities of the transect. It could merely signify different responses in different disturbances. In this it accords very well with the tree pollen gradient evidence. Potentilla follows a similar pattern. Ranunculus and Rumex are harder to categorise as both may fill a wide range of ecological habitats. Although some Rumex grains may be from ruderal or grassland areas, its higher values at the lower end of the transect suggest a population either associated with the streamside carr environments or perhaps a tall herb community at the edge of the disturbed area. The dominance of Melampyrum in this phase at NG5 suggests very local growth, often grains being recorded in clumps (Janssen 1986). Pteridium is spatially very variable suggesting that, like Melampyrum, it may have occupied a variety of grassland, woodland and woodland edge locations.

Interpretation of the pollen data in terms of the woodland edge communities at North Gill is difficult as the spatial location of this ecotone area could have been most complex, but it is one of great importance in assemblage diversity (Edwards 1982). It is most difficult, however, to distinguish heliophyte shrub taxa of the woodland edge, entering the pollen record due to increased flowering or improved pollen transmission, from similar communities regenerating upon the disturbed areas. Also, since the sizes and locations of disturbances are not known a significant area of woodland edge flora may have been quite close to each of the profiles. Thus the minor heliophyte shrubs are recorded at each profile, albeit in low values. The extremely local nature of these taxa's pollen record may be gathered from the curves for Lonicera at NG5, being absent at NG5A yet at NG5B being its most significant at North Gill. Some shrubs would have been directly encouraged by burning, however, including Prunus and Sorbus (Ahlgren 1974). Rubus is recorded only in the NG3 area adjacent to the postulated most heavily burned ground. Its seeds are able to survive fire in the soil and may be stimulated to germinate by heat (Uggla 1950) allowing it to be among the first post-fire shrub colonisers. Its pollen has not been recorded away from the central area of North Gill. The process of regeneration of woodland occurred at North Gill through a range of successional woody taxa and their more abundant pollen representation allows a spatial consideration of their role in succession to be made. Pinus appears to have been favoured by the disruption of the oak forest, for it increases markedly in all profiles. Between NG1A and NG4, however, it rises to only 15%, while in the rest of the site it reaches up to 30%. The difference may be due to better pine pollen transport to these areas than to the lower part of the site perhaps from a pine population upon the sandstone plateau to the north. Since Pinus is fire resistant and responds positively to fire clearance (Carlisle and Brown 1968, Smith 1982), however, its colonisation of the site cannot be ruled out. The gradual increase of the pine values from NG2 to NGHead might suggest a combination of the two effects. Fraxinus reacts similarly to disturbances, being better represented, albeit in low values, in those which took place between NG4 and NG3. This must be due to actual ash colonisation of the disturbed area and its margins, given the opportunist, heliophyte ecology of the tree (Wardle 1961) and its poor pollen dispersal. Grains of Fagus at NG1A and Carpinus at NG6 suggest that other, more telocratic elements of the tree flora were assisted to join the local woodland, or at least having their pollen more easily dispersed.

There were, however, three main shrub components of the regeneration complex, Corylus/Myrica, Betula and Calluna, and these do show important spatial differences across North Gill. Since few grains show clear Myrica affinities, the burned area seems to have regenerated through an association of birch and hazel. Again, the presence of the more densely wooded terrain around NG1A had the effect of reducing the birch-hazel abundance in that profile. From NG4 upwards, however, the two taxa dominate the site. Apart from the base of NG5B, where birch reaches 50%, it remains steady at between 30% and 40%. Corylus/Myrica in this area is present as at least 70% everywhere, with even higher values at NG6 to NGHead. Birch differs from hazel in showing a gradual decline through D1, while hazel values are largely maintained at initial levels. Much of the early hazel pollen in D1 could have come from increased hazel flowering at the woodland fringe as well as from quickly sprouting individuals (Rawitscher 1945) within the burned area. Initial recolonisation of burns could have been mainly achieved by Betula, however, as the fastest growing pioneer tree type. As shrub cover developed, birch stands in the disturbed area would have given way to hazel, with the latter more suited to dominance upon soils showing no real evidence of acidity. Thus although hazel distribution could change, finally forming dense stands and the woodland edge pollen component reduced, average pollen abundances would remain steady. Towards the end of the phase, birch may have joined willow in the wetter streamside areas of the site, replacing alder, and may no longer have been able to compete within the main regeneration shrub community.

Some extreme spatial diversity occurred in the post disturbance distribution of Calluna at North Gill, which is complicated by the plant's ability to prosper in both mire and dryland situations. No heather macrofossils occurred in the peat and so Calluna had not colonised the mire surface, but could still have been present at the mire edge. Calluna growth is stimulated by burning (Gimingham 1960, Mallik *et al.* 1984) and so heather should have been favoured during this phase, perhaps present as part of the woodland fringe flora, in locations of more suitable rocky or sandy soils. At all sites Calluna is very steady through this phase, suggesting that heather had stable source areas at North Gill, rather than showing more erratic very local frequencies as a rapidly successional taxon. From NG1A to NG3 Calluna values are moderate at between 10% and 15%, but reach 30% at NG6 and more than 50% at NG7 and NGHead. As with pine, there is a possibility here of distance decay effect from extensive populations on the nearby upland plateau surface. The evidence for such stable plateau ericaceous heath is not strong, however, (Simmons and Cundill 1974) and the very high percentages involved, over 20% of total land pollen, must mean local growth of heather in the NG7 area in some abundance (Evans and Moore 1985). It is likely that, since carr vegetation was apparently absent from the upper part of the site in these disturbances, heather colonised the stream edge and the thinner, more acid soils of slightly steeper gradient around NG9 and NG7, where shallow organic deposits were still very spatially restricted, perhaps at the upper margin of the zone of disturbance at North Gill. The lower values of heather recorded lower down the stream are unlikely to be a reflection of this patch of heather growth, and some limited Calluna presence at the lower part of the site must have contributed. Values do tend to be lowest in the NG5 area of the transect, as if competition among other taxa in that area was too great for heather to become established.

9.5.3 Phase NG-S2

This phase is one of vegetation stability in which pollen evidence of active disturbance is no longer recorded. Vegetation diversity is consequently much reduced from the previous phase, but disturbance results may be present in the spatial patterning of plant communities which became established when regeneration was completed. Closed canopy woodland was apparently re-established over much of the site, for tree pollen, with alder, accounts for over 50% of total pollen at every profile, and in the lower and central area of the site much more. Quercus is present at about 60% in all diagrams, being restored throughout the woodland, while the Ulmus pollen count varies very little from 20% at every profile. This is only slightly below its consistent value in D1, when pollen transport was easier, and it would seem that elm was not involved in the cycle of disturbance and regeneration. Other trees do show some altitudinal variation in their pollen values in this phase. Tilia occurs at almost 10% from NG1A to NG3 which, after correction for its low pollen productivity (Andersen 1973), makes it a substantial component of the forest. Berglund (1966) considers that lime may be encouraged by fire clearance, unless edaphic factors are unfavourable. This may have been the case between NG6 and NGHead, where lime frequencies suggest a smaller population of the tree. Betula maintains a reduced but significant presence of nearly 20% at most sites, exceeding 30% at NG7 and NGHead and being lowest at NG1A. Pinus shows a similar gradual increase in frequency with altitude and distance upstream, although in pine's case this could reflect the openness of the woodland, and thus transport effectiveness for airborne pollen, than real distribution of populations across the site, as will be the case with birch. At 20% in this woodland phase at NG7, however, stands of pine trees may have persisted not far away, perhaps on sandstone outcrops of the plateau edge. Alternatively, since every profile contains microscopic charcoal during phase S2 it may be that burning somewhere in the forest was encouraging pine survival.

The local origin of birch and ash pollen shows the regenerated woodland at the site to be of an open, secondary nature, at least within the area of influence of previous disturbances. The behaviour of Corylus/Myrica suggests this, as hazel falls in frequency between NG1A and NG6 to about 50% which probably still represents a high degree of local broken canopy conditions in the restored woodland with hazel continuing to flower profusely except when directly shaded by the recovered oak canopy. Hazel values remain very steady in this phase, implying that once established the secondary woodland remained stable with little tendency to further canopy closure except perhaps at NG5 where oak seems to increase at the expense of hazel late in the phase. At the head of the transect between NG7 and NGHead, however, hazel values remain as high in S2 as in D1. Hazel woodland or scrub must have dominated the higher part of the site and formed stable communities, perhaps as a transition zone between the oak-birch woodland and even more open communities of the plateau surface, the hyper-forest of Simmons (1975a). Woodland is known to have covered at least part of the Central Watershed summit during Flandrian II (Simmons and Innes 1982), however, so perhaps the hazel abundance around NG7 was a localised phenomenon, for hazel established as a thicket after burning can be locally very difficult to dislodge. Certainly hardly any bare ground was maintained around North Gill, for weed pollen types virtually disappear from the site record. Occasional grains of disturbed habitat occur at NG1A and NG4 in S2, the more heavily wooded end of the transect. This could be a result of short-lived disturbed habitats being created within the stream valley by flooding or course changes by the stream itself, destabilising sections of its bank downstream where it has greater erosive power. Most herbaceous grains in this phase are of wetland type and very local to each profile. Maintained Pteridium values and odd features such as the consistent, although very low, Melampyrum curve at NG5B at this time argue for the possible persistence of small herb-grassland associations in favoured locations.

Of greater significance, however, is the clear evidence of local concentration of certain taxa in different parts of the site so that, while some taxa like birch appear to have found a stable role within the wider vegetation mosaic, others achieved almost total local dominance in favoured situations. Calluna is a case in point, for every profile shows heather to have maintained most of its representation from the previous phase, normally 10% to 20%. Heather had found an ecologically stable role in the site flora, perhaps in association with birch in heath-type communities, although birch would tend to shade heather out (Gimingham 1975) unless acidity had increased enough to prevent birch establishment at all, in which case heather would tend to alter soil acidity to its own advantage and encourage podsolisation. It is more likely perhaps, with heather values comparable from NG1A to NG3, that Calluna colonised the edges of the mire which occupied the stream valley. At NG7 and NGHead values do not decline from D1, and even increase at times to about 60%, so that heather must have continued to dominate the ground surface at the head of the site, forming an ericaceous heath layer in the wetter and more acid areas where the hazel scrub of this zone could not become established. Evans and Moore (1985) state that Calluna is only present in values of more than 20% of total pollen in locations where heather is growing on site. At NG7 this figure is exceeded in much of the diagram. The boundary of this *Calluna* zone may be observed above NG6, for at that profile the high frequencies established in D1 do fall to more moderate values of around 20%, akin to the lower part of the site. If *Calluna* were concentrated around the spring-head area, it is possible that the heather frequencies recorded downstream of the NG9 and NG7 area may reflect water transport of *Calluna* pollen downstream and its redeposition where areas of flatter gradient formed small pools. The stream transport of pollen is a well known phenomenon (Peck 1973, Brown 1985). It is a factor also likely to be related to the distribution of other streamside taxa, especially *Alnus*. Alder frequencies show marked variation from profile to profile, changing little at NG1A at 60%, being superabundant from NG4 to NG6 at over 80% and rising markedly at NG7, but only to 40%. The central part of the site must have sustained a dense alder carr, for only under an alder canopy could such high frequencies be recorded. *Salix* was important around NG3, and alder seems to have had a reciprocal relationship with *Salix* in the carr vegetation around NG1A, but gradually supplanted it. The increased density of the carr woodland at NG1A at the end of S2 is shown by the loss of *Pinus* from the pollen record. Air transport of alder pollen is weak (Tinsley 1975), so these values are considered representative of alder concentration close to the profiles. As explained above, alder is considered a predominantly very local pollen source, and alder wood in the stratigraphy in this phase from NG5 downstream supports this view. Given a direct relationship between pollen abundance and plant distribution, the dense alder carr would appear to have extended along the stream sides as far as NG6, while at NG1A it was of a more diverse, lighter type. The latter had perhaps never been subject to disturbance and thus evolved more slowly, while in mid-site the seral replacement of willow by alder seems to have been accelerated, perhaps due to post disturbance ecological factors. Some establishment of alder probably took place in the vicinity of NG7, for pollen values are significant, but here other taxa are of far more importance locally. The great rise of alder may be a response to increased wetness of the stream valley, for the area of the site covered by peat grew at this time, probably in response to the hydrological changes set in train by previous disturbances and peat depth in the central basin increased. The mire was becoming less confined topographically, and 'secondary' type basin peats were beginning to form, perhaps due to paludification after pedogenic change (Taylor and Smith 1980) after disturbance. An increase in Sphagnum spores at NG4, NG5 and NG6 may reflect these changes, at least in the centre of the mire, while alder carr, with some willow and birch, densely covered the damp ground and shallow amorphous peat at its margins and occupied the pool areas with swamp-carr flora, to the south of the heather dominated, more open environments above NG6. Pollen features peculiar to individual profiles occur which show the importance of very local pollen sources, for example Rumex is common in most of the lower and central profiles and its record in both D and S phases alike suggests that it was part of the streamside herb flora, probably in fen-carr tall herb habitats with taxa like Filipendula and Umbelliferae. At NG4, however, Rumex is present at the end of S2 as 20%, and presumably reflects growth of the taxon very close to the pollen sampling point itself. Only low frequencies occur at adjacent profiles, however, demonstrating the very localised profile specific nature of the herb pollen curves.

9.5.4 Phase NG-D2

This phase is one involving major woodland disturbance, with Quercus much reduced in abundance although once again NG1A has higher oak percentages (40%) than the rest of the transect profiles which all fall to around 30%. This again may reflect the proximity of NG1A to undisturbed forest downstream. The disturbances are associated with stratigraphic evidence for local deforestation. Fire and soil erosion occurred at all of the stream valley profiles and disturbance had dramatic impacts upon vegetation patterns. Once again, however, the most badly affected area seems to have been between NG4 and NG6, where both stratigraphic and pollen changes are the clearest. Ruderal herbs and fire-following weeds are again represented mainly by Melampyrum with highest frequencies at NG5, although also substantial at NG7, where Epilobium also occurs, so that burning may have taken place further upstream. Also, broken ground ruderals like Artemisia and Plantago major-media occur at NG1A, so here disturbance may have been more serious than before. The abundance of weed pollen as a whole is rather less than in D1, and it could be that disturbed areas were no longer so adjacent to the respective pollen profiles. This could be due to the expansion of the surface area covered by wetland sediments at this stage, for the North Gill mire had certainly spread both laterally and along the stream valley since earlier clearances. The dryland pollen source of most of the ruderal weeds may have been a little further away than in D1, hence the restricted ruderal range and abundance compared with that phase. A few metres may have been sufficient to have this effect. Melampyrum is the exception and this taxon must have been locally abundant in many places. Since Melampyrum's frequencies hardly diminish during the phase, either it found stable habitats where it was not replaced during plant succession, or some burning occurred throughout the phase, rather than as single events. The Pteridium curve behaves similarly, suggesting recurrent expansion of bracken on to burned areas from woodland fringe habitats and its possible persistence in dense stands (Ahlgren 1974, Rymer 1976).

The most significant diversity in spatial distribution, however, occurs with Alnus which clearly suffered greatly in disturbances in the centre of the site where its previous abundance was greatest. The charred alder and birch bark associated with the silt and charcoal horizon in this phase supports this view. That alder falls sharply to 20% from 80% at NG5 must mean removal of alder carr from adjacent to the profile itself. The fall in alder is almost as great at NG4, while the smaller scale but significant fall in Alnus at NG7 shows that disturbance of this kind probably occurred there also. At two areas of the site, however, alder values do not diminish, or even rise slightly, in both cases being present as around 70%. Between NG1A and NG8 it would seem that alder was not disturbed. Only dryland tree types decline at this site; mainly oak, but it is interesting that Tilia frequencies also fall at all profiles from NG1A to NG3, suggesting that lime was a significant local constituent of the upland oakwoods, perhaps expanding in previous woodland consolidation, and was undergoing disturbance at the lower end of the North Gill site.

The other anomalous area of the site with regard to disturbance effects is that around NG6 which differs from nearby NG3 and the rest of North Gill in that both Alnus and Tilia are unaffected, even though other clear signs of deforestation occur in the profile, the decline of oak being just as strong as elsewhere and with the full range of disturbance indicators recorded, including charcoal and silt inwash to the profile. Tilia even increases in value, although falling further downstream. One explanation is that fire did not affect the vegetation around NG6 directly, although the rest of the evidence would suggest that this profile was close to disturbance impacts. Ruderal pollen is as prominent and oak pollen as diminished as at the other profiles. Alder populations by the stream may simply have escaped the disturbance which occurred nearby. An alternative explanation may be different source areas of the pollen types. Pollen transport of alder by stream flow is extremely efficient, much more so than by air (Tinsley and Smith 1974) and streams can carry great quantities of pollen from their fringing vegetation, particularly of abundant producers like alder (Brown 1985). A major tributary stream enters North Gill just above NG9 and, since there is no evidence of peat accumulation at either NG9 or NG10 at this stage, the first area of flatter gradient and organic accumulation where reduced water speed would allow this stream's pollen input to be deposited and preserved is in the vicinity of NG6. The high Alnus pollen frequencies at NG6 could very well result from the carriage of pollen from undisturbed Alnus carr down the tributary stream and its release at NG6 as the first area of sediment deposition south of its confluence with the North Gill beck. Undisturbed woodland not far to the east of North Gill would also explain the rise in lime pollen at this level. This could mean that the lateral extent of the disturbed area was mainly to the west of North Gill, which is supported by the greater distribution of charcoal across the western part of the site. The stream-borne pollen load would be released by the stream close to its entry point (Peck 1973) and so hardly any of the stream inflow component would reach the profiles lower down North Gill. The vegetation around NG6 itself at this stage shows all the signs of adjacent disturbance.

Salix is favoured along the stream at all profiles, while Betula and Corylus/Myrica respond positively within the disturbed zones, with the latter more successful at greater altitude, and birch favoured virtually everywhere. Hazel seems not to have expanded at all within the wooded area below NG4, whereas birch does so. Perhaps the removal of canopy or undergrowth by a lighter burn, rather than actual tree removal, would have favoured regeneration by the less heliophyte birch, with no woodland edge communities present. Opportunities for hazel to form scrub or thicket dominance apparently were greater upstream, for hazel frequencies are higher there, being 80% at NG4 and NG5 and reaching 90% at NG7. The latter figure suggests pure stands of hazel at the northern end of the site, prompted by fire opening of a lighter woodland which would have contained a great deal of hazel already. The Calluna community which became established around the spring area at NG7 and NGHead contracted somewhat during this disturbance. Since hazel seems to have occupied the drier areas at this altitude, the decline in heather abundance at NG7 probably reflects increased wetness of the mire system at this time. Although the bog area at NG7 was still very restricted the increased wetness at that point may be indicated by the stratigraphic change to a fluviatile clay deposit and high Sphagnum spore values. The area of shallow, drier peats at the mire edge where Calluna may have become established could well have shrunk as a consequence, with heather not competitive on the drier soils where there are no real signs of major acidification. The slight rise of Calluna in mid site and slight fall at the lower end, may reflect local reactions to individual disturbance scale. Burning at NG5 may have been sufficiently intense to devegetate completely the ground surface, allowing some Calluna expansion on the burned soil. At NG1A, however, the persisting shrub flora of birch, willow, hazel and alder may have limited dwarf shrub opportunities by heavy shading and maintained base-status soils. Increased wetness of the mire, as suggested by increased Sphagnum values at NG5 and NG7, is supported by the recognition of aquatic taxa, particularly Potamogeton, at NG1A and NG5, and other open water indicators like Mougeotia. Mire pools had evidently begun to form, perhaps as a direct result of hydrological changes after vegetation removal (Wiltshire and Moore 1983) had led to flooding within the stream valley. Much of the pollen concentration evidence suggests a general increase in the rate of peat formation at this time, and raised water levels in the mire in at least the lower half of the site. Although Calluna seems to have been reduced in distribution due to these hydrological changes at the spring head mire, the area to the north of it towards the plateau edge near NGHead saw a marked expansion of heather at this stage, at the expense of both oak and hazel. It would seem that where perhaps thinner soils were more prone to acidity on the sandstone plateau, and the vegetation was in any case more open, a heathland community could become established and maintain itself. Replacement of oak and hazel by heather under such circumstances on poor sandy soils is a phenomenon reported from several sites with a Mesolithic fire-disturbance history (Keef et al. 1965, Radley et al. 1974). Alnus seems to have expanded onto the plateau surface in quantity near NGHead. In suitable habitats it could have been established on the Central Watershed for quite some time previously (Simmons and Innes 1982). The effects of the North Gill disturbances do not seem to have registered very stongly at NGHead, perhaps due to different pollen sources at the plateau edge and above. There is no reason why deciduous, broadleaf trees could not establish woodland upon the plateau summit (Simmons and Innes 1988c). Tallis and Switsur (1983) have reported alder macrofossil remains from the Pennines at heights well in excess of the North York Moors summit, so that altitude is not a limiting factor. Indeed the frequencies of Ulmus at almost 30% at NGHead suggest that mature mixed oak woodland could sustain itself there. It is likely that the more open elements of the vegetation which are prominent at and above the highest parts of North Gill reflect curtailed forest development after disturbance and its effects upon soils, hydrology and associated factors. The behaviour of Pinus in this phase supports this, for pine is low at NG1A,is very sharply increased in mid site near NG5 and NG1969, is less clearly increased in the hazel and heather dominated area of NG7, and not encouraged at all at NGHead. Response to the location of fire seems of more influence in the distribution of pine than any altitudinal control, although a trend towards a general decrease in all tree values with altitude does seem to be present. The pollen concentration evidence from NG5 supports this view, for the peak in pine in phase D2 at those profiles is shown to represent a real increase in the number of pine grains in the pollen rain (not due to a relative increase in percentage terms due to the decline of Quercus) from a point where it had virtually vanished from the pollen record, itself an unlikely situation if a stable background population were contributing to the pollen rain from the plateau surface. It seems quite likely that pine did become re-established in the burned zone at North Gill, along with the other fire-response taxa recorded as growing locally at this time, such as Melampyrum, Polygonum, Epilobium and Pteridium.

9.5.5 Phase NG-S3

This phase is one of vegetation stability and, to varying degrees, the profiles at North Gill record the restoration of woodland, although of a type rather different to previous stable phases. The extreme diversity of the previous phase is replaced by a more homogeneous deciduous forest in which a much greater dominance is achieved by the major thermophilous trees than hitherto. Mixed oak woodland is recorded at most of the site, even at NG7, in which Quercus represents 60% in each profile. These remarkably consistent percentages suggest that woodland colonised the dryland area even up to the plateau edge and probably onto the summit surface itself, and that oak had been able to form a more complete canopy than before, with habitats for birch and hazel much reduced, although the frequencies for the latter remain the greatest around NG7 suggesting that the hazel abundance of the disturbance phase there was not entirely removed, and that a zone of scrub woodland persisted in this area. It is possible that this more open vegetation existed only in the vicinity of North Gill, being a product of disturbances, and that away from this, and perhaps other, springheads the closed oak woodland prevailed. Ulmus and Tilia became very substantial contributors at all parts of the site and, after allowance for low pollen productivity and poor transport, the lime may very well have formed stands in the vicinity of North Gill, and have spread throughout the upland forest. The increase in importance of lime is a major factor in later Flandrian II (Greig 1982) and in many areas fire may have altered environmental conditions to encourage its germination and establishment (Berglund 1966). If anything, its frequencies are higher at the upper part of the site, suggesting that factors other than altitude governed its success. Post fire colonisation of better soils could account for its increase. Fraxinus becomes a major forest tree in this phase, apparently retaining some of the area into which it expanded after the previous disturbances, showing that soils in part of the site at least remained base rich, although disturbed. Ash would have joined the other forest trees in the canopy, for openings in the forest seem to have been very few as heliophyte shrubs disappear almost entirely. That Fraxinus occurred in patches in the forest where soils were suitable is suggested by the spatial differences in its pollen record, important at NG1A and NG5, less so at NG4, NG6 and NG7. That the forest canopy was largely continuous away from the break provided by the wetland area is suggested by the fall of Pinus pollen to very low values, even at the more northerly profiles. Certainly the herbaceous indicators of open ground which might point to the presence of local breaks in the canopy are virtually absent.

While the dryland forest seems to have formed, with some internal variation, a single unit, real spatial differences occurred in the development of the mire and the plant communities associated with it. The hydrological changes resulting from the previous deforestation had caused a great increase in water supply to the mire, giving a great impetus to peat growth. Concentration evidence from all profiles shows that peat was accumulating much more rapidly, and the peat deposited was of a type far less humified than the earlier amorphous peats. A basic change in mire character occurred, with *Eriophorum* becoming the major peat forming material in many places, and indications of an increased acidity in some profiles. Varying degrees of wetness in the stream valley also seem to have developed, which would have had major impacts upon wetland vegetation patterns.

Three main wetland vegetation zones may be recognised at North Gill, the boundaries of which appear to be quite well defined. The lower half of the site from NG1A to beyond NG5 was dominated by *Sphagnum*, supported by Gramineae and Cyperaceae in varying degree at different profiles. *Sphagnum* values are particularly high at NG4 and NG5 and that area must have supported very wet conditions in its centre, with bog moss dominant, with a grass and sedge flora in less wet areas and at its edges, probably comprising *Carex*, *Molinia*, *Glyceria* and *Eriophorum*. The abundance of carr type vegetation of the previous stable phase did not recur, with *Alnus* in moderate values and *Salix* almost absent. Bog pools existed around NG5 and NG1A, and presumably were common across the site, with aquatic taxa like *Potamogeton* and *Hydrocotyle* present. Many of these could be persistent features of the landscape, since pond muds formed the sediment in phases D2 and early S3 at these profiles. The substantial values for *Alnus* suggest that alder was still important locally, either in the woodland or as carr elsewhere along the stream, but there is no evidence of carr vegetation around these lower profiles. The second area of wetland type is around NG3 and NG6, where the local Alnus dominance was not reduced during phase S3, and quite dense alder carr probably existed around these profiles. If the disturbances of phase D2 removed carr from this area, its re-establishment must have occurred in this renewed phase of stability. Salix joined alder in the formation of these carr communities, which could have expanded to around this area from undisturbed carr up the eastern tributary stream of North Gill, from where it is postulated water-borne Alnus pollen was derived during phase D2. A transported component could still have been important in S3. An alternative is that wetland shrub-carr types had maintained populations around NG9, where the tributary enters North Gill, for there no peat deposits of this age have survived, if they ever were formed. It seems certain that this area around NG9 would have supported alder dominated scrub as alder values increase at NG7 also, adjacent to this area upstream. A difference in mire water levels, and perhaps also in acidity, may account for the different types of mire vegetation between the carr zone around NG6 and the bog area below it. The third main mire vegetation type appears to be around NG7 and above, where Calluna and Gramineae values suggest that a grass-heath flora characterised the shallow organic deposits in that area. Much drier conditions are reflected by the low values for Sphagnum and absence of willow and streamside or aquatic herbs. Potentilla at this profile echoes the grass pollen curve and is a major component of burned heath areas (Kaland 1986).While it is difficult to separate the mire and dryland roles of heather, it is very probable that the drier conditions at NG7 and NGHead allowed it to play a leading mire role. It is likely that the mire was not as spatially widespread at the upper part of the site as in the wetter areas between NG1A and NG5, where peat formation had by now begun to spread out of the stream valley, having laid down considerable depths of sediment, and onto the surrounding hillslope.

9.5.6 Phase NG-D3

Disturbance at North Gill is registered at all the pollen profiles, but the effects upon the vegetation are rather different in the various sectors of the site. There is evidence that the whole length of the site was affected by forest burning at some stage as charcoal appears in each profile. The density of the charcoal evidence is very variable, however, with a thick lens at NG7, a thinner but still clear band at NG1A, and much fewer charcoal pieces at the other profiles, although the micro-charcoal record is comparable everywhere. It seems that at some sites the bog surface had grown high enough to reduce the inwash component of larger charcoal pieces, or else the sampling profiles were too far from the edges of the bog to receive major input of inwash material. At most profiles except NG7 and NGHead the peat forming material was by now poorly humified *Eriophorum* with some *Sphagnum*, so that the spread of the bog in both horizontal and vertical directions had clearly accelerated. The Cyperaceae, Gramineae and *Sphagnum* curves represent the wetland flora at almost all sites now, as a more acid bog environment developed. While already well developed at NG1A and NG4, the fire disturbance during D3 encouraged this trend. Concentrations show rapid peat growth at all profiles in the main stream valley. The surviving alder carr between NG3 and NG6 was removed in this phase, and was replaced by seral growth of *Salix* which temporarily achieves very high values in this area, indicating abundant local growth. *Sphagnum* increases markedly at NG6, showing that bog growth spread to this profile which previously had resisted the immigration of acid-tolerant flora. Acidification of the environment probably also contributed to alder's decline, since it requires fertile soils to regenerate (McVean 1963) as well as damp, humid conditions. Alnus also falls in frequency at NG7 and NGHead, but very slightly, and the alder record there is likely to represent stable local communities. The increased wetness recorded at NG6 and the heavy charcoal layer at NG7 are both symptoms of the intensity of clearance and this was sufficient in the upper part of the site to cause peat formation to occur in the area of profiles NG9 and NG10. Presumably the water-shedding of the steeper slope in this area had prevented peat inception, but the effects of major input of drainage water and its reduced ability to drain away downstream due to the growth of bog peats around NG6 now seem to have created local water surpluses in this area, leading to organic accumulation. This also occurred at NG10, showing that this process took place all around the head of North Gill,even upon the eastern side. Surviving alder and other streamside populations in the area, previously providing a non-disturbance element of wetland flora, may have been destroyed in this phase. An alternative explanation, however, would be that earlier peats had existed at NG9 and NG10, but that the disturbance and erosion cycle was so great that these were removed entirely, causing post disturbance deposition to form the basal deposit. The first explanation, delayed peat inception due to topography, is much more likely.

The behaviour of Alnus in D3 at NG9 and NG10 suggests actual removal of alder from NG9, whereas higher frequencies at NG10 point to that site being nearer to surviving alder populations, perhaps further up the tributary stream to the east. The other wetland flora from D3 at NG9 and NG10 reflect the paludification of damp grassland very clearly, with Equisetum, Lotus, Thalictrum and Sphagnum among several such indicators. Thus the wetland and wetland edge flora reflect a similar pattern between NG6 and NG7, with Alnus scrub being replaced by willow, acid damp grassland

and bog taxa, with a shift towards acidity and wetness causing bog growth at NG6 and peat inception at NG9 and NG10. An interesting development takes place at NG1A, for Alnus actually increases at this site, although very high Sphagnum peaks show that wet, acid bog filled the valley both here and at NG4. It seems that at NG1A alder was encouraged by forest disturbance in the same way as Salix or Corylus/Myrica. This has been reported at other sites (Smith 1970, 1984) and increased alder values here probably represent alder populations within the general mixed oakwood being able to regenerate and colonise the wetter situations away from the mire after removal of mature forest trees. It need not represent re-establishment of Alnus carr. It seems that the Alnus frequencies of NG-S3 may reflect the local woodland representation of alder after the end of its abundance phase at the lower part of the site.

The effects of this fire-disturbance upon the flora of the dryland forest is evident in all of the North Gill diagrams by the replacement of tree frequencies by the familiar assemblage of successional taxa. Melampyrum is present in frequencies of up to 10% in all profiles, but is highest at NG5 and NG9 at over 15%, and much less prominent at NG1A and NG4, although frequencies are still high enough to signify local post-fire growth. Few ruderal herbs accompany Melampyrum in this phase at NG4 and above, however, but a wide range of weeds is recorded at NG1A, where Melampyrum evidently did not dominate the herb flora. A major peak of Plantago lanceolata is unique to NG1A, and of particular interest is the record of cereal-type pollen. This association points to a more intensive usage of the lower part of North Gill, with cultivation within the disturbed area as well as heavily grazed and trampled grassland (Sagar and Harper 1964) and much broken ground. The central and upper part of the site, although subject to major fire-disturbance appears not to have been utilised in the same way. Unusually high Pteridium values and temporarily abundant Calluna suggests that the type of disturbance at NG1A was rather different to the upper site where only the kind of evidence shown in previous D phases is repeated. Certainly the complex clearance phase at NG1A, resembling 'landnam' style activity, seems centred around NG1A. The 'regeneration' type flora, in contrast to the immediately post disturbance herb taxa, show much fewer spatial differences in D3. Corylus/Myrica increases in most cases, although at NG7 and NGHead Calluna figures more strongly, perhaps reflecting existing distribution patterns. The ability of heather to induce podsolisation beneath it tends to prevent its invasion and shading by shrub taxa, and soil acidification around the upper limit of the site may have progressed far enough by this stage to maintain Calluna dominance during stable and disturbed phases alike. Around NG4, Fraxinus and Betula respond rather better than Corylus/Myrica, while Pinus attains frequencies around 20% at NG1A, NG5 and NG9 and expands more modestly elsewhere. It must be concluded that pine once again may have found suitable locations within the post fire mosaic of vegetation to re-establish itself locally. Fraxinus and Fagus certainly did so, perhaps upon areas previously occupied by Tilia, which loses ground within the most heavily disturbed lower site, although increasing around the upper margins of the site at NG7. Quercus is the main tree affected by the disturbance, but at NG1A and NG4 Ulmus is also reduced in value, a change not seen at the rest of North Gill. This reflects the different composition of the forest near the lower limit of the site, with more elm and lime, but also indicates that in places the D3 disturbance was of a type not seen at North Gill in previous D phases.

9.5.7 Phase NG-S4

The ensuing phase of stability is one in which closed woodland conditions were restored, for in each profile the pollen values for the dryland tree taxa reach the highest frequencies so far seen at North Gill. Quercus, Ulmus and Tilia were all very common in the forest, while substantial values for Fraxinus and Betula show it to have been of a secondary character, although quite dense. Tilia in particular must have expanded its local population quite markedly, and it is as important at the higher part of the site as at NG1A, so that the degree of spatial diversity in the woodland was probably at its least during this phase. The behaviour of more heliophyte shrub types supports the idea of an upward extension of the mixed woodland at this time, for at NG7 and NGHead, Corylus/Myrica and Calluna are at their lowest frequencies for the whole diagram. Since the frequencies for heather, for example, are still substantial it seems that the environmental effects of disturbance in creating areas of poorer soils where grass-heath or scrub vegetation persisted were not reversed. It seems more likely that the forest surrounding the stream head heather community had become more dense, reducing both the flowering and areal distribution of hazel, and even encroaching upon the more open areas. There seems to be little variation in this closed latest Flandrian II woodland along the North Gill transect, with only the Alnus curve showing any change. Alder in general declines in frequency in this phase, with the exception of the NG5 area, and this may be attributable to autogenic changes in soils and hydrology. An unusual feature of the Alnus curve, however, is a short-lived restoration of high alder percentages in the first one or two spectra of NG3 and NG6, prior to a general decline to lower levels. This could reflect very restricted regrowth of Alnus in this area after the disturbances of NG-D3, after which continued bog growth and acidification rendered alder regeneration at the site untenable. Alternatively the water-transport of Alnus pollen as described above may have continued until bog growth prevented such influx or the level of post disturbance flooding in this part of the North Gill stream fell and had the same effect of cutting this area off from any external alder pollen source. Interestingly, the S4 levels at NG9 and NG10 do not show very high initial alder percentages at this time, so that perhaps the brief alder maximum reflects a more local alder presence around NG3 and NG6. The growth in the bog which probably ended any local carr at North Gill is well illustrated by great increases in Sphagnum, Cyperaceae and Gramineae during this phase. At every profile Sphagnum values rise very sharply and are maintained at high frequencies, and the development of acid blanket peats from more soligenous basin deposits seems to have been completed by this stage across much of the site, with the exception of the sediments around NG7 where amorphous peats occur and NG9, where the peat growth was still at an early stage. The stream valley may be divided at this time into two main areas, the acid bog valley mire at NG6 and below, and the amorphous well humified peats of NG9 and above. Concentration values show this difference very clearly in relative peat growth rates. The lateral extent of the mire is less well known, but basal Flandrian II peats occur well to the west of the confines of the North Gill stream. A less local, and more extra-local and regional, pollen source area may have characterised the North Gill profiles by now, perhaps accounting for the less diverse pollen record, especially for taxa of more local type. Wetland herbs do still occur, however, and the occasional Pteridium peak or grassland herb grain suggests that areas of less wet, grassland flora still existed not too far away. Localised higher topography within the mire area or at its margins may be recorded here, but no conclusions may be drawn regarding their location as every profile is rather similar in this respect.

9.5.8 Phase NG-D4

The elm decline which characterises this phase (c. 4750BP)is clearly marked in the pollen profiles, with Ulmus falling from its maximum values in late S4 to a mean of 10% or less in each diagram. The decline is even more clear in the sites adjacent to the plateau edge, at NG7 and NGHead, where elm frequencies fall to almost zero before recovering to levels more akin to those at the lower profiles. This spatial difference in elm percentages will have been the product of a number of factors. It is quite probable that elm populations were present in the local woodland at North Gill, and extended to the plateau edge and even onto the plateau itself. Elm would be likely to be less common at higher altitudes, however, and so any displacement of elm trees at this time would remove a greater proportion of the local upland elm population and hence cause greater diminution of elm pollen percentages. Elm could have virtually disappeared from the pollen catchment at the head of the stream, while surviving individuals in the lower forest, around NG1A, could have maintained a contribution to the pollen assemblage from undisturbed areas such as the Northdale Beck valley, too steep to encourage clearance. The regional pollen rain evidently contained very little elm indeed, at least during the time of active clearance at the start of the phase, whereas at lower altitudes some viable elm populations remained.

The behaviour of other tree and shrub pollen curves does not show very great spatial diversity, and each seems to react in a broadly similar manner at all profiles. This may reflect the fact that the late Flandrian II expansion in area of the North Gill mire greatly reduced the potential for very local non-mire vegetation to dominate the pollen rain at individual profiles. With a very local pollen component no longer dominating the pollen rain, the extra-local component of the assemblage would be the major pollen source, producing pollen curves derived from the vegetation of a wider area and thus likely to be more homogeneous and less prone to local abundance.

The decline in Ulmus seems to have favoured most of the other tree and shrub taxa, for Quercus, Betula, Alnus and Corylus/Myrica all expanded to occupy some of the ground lost by elm. Oak, alder and hazel were the immediate beneficiaries and although elm does recover somewhat, the composition of the regenerated woodland had changed, with the other trees retaining their extended distribution. That elm had been cleared from the better soils is suggested by NG7, where Fraxinus at first also falls, but with regeneration recovers to become a most important forest tree. By contrast, at NG1A it is Betula which becomes abundant after the initial success of oak, alder and hazel. Consistent records for Fagus at NG1A and sporadic grains at NG5 and NG6 confirm that the clearance of elm modified the character of the upland woods. Tilia, which may have been expected to be adversely affected by clearance, remains virtually unchanged in most profiles, and was clearly well represented in the woodland around North Gill during D4. Considerable variation does occur in the behaviour of the Calluna curve. Although in every case Calluna values rise to some extent, at mid site profiles like NG5 the rise is rather muted while at NG4 and NG6 it is an important feature but of a similar order to the increases noted in other shrub taxa. At NG7, where an established heather population had been present for some time, values are restored to near maximum of 60% - 70%. At NG1A, however, Calluna values rise, first to over 50% from a very low base, then rise steeply to superabundance at 90%. The herbaceous indicators of clearance and agriculture at NG1A behave in a similar way, with an early

D4 phase of grassland type clearance with moderate values of Plantago lanceolata followed by a phase of major clearance, with Plantago lanceolata and Pteridium extremely increased and a wide range of ruderal and other types present. All the other profiles differ in that the indications of forest clearance are not so great as at NG1A, being restricted near the head of the site to merely a consistent but low presence of Plantago lanceolata. A further significant difference is that at profiles where peaks of P. lanceolata and associated weeds do occur, as between NG4 and NG6, the most intense phase of clearance was in the first few levels of D4, and little evidence occurs after that time.

The implications of this spatial and temporal contrast between NG1A and the rest of the site are that the elm decline clearance was not a single event, but included at least two and probably more, phases of clearance. The initial phase was located closer to the middle of the site, its relatively low intensity placing it at some distance from the sampled profiles, perhaps within the woodland beyond the edge of the North Gill mire, at around the altitude of NG5, receiving a muted clearance signal due to the distance decay effect on the clearance indicator pollen (Groenman-van Waateringe 1988). The NG7 and NGHead area was well to the north of the clearance, receiving a much fainter signal still, while NG1A was located toward the southern edge of the area where the pollen changes were recorded clearly. The second phase was placed much closer to the NG1A profile and it is very poorly recorded at all the profiles upstream of NG1A. It must have been very close to NG1A, however, for cereal pollen to be recorded (Vuorela 1970) and the ensuing classic 'landnam' succession of grassland and regeneration phases to be differentiated so clearly (Vuorela 1986). The great increase in peat growth rate at the Ulmus decline, a site-wide feature, helped in this respect. The consequences of this major clearance were felt much more acutely at NG1A than elsewhere, with the establishment of a grass-heath flora, with birch and bracken, and with local dominance of Calluna, presumably both on and off the mire surface. There seems to be little spatial differentiation in the mode of disturbance in this phase, for charcoal is poorly represented, even the microscopic size-class, while Melampyrum, the main indicator of the previous D phases, is virtually absent. There seems to be little evidence that fire played any part, either at its centre or at the fringes, in the deforestation of phase D4.

9.5.9 Conclusion

The initial conclusion to be drawn from the preceding comparison of the spatial vegetation history at North Gill is that the pollen data, both percentage and concentration, provide a good echo of the mosaic effects existing in the North Gill vegetation because of successive disturbances in late Flandrian II and at the Flandrian II-III transition. In addition, each profile records very local vegetational conditions, so that the spatial location of individual vegetation patches within the overall mosaic can be deduced with some accuracy from this suite of sites (Jacobson and Bradshaw 1981). They appear to be true at all life-form levels, with different herb, shrub or tree taxa showing aberrantly high values in a single spectrum at a single profile, indicating very local growth of undisturbed taxa. In some cases, however, unusually high frequencies extend across two or more profiles at the same level, possibly indicating more extensive colonisation of the site by particular plant types or else similar local patches. The behaviour of Rumex in late S2 at NG4 is a case in point, or that of Galium-type in late D2 at NG8.

The great diversity shown in plant communities between adjacent profiles is a theme which characterises the spatial mosaic at North Gill, in both post disturbance regeneration flora and in the restored stable vegetation after regeneration. Much of this variability is of very local origin and the vegetation mosaic evolving at North Gill was clearly quite complex. Even over a distance of only a few tens of metres, the vegetation patches created by the disturbance / regeneration / stability cycle were very different, and pollen analysis has been sensitive to such differences although unable to correlate them temporally. These data from North Gill substantiate the view of workers such as Bradshaw (1981b), Jacobson and Bradshaw (1981) and Edwards (1982), that in a well vegetated context such as woodland, the pollen rain will reflect mostly very local conditions and that extrapolation from single profile pollen data will provide an unreliable picture of conditions over a wider area. In particular, pollen data may not provide a reliable insight into the character or effects of small scale prehistoric forest disturbance unless the pollen profile is situated immediately adjacent to it. Even natural spatial differences in community structure may be sufficiently great at the local scale to prevent confident extrapolation from the site to the adjacent landscape. Thus if the analysis at North Gill had been confined to any one particular profile, a view of vegetational history at the site would have been gained which, at least in parts of the profile, was quite atypical. Despite the complexity of the vegetation mosaic at North Gill, however, the multi-profile approach has allowed sensible comparison of spatial variability to take place. Multi-profile FRPA should be capable of refining these comparisons of plant communities at North Gill, so that the study of the evolution of community structure as a response to disturbance and other environmental stimuli may be possible.

A number of environmental factors may be recognised from the one centimetre spatial analysis, however, which will have a bearing upon the interpretation of the FRPA data. The first confirms the necessity of doing an FRPA analysis at all, for the resolution of the pollen data at the centimetre level is in some respects too coarse to allow detailed ecological interpretation. Thus several curves are relatively smooth throughout a phase of disturbance when in theory perhaps they should not be. In many cases Melampyrum, for example, is present from the beginning to the end of a D phase (e.g. D2 at NG5) in almost constant frequencies, whereas regeneration of vegetation after an initial burn should cause Melampyrum frequencies to fall slowly during a D phase after an initial high peak. Similarly Quercus should in theory gradually recover in percentage towards the end of a D phase until 'normal' frequencies are restored. Again, in simple terms, percentages of heliophyte shrub pollen should show a frequency distribution with a peak in mid D phase, but lower values at the beginning and at the end. Thus in many cases, the successional pattern which one would expect to see in the post disturbance pollen flora does not occur, and instead either a relatively smooth, or a randomly erratic type of pollen curve is recorded. The implication is that the pollen assemblage in D phases at the centimetre level is often a composite feature, with perhaps several separate disturbance events in the near vicinity creating a patchwork distribution of several clearings all at different stages of regeneration. The combined pollen rain of all these successional communities would have the effect of homogenising the pollen record so that a 'mean' pollen assemblage of disturbance type would be preserved, but with each pollen taxon represented by a merged, average assemblage, often producing smoothed pollen curves. This is supported by the presence of two or more peaks of certain pollen types in places where increased sedimentation rate allows the temporal resolution to be improved, separating D phase curves into separate features. Phase D3 shows this better than D2, with a double *Melampyrum* peak at NG5 and NG1A, while the double ruderals peak in D4 at NG1A, and the suspicion of minor woodland perturbations in late S2 prior to the D2 clearance at NG4 are further examples. If the D phases at North Gill do represent aggregations of post disturbance assemblages, then spatial comparison of vegetation patterns at that level of resolution can only be superficial. The increase of temporal resolution by the use of FRPA is a necessity if single event post disturbance vegetation patterns are to be observable.

Other relevant information gained from the first stage spatial analysis refers to the site as a whole. It is quite clear that the D phase burns had a profound effect on the nature and distribution of the vegetation around the site. Other factors were also important however. One is that there is an underlying altitudinal trend in both the stable and the disturbance vegetation data. At almost every stage of the observed vegetational history the lower, middle and upper sections of the site react rather differently to disturbance. The borders of these three sectors seem to be around NG4 and NG6, with those two profiles being transitional areas, resembling either the middle or the extremities of the transect in different phases. There is a clear gradient in the degree of openness of the vegetation in both S and D phases, with NG1A showing less open conditions than NG5, which in turn was less open than NG7. This reflects the geographical position of North Gill, at the spring-head ecotone between the denser vegetation of the dales and lower plateau edge, and the lighter vegetation of the plateau and upper plateau edge. Although less than 400m in length, North Gill lies across this critical environmental boundary, which gives the site a natural degree of vegetation diversity upon which the deflected successions and regeneration flora created by disturbance superimposed further complexity. The pollen evidence suggests that NG1A throughout contained a pollen component from the denser forest below it, while NG7 received an element of its pollen rain from a light woodland - scrub - heath community of the upper plateau edge. North Gill seems to have supported a sequence of vegetation zones with the closed forest below NG1A grading into less dense woodland at NG1A, open woodland above it, then scrub woodland, then a zone of shrub communities, then scrub - heath around NG7, then heath - grassland above it. That the ecotone between forest and more open vegetation lay around the centre of North Gill may in itself have provided the reason for it being the location of disturbance, the woodland fringe being easier to clear, preferred plants like hazel and willow already being common there, and the spring and mixed vegetation together providing a productive location for hunting and foraging.

At North Gill, therefore, gross post disturbance vegetation changes were added to the diversity created by a natural environment gradient. Further complexity was created, however, by environmental factors which operated at the micro-scale. Among these would have been micro-topography, variations in which would have governed the date of peat formation, which has been shown to differ in various parts of the site, possibly by up to a millenium, if the basal deposits at NG1969 and NG9 are a true record of peat inception at those profiles. On an altitudinal transect like North Gill, local hydrology and soil variations would also have caused major variability in plant associations to occur over quite small distances. The substratum changes from sandstone to limestone in mid site can only have compounded the variability of soil types existing there. While the specialised hydrological conditions of the stream environs were responsible for much of the local diversity of the flora, as in the complex history of alder at the site, a strong measure of lateral variability in soils, moisture and micro-topography probably occurred in addition to the more predictable effects of the altitudinal gradient at North Gill. Maguire (1987) considered these factors in a study of local ecological variability at Broad Amicombe Hole on Dartmoor, concluding that degree of slope was fundamental to the other factors in determining the level of local spatial variability in vegetation patterns and other environmental phenomena. Edwards and Hirons (1982) also conclude that variation of slope and local topography may most often be the decisive factor regarding peat formation and mire development, often after human activity had provided the stimulus for local hydrological changes. The evidence from North Gill, a hillslope site with major variations in local topographical and other factors, strongly supports the findings of the above authors in that high levels of local spatial variability occurred in environmental phenomena, such as peat development and vegetation patterns, over small areas. The above discussion suggests that each of the North Gill phases of overall S or D character is a complex, composite feature, the synopsis of highly varied, local vegetation patches, the structure of which fluctuated through time. This degree of complexity is too great at the one centimetre level of temporal resolution to allow the observation of ecological processes as any other than a blurred environmental picture. However, the detailed data gained by FRPA on phase D2 at individual

North Gill profiles allow the vegetational changes in the structure of the post disturbance vegetational mosaic to be observed with much finer temporal precision. This has enabled the successions of local vegetation communities after disturbance to be better understood and has provided new insights into the nature of these disturbance events at North Gill. The fine temporal resolution data are considered in chapter ten.

CHAPTER TEN

FINE TEMPORAL POLLEN ANALYSIS AT NORTH GILL

10.1 Temporally Precise Pollen Analysis

The potentialities and limitations of the fine resolution pollen analysis technique, which were outlined in chapter one, have been tested at North Gill by the analysis of contiguous peat samples one millimetre thick from five separate profiles, leading to the preparation of six FRPA pollen diagrams. Virtually continuous, highly detailed vegetation records, with a very short time interval between spectra, have thus been obtained which contain data about processes in plant community ecology and population change. Complex fluctuations in pollen curves have been observed at the FRPA level which are consistent with the rapid successional vegetation changes which occur following woodland ecosystem disturbance, supporting the view (Green 1983, Moore 1980, 1989) that FRPA may be particularly suited to study of short-term, dynamic ecological changes. The time interval between spectra in the North Gill FRPA diagrams will vary (see below) but is likely to be of the order of 2 or 3 years at NG5B (Simmons _et_ _al_. in press), and so these data comprise vegetation histories which are temporally precise (Turner and Peglar 1988). Community processes which are of short duration, perhaps of only a few decades, have thus been observed by FRPA which would almost certainly have not been visible at the centimetre or wider sampling intervals employed by conventional pollen analysis. The well defined, local pollen source areas of the North Gill profiles, being within a forested area, have made each diagram a spatially precise record, so that the temporally precise pollen data may be interpreted in terms of individual plant successions and community structure within the local forest stand. It is this combination of spatially and temporally precise information at five neighbouring but separate pollen profiles which makes the North Gill fine resolution data set one of particularly high potential for elucidating the vegetation patterns developed as a response to repeated disturbance impacts within the Flandrian II forest, as well as the character of post-fire temperate forest successions in general.

The disturbance zones recognised in the FRPA diagrams are comparable in that they are broadly associated with the coarse level pollen phase D2, except for those of phase D3 at NG1A. As at the centimetre level of resolution, however, there can be no question of correlating these d zones between profiles as there is no means of dating them precisely. Direct dating by radiocarbon is not available and would be hardly practical on such small amounts of material. The standard deviation error limits of several decades which as yet are unavoidable with radiocarbon assay would in any case be too great to make dates a reliable chronological control at this temporal scale.

An alternative dating method is to assume a constant rate of sediment accumulation between levels which have been radiocarbon dated and thus to calculate the average numbers of years each centimetre of sediment represents. At North Gill this is only possible in the upper part of the NG5B profile, where four radiocarbon dates are available. It would result in rates of 20 years cm^{-1} between phase NG5B-3 and the start of NG5B-5, 23 years cm^{-1} for the duration of NG5B-5, and 25 years cm^{-1} between the end of NG5B-5 and the Elm Decline. With steady sedimentation rates, changes in total pollen concentration from level to level could be interpreted as changes in pollen influx rates to the surface of the mire, probably caused by vegetation structure change.

In practice, however, it is far from likely that the sediment accumulation rate will have remained constant in peat deposits, as hydrological conditions, peat forming material and humification rates may be very variable in peat mires. A more reasonable assumption is that pollen influx is constant, in which case the pollen concentration fluctuations are a function of changes in the rate of peat accumulation. This forms the basis of the method known as peat density dating (Middeldorp 1982, Van Geel and Middeldorp 1988) wherein concentration figures are used to gain an estimation of the rate of peat accumulation for individual pollen samples, and hence the length of time each sample represents. These authors, as have Rowell and Turner (1985), have shown that concentration changes do seem to be related closely to the rate of peat sedimentation per sample, and this method promises to make possible the calculation of chronological frameworks for fine resolution pollen spectra. The method has been proven, however, in large raised bogs which would have had a very large pollen source area from which constant pollen influx can reasonably be assumed. As Turner and Peglar (1988) have pointed out, however, a within-forest, small peat mire with a local pollen source area is rather less likely to have had constant pollen influx, for events such as disturbance of the local forest could have radically altered the productivity and dispersal of pollen around the site. Assumption of constant influx to the North Gill profiles would therefore be unwarranted, and the method has not been used in this research, although it remains of high potential for FRPA in general. Also, a greater number of radiocarbon dates would have been required at North Gill to act as chronological index points than have been available.

The fine resolution pollen diagrams from North Gill therefore cannot be assigned a precise internal time scale, nor can temporal correlations between profiles be attempted. Only in the upper part of NG5B FRPA can an average age per sample, ranging from 2 to 2.5 years, be calculated but level by level fluctuations in peat accumulation rate must make this only an approximation. It forms a good basis for the chronology of NG5B but, since sedimentary conditions at each profile were different, can not be applied to other diagrams, although it is likely to be of the right order.

As with the centimetre level samples, there are no grounds for chronological comparisons of FRPA disturbance zones between profiles, either individually or as a group within each larger D2 phase in each diagram. Each D2 centimetre phase is itself a prolonged period of time, probably a few centuries, throughout which the pollen rain was at least partly composed of post disturbance successional vegetation at all of the North Gill profiles. It is therefore ecologically, but not chronologically comparable, across North Gill. Because the FRPA spectra can represent the events of only a few years' duration, however, each FRPA zone can represent only a few decades and so in palaeoecological terms are very short-lived indeed, with zone boundaries which span only a few years. Even more so than at the centimetre level, there can be no prospect of chronological control between profiles. The FRPA zones represent a succession of spatially and temporally restricted disturbances local to each profile. It is intriguing that each D2 phase contains three FRPA d zones. This need be no more than coincidence, however, and more could be revealed by additional millimetre level counting. It is possible that some of the FRPA d zones actually do represent the effects of the same disturbance event reflected in more than one pollen diagram, if D2 is synchronous between any of the profiles. Since any such correlation can not be demonstrated, however, the d zones can only be compared in ecological terms, without chronological inferences.

The millimetre North Gill data probably represent the approximate sampling limits for pollen analysis in peat sediments, although the experiment with half millimetre samples at NG1A also gave reasonable results. Its temporal limits of 2 to 3 years per sample also approximate to the resolution limit postulated by Moore (1980) with regard to problems of redeposition or pollen mixing in sediments. As Moore (1980) and Aaby and Tauber (1974) have pointed out, however, the scale of temporal resolution achieved is dependent upon the accumulation rate of the sediment as well as upon the sample interval or thickness employed. Thus although the North Gill samples are very fine, the well humified nature of the peat means that the temporal resolution of 2 or 3 years per sample is not as great as that achieved by authors working on quickly growing peats. Thus Garbett (1981) using only 2mm thick samples in Sphagnum peat was able to achieve a temporal resolution of one year, similar to that of Sturludottir and Turner (1985) using 1 mm and 2 mm samples of upland blanket peat. In contrast the 2 mm sampling interval of Scaife (1988) yielded temporal resolution of only about a decade in well humified fen peats. The finest temporal resolution therefore lies beyond the scope of the North Gill peat sediments, for only where laminated sediments exist may a precise and consistent time-scale be achieved (Turner and Peglar 1988, Green and Dolman 1988). Annual or even seasonal laminations represent the ultimate in fine resolution temporal control, and many studies have now been completed which include such a temporally precise pollen or charcoal record. In this way Craig (1972) and Swain (1973) investigated the effects of fire upon North American forests, while Simola et al. (1981) and Peglar et al. (1984) were able to study annual and seasonal pollen fluctuations respectively.

Although the North Gill study has not matched these temporal resolution limits of the method, however, it has observed the criteria required for reliable interpretation of FRPA samples. Tolonen (1978), Green and Dolman (1988) and Green et al. (1988) have demonstrated the benefits of analysing contiguous samples at the FRPA scale, so that there are no time intervals between pollen spectra which represent gaps in the ecological record. The contiguous millimetre samples at North Gill therefore provide a continuous record of ecological change at a precise fine temporal scale.

Although the removal of any time interval by the taking of contiguous samples is fundamental to the aims of the temporally precise FRPA method, it renders the accuracy of the results vulnerable to any processes of post-depositional movement of pollen within the profile. This is clearly a particular hazard at the FRPA vertical scale, and may indeed define in practice the application limits of the method. Virtually all workers with the FRPA technique have stressed that the potential problem of pollen mixing is critical to its validity, and so the North Gill research provides a major field assessment of the significance of this factor in FRPA data. The experimental work of Clymo and Mackay (1987), in which pollen was added to peat columns under controlled conditions, suggests that up to a quarter of pollen moved vertically up to a distance of 3 cm through the less compact upper layers due to water flow. This degree of migration would render FRPA data almost meaningless. Field observations, however, seem to show that such vertical displacement of pollen does not occur, grains maintaining their stratigraphic position upon primary deposition. Rowley and Rowley (1956) found that pollen downwash was not significant except possibly in very fresh, surface Sphagnum. Turner and Peglar (1988) suggest that the form of the pollen curves themselves provides a clear indication of whether pollen mixing has taken place. They stress that FRPA diagrams which contain a combination of sharp and gradual changes should reflect an unmixed assemblage. Isolated very high or low values for individual taxa, or very sharp rises or falls in particular curves, should not occur in mixed assemblages due to the smoothing effect of pollen migration through the profile. Many FRPA profiles (Garbett 1981, Sturludottir and Turner 1985, Scaife 1988) do show very sharp curve changes against a background of more stable curves, however, including fluctuations which are ecologically sensible, and so these may be regarded as indicating that pollen mixing is not a serious problem. Van Geel and Middeldorp (1988) recorded sharp peaks in taxa like Pinus and Gramineae even within recently forming, unconsolidated peat, suggesting that downwash of pollen had not taken place. The results of Green et al. (1988) from recent peat sediments convinced them that significant vertical migration of pollen was not a problem, for good pollen stratification occurred in both near surface and deeper layers, and for grains of contrasting morphology. In addition, their pollen concentration data remained very variable between levels, showing no signs of the smoothing which would have accompanied assemblage mixing. The concensus of evidence therefore suggests that vertical pollen displacement may be largely discounted as a limiting factor in FRPA under field conditions.

The data from North Gill support this contention very strongly. Without exception the North Gill FRPA diagrams contain consistent curves which reflect stable vegetation, gradual changes which reflect slow vegetation change, and sharp frequency changes which record sudden vegetation changes. This combination shows that mixing has not been significant in any of the FRPA diagrams. This is confirmed by the pollen concentration evidence at each profile, which in many cases shows rapid fluctuations from level to level, and often differential fluctuation between taxa in single spectra. The testing of lateral pollen variability at the fine spatial scale at NG1A has also strongly supported both the horizontal integrity of the FRPA spectra, and the lack of pollen downwash across zone boundaries at that fine scale. The lack of hiatus in FRPA profiles can not so convincingly be demonstrated, but in most cases the combination of both sharp and gradual curve changes across zone boundaries suggests that hiatus is not a major problem at North Gill.

In the light of the above discussion, the character of the North Gill FRPA pollen curves themselves, and the ecologically intelligible interpretations they allow, suggest that even at this extreme level of resolution, they represent a sequential and therefore dependable record of vegetation change at the fine temporal scale. Allied to their fine spatial character, they provide a precise ecological record of vegetation successions following local fire disturbance of woodland.

10.2 Fine Temporal Ecological History at North Gill

10.2.1 Introduction

There are fifteen FRPA disturbance zones which lie within the longer phases of disturbance which have been summarised under the site category D2, three d zones being recognised at each profile. While their chronological relationships are not known, they may be compared as ecological events, each representing the history of a local patch of woodland vegetation before, during and after disturbance. Thus local differences in responses to disturbance may be compared, and the sensitivity of the FRPA technique to short time scale processes evaluated. The broad changes in vegetation have been described and discussed as indicators of disturbance or stability differences between zones within the wider s/d categorisation which have been revealed by FRPA.

Of most immediate significance, however, is that the D2 disturbance phase which appears as a single event in each of the 1 cm interval diagrams has been recognised as clearly composite in nature, comprising discrete sub-zones of disturbance activity, separated by periods during which some restoration of woodland took place. The degree to which woodland regeneration took place between disturbance zones varies significantly from site to site, according to the scale, character and location of the previous disturbance event. It is very likely that the North Gill FRPA data record the consequences of a cluster of disturbances within the very localised area of each individual sampling profile, occurring at intervals of a few decades. As with the longer D phases as a whole, the relationship of any one of these disturbances with other profiles can not be deduced, as their size remains unknown. They are best regarded as purely local phenomena. Some lie outside the boundaries of the D2 phase defined at the centimetre level and their recognition has depended upon the fine temporal pollen record. The degree to which the ecological sensitivity of the pollen data is refined at different scales of resolution is illustrated in figure 142, which compares the NG1A 1 mm record with that at the 1 cm and 5 mm scales. It is not known whether the short FRPA s periods of increased woodland cover in any North Gill profile represent the absence of disturbance from the whole site, or whether disturbance was occurring elsewhere at North Gill at this time but too far away to be recorded there.

These ecological data represent, if the NG5B time-scale is representative of the site as a whole, a period of about two centuries during which repeated small disturbances took place within small patches of woodland around the North Gill spring-head. Fifteen have been observed within the D2 phase at the five profiles, but additional profiles would be likely to reveal more, and it seems that the entire area of the North Gill spring-head and valley was involved in this cycle of fire disturbances. Such a disturbance pattern may be consistent with the activities of prehistoric man, presumably late Mesolithic given the age of D2 at NG5B, in the rotational burning of selected upland sites (Simmons and Innes 1981, 1985), although relating pollen evidence to human activity in wooded environments is very difficult (Edwards 1979, 1982). Whether the North Gill pattern of disturbance may represent Mesolithic manipulation of vegetation by the use of fire is considered further below, in the context of Mesolithic systems of land-use.

Whatever the origin of the cluster of disturbance events in D2 at North Gill, FRPA allows the definition of the character of individual disturbances, so that their impact upon the environment and consequences for ecosystem development may be clarified and compared.

While each FRPA diagram from the D2 phase at each profile contains three disturbance zones, there is little analogy between the triple sequence at each site. The first, second and third zones (termed zones B, D and F respectively at each profile) are not comparable between profiles in terms of their relative impact, for example. The earliest, zone B, at NG1A, NG4, NG5B and NG7 records quite a limited impact upon the pollen curves at these sites, whereas at NG6 the earliest d zone is the most significant of the three recorded there. In contrast, at NG7 the second zone (D) is the major disturbance impact, while zone D at NG5B and NG6 is of moderate strength, and at NG4 and NG1A is relatively low. Finally the third d zone (F) is the most severe of the sequence at NG1A, NG4 and NG5B, relatively large at NG6, but quite a small event at NG7. Whether these impacts on pollen curves in individual profiles reflect relative proximity or magnitude of disturbance (Oldfield 1970), and in fact are presumably a combination of these factors, it is clear that there are no trends in disturbance size common to all profiles. While repeated disturbance may have had a cumulative effect on the ecosystem, there is no common pattern in the order of disturbance size within the profiles. The character of each disturbance impact must be regarded as related to location and size, and not to relative chronology.

10.2.2 Fine Temporal Woodland Succession

As stated above, many authors regard rapid post-disturbance woodland succession as the key research area which may be best illuminated by FRPA (Green 1983, Green and Dolman 1988, Turner and Peglar 1988, Moore 1989), for the short time interval, continuous ecological record provided by FRPA should reflect sequential community changes within a small area of woodland. The work of Mitchell (1988) for example has shown that FRPA can record post-disturbance woodland successions quite sensitively.

Inspection of the North Gill FRPA disturbance zones shows that in a number of cases a clear succession is visible in the pollen record. Zone NG7-B is a good example, whereby oak falls sharply and fire promoted herbs Epilobium and Melampyrum occur. Alder and pine show peak values, but the latter is almost certainly due to improved pollen transport, while alder may have initially been favoured around the mire edges. Regeneration of the disturbed area itself proceeds through willow and birch, both curves rising through the zone, while the herb indicators of disturbance disappear or decline over the same period. As tree cover is restored, Polypodium increases but pine and alder fall. Finally oak values rise to a point where regeneration of woodland has been completed, but birch remains a major constituent.

Successional changes also occur in zone NG6-B, where a fall in oak occurs with peaks of Melampyrum, Pteridium and ruderal weeds in the first stages of succession, which then fall. Birch, pine and willow values are high following this initial stage, but then decline as oak and alder begin to increase. As this continues ash, lime and beech are prominent, until when oak values return almost to normal at the start of zone C, the curves of the successional types are reduced to pre disturbance levels.

Zone NG4-B also contains evidence of successional communities with Melampyrum, Pteridium and weeds present only at the start of the zone, when the fall in oak percentages is greatest, and pine, birch and willow also high then. A gradual recovery of oak values through the zone sees these disturbance indicators fall, although birch maintains its percentages in the latter phases of succession until oak recovery is complete when it is finally replaced. In each of these examples Corylus/Myrica does not seem to be involved as a successional taxon. In some cases its pollen curve matches that of oak, in others it is high then falls, as though increased flowering from disturbance edge individuals were the main hazel pollen source. Hazel seems to have occurred in a number of ecological situations in the forest, not primarily as a successional shrub. The shrub phase of succession seems to have been primarily through willow, birch and minor heliophytes, while the successional tree taxa mainly were birch and ash, although hazel was involved in some cases in each stage.

The classic successional sequence of taxa is not recorded at many of the North Gill FRPA zones, however, and this may be due to a range of complicating factors. A single impact disturbance may be expected to set in train the plant changes associated with the simple successional sequence, as in the above examples. In many North Gill zones, however, a less ordered sequence of pollen changes follow disturbance. In many cases Melampyrum pollen remains high throughout a zone or even rises towards the end. Open ground weeds are encountered sporadically through the zone, not only at the beginning as theoretically should occur. Regeneration tree and shrub taxa may often show consistently high values through a zone, not falling as oak pollen continues to rise as woodland canopies close again. In some cases, as in NG1A-D, the lowest oak and highest disturbance taxa values occur in the centre of a zone, not at the start. In the majority of cases at North Gill, in summary, the successional taxa pollen occurs in an homogeneous or disordered, and not in a sequential, way.

The most likely explanation for this is that many of the FRPA zones do not represent vegetation recovery after a single impact, but a period of time perhaps a few decades long in which disturbance was a small scale but continuous process. Alternatively a small number of discrete but small impacts within the local area could produce the same effect. Several of the d zones quite clearly do contain more thatn a single impact. NG4-F is a good example, where an initial fall of oak, alder and hazel occurs with a rise of birch and ash pollen but no response from disturbance herbs. This could represent an impact at the limit of NG4's pollen source area or a closer event in which a break was made in the forest canopy but no trees were actually killed, so that after birch and ash were stimulated to flower for several years (and pine pollen transport through the canopy was improved) oak, alder and hazel recovered to close the canopy and again suppress the understory types. Such a limited recovery in oak and alder pollen frequencies does occur in NG4-F. There then follows a major disturbance impact, probably very close to NG4, in which the full range of indicators occurs with oak and alder very low, and hazel, pine, willow and birch very high for the rest of the zone. Melampyrum shows a double peak in this zone, however, and remains high right to the end of the zone. Again, a repeated or continuous disturbance pressure may have occurred, which would also account for the homogeneous form of the tree types involved in regeneration until the end of the zone.

A complex situation also occurs in NG4-D, where the initial fall of oak has no response in other taxa except for possibly increases in ash and elm. The usual indications of disturbance, with Melampyrum, Pteridium, birch and hazel do not occur until mid zone. Zone NG7-D is similar in that ruderal herbs occur throughout, Melampyrum is consistently high and shows a double peak in percentages, while the successional trees and shrubs have little pattern to their curves. Zone NG5B-F is a particularly good example. The fall in oak frequencies occurs with rises in Melampyrum, hazel, birch and bracken. The steepest fall in oak occurs at the end of zone Fi, however, when Plantago lanceolata and other ruderals are recorded and hazel, pine and Melampyrum are high. A second, more severe impact seems to have followed the first disturbance in this zone. The events of the following zone Fii are more like those of forest regeneration, with gradual fall in pine and hazel, a gradual rise in oak, and the reduction to low values of Melampyrum.

The clearest example of a multi-impact zone of disturbance, however, is that of zone NG1A-H, where an initial Melampyrum peak is followed by a pause, followed by a protracted Melampyrum curve, followed sharply by a cultivation phase with cereals, Plantago lanceolata, ruderals and heather. Three, and perhaps more, impacts in NG1A-H led to homogeneous shrub and tree pollen curves of disturbance character but with little evidence of successional change.

Even where the evidence of renewed impacts within a d zone is not as clear as in the above examples, the pollen curves show a uniform intensity of disturbance effects which is maintained throughout the zone, rather than a series of successional stages. It is likely that such zones are not singular events, but represent a continued disturbance over a period of time, and are thus a composite signal of successional stages within the limited pollen source area of the profile.

Such a continued presence of disturbance is supported by the form of the Quercus and other curves in the stability zones which interleave the d zones. In many cases the oak curve, although significantly increased, does not regain fully pre disturbance levels. NG7-C, NG5B-E, NG6-C and NG6-E are such examples. Perhaps disturbance pressure came to an end very close to the profile itself, allowing local regeneration of oakwood, yet continued rather further away, but sufficiently within the profile's pollen source area to depress the representation of Quercus in the pollen rain. The Quercus curves in these zones do not have the shape of a rising curve truncated by further impact, but rather have achieved a plateau in frequency, implying that very local regeneration of oak was complete but disturbance nearby was continuing to depress oak frequencies.

It seems very likely that during the period of time which makes up the D2 phase at each profile, small disturbances of woodland were being created at different places across North Gill almost without pause, with areas in different stages of regeneration between local impacts. How each disturbance impact is manifest in the pollen record would depend upon its intensity and its proximity to individual pollen profiles. A disturbance which removed the tree canopy only would have effects less well defined than one which altered vegetation at ground level, or one which killed vegetation altogether and created open ground. Similarly a disturbance in situ at a pollen profile would have effects of a greater magnitude than one several metres or tens of metres away. A disturbance beyond the effective pollen source area of a profile would not be recorded at all. However many disturbances occurred at North Gill during this period, clearly each profile would record only that small number that occurred close by. Even at the spatial scale of individual pollen source areas, a few tens of metres, chronologically or spatially overlapping impacts would produce a confusion of disturbance signals in the pollen rain.

This would explain why the FRPA zones, whether of disturbance or stability type, vary so greatly in individual character. The fine temporal precision of these FRPA data is very high, certainly high enough to recognise a series of peaks in the pollen curves of taxa indicating the various stages of woodland succession which would take place after local woodland disturbance. That some North Gill zones do reflect this kind of seral community change very clearly is proof of the technique's temporal sensitivity at this site. That so many zones do not show this simple disturbance - succession - stability sequence, although the general ecological trend is usually clear, is good empirical evidence that a more spatially and temporally complex ecological situation has been observed at North Gill.

10.2.3 Comparison of FRPA Ecological History

The various disturbance impacts at each profile had different ecological consequences which, although their spatial and chronological relationships are uncertain, may be compared as fine temporal records of vegetation change.

The FRPA ecological changes are influenced by the kind of vegetation existing before the sequences of disturbance summarised as phase D2 began. Variations which already existed may be ascribed to local differences in geographical factors and the effects of previous disturbance. Thus, as already noted at the centimetre interval, woodland was lighter at NG7 than further down the site transect, with Corylus/Myrica more abundant and Quercus less dominant. Betula does not appear to be any better represented in this lighter woodland than in the denser forest of NG1A probably due to birch's inability to compete successfully with hazel under these upland conditions (Kullman 1979). Calluna values are markedly higher at NG7 at the upper end of the North Gill soil catena and their smoothness of curve at this level of resolution suggests the self-perpetuation of heather heath in this area. Other existing differences between profiles are in local hydrophilous taxa. Alnus and Salix contribute the majority of such variability and it confirms that recorded previously at the coarser scale of analysis. Willow shows a most interesting disjunct distribution, with peak values at NG1A and NG6.The poor transport capacity of willow pollen suggests local centres of population at these two points, with its virtual absence elsewhere. Alder representation is much more consistent, and all the profiles in the stream valley, NG1A to NG6, have high percentages of 70% suggesting carr growth at the stream side. Only at the highest site by the plateau edge, NG7, are alder values too low to represent local carr populations. Heather seems to play the local role at NG7. All other taxa prior to disturbance are broadly similar at each profile, and within the random level of natural fluctuations in pollen production which occur on an annual basis in plant populations. Some of the rarer pollen type indentifications made at the FRPA level allow further insights, however. Open water aquatic taxa, Potamogeton and Hydrocotyle point to bog pools around NG1A while these are not recorded elsewhere. More open grassland herb types such as Valeriana or Succisa occur at NG1A, with sporadic ruderals, than elsewhere. In particular Rumex is rather more important at NG1A and NG4 than in the upper part of the site. In general, however, the environment before disturbance is characterised at the five profiles by similarity rather than variation in pollen spectra.

The earlier FRPA d zones at each profile are marked by a significant and maintained fall in oak pollen frequencies, with a decline to 50% in all diagrams except NG7, where the figure of 30% reflects the already lighter woodland cover near the stream head. Important differences occur in the behaviour of Alnus, the other taxon reduced during disturbance. At NG5B, alder is sharply reduced through zone B, at NG6 it is reduced during the early part of zone B only, while at NG7 only a faint indication of any decline in Alnus frequencies exists. At the lower sites of NG1A and NG4, however, Alnus is unaffected, maintaining high values. Betula is the regeneration taxon most encouraged in this zone, and could be seen as replacing Quercus directly following destabilisation of oak woodland within which birch would have been a significant secondary tree. It seems to have outcompeted Corylus/Myrica during this disturbance, for hazel frequencies in general are not very much enhanced. Since hazel would tend to be favoured over birch in the upland of Flandrian II (Kullman 1979) in recolonising disturbed areas, it may be induced that this phase of disturbance may have been of a low intensity kind, which did not kill local birch trees and allowed their temporary dominance after breaking of the oak canopy. A reciprocal correlation between birch and oak, and between alder and hazel, seems probable. Other local patterning effects include the sustained peak of re-established Salix at NG1A and maintenance of willow carr at NG6. The very low frequencies of willow at NG5B are surprising, since the fall of alder may have created ideal conditions for its expansion. Since willow expands most effectively by vegetative means to colonise fresh ground, individuals of Salix need to have been present for efficient regeneration. The superabundance of Alnus pollen in centimetre interval phase S2 at NG5B could suggest that no local Salix population existed from which Salix expansion could take place. Corylus/Myrica and Calluna appear to have increased as a consequence in this central area. This is in contrast with their behaviour at NG7 where they even show a slight fall, probably due to their being more abundant already in that part of the site. The possibility of bog myrtle being involved in these stream edge successions must not be overlooked. The increase in Pinus which occurs to greater or lesser degree at all profiles after disturbance is probably best explained by increased pine pollen transport due to the opening of the extra-local oak woodland. Pinus is capable of exploiting a range of habitats, however, including damp soils of wetland edges and dry peats (Bennett 1984) as well as being able to survive burning and then efficiently exploit burned soils which offer good conditions for its germination and growth. It is possible that the removal of alder by burning provided short-lived but favourable conditions for colonisation by pine of areas across North Gill. Evidence that local fires occurred is provided by records of Melampyrum, but it is clear that the upper profiles from NG6 to NG7, experienced closer disturbances because Melampyrum frequencies are higher there. Some ruderals do occur at the other profiles but they are most abundant at NG6, with Plantago lanceolata, Pteridium and Chenopodiaceae important, while the fire-following Epilobium occurs at NG7. The massive increase in Rumex pollen which is a feature specific to NG4, although it is also important at NG1A and NG6, is coincident with these early disturbances, and so may be a further example of localised responses to the changed environmental conditions. The Rumex communities which were responsible were clearly growing virtually above the sampling point at NG4, such is the local abundance and were perhaps a specialised component of the wetland flora. The pollen evidence suggests that these earlier disturbances in the lower part of North Gill may have been of limited intensity or limited proximity to the profile, for fluctuations are not strong.The data, particularly for Alnus, Melampyrum and charcoal abundance, suggest that disturbances were located closer to NG6 than to any other profiles, although significant local effects were also present at NG5B and NG7.

After these first disturbances, the restoration of oakwoods around the profiles seems to have been very successful except at the higher parts of the site, where a more open woodland persisted. The composition of the forest at NG1A and NG4 seems to have returned to closed canopy, deciduous trees, and the negligible changes which occur in most forest taxa after these early disturbances at the lower end of North Gill suggest that it was a stable forest community. Differences between profiles were very local, with the high Salix representation persisting at NG1A and the unusually abundant Rumex community of NG4 maintained after disturbance ended. Since other herb pollen types are either very isolated or else probably wetland, a local mire origin for this Rumex seems almost certain. A source of contrast is the history of Alnus at NG5B after the first d zone there, for alder's recovery is only partial, and for a while alder did not recover at all from the destruction of the local alder carr community which dominated the NG5 area previously. Some re-establishment of alder nearby may be envisaged since its frequencies do recover somewhat, but the end of the abundant Alnus period due to the disturbance in zone B was evidently a lasting effect around NG5. Alder's failure to regenerate dense carr vegetation must be due to local environmental conditions, for there is no evidence for continued disturbance. At all profiles stability of vegetation was the norm, although local differences which were of long standing, such as Salix at NG6, Calluna and Corylus/Myrica at NG7 and Rumex at NG4, are maintained.

Further disturbances are clearly defined at all five profiles as local zones D, but there are marked local contrasts in the type and range of vegetation change recorded. The degree of Quercus decline is quite even except for NG7, where oak falls to 30% rather than to the average of around 50% elsewhere. At each profile except NG6 the effects of renewed disturbance exceed those of the earlier zones B. This is most clearly seen at NG7, where pollen fluctuations are most extreme, but NG5B was also greatly affected, while the tree pollen changes at NG1A, NG4 and NG6 are more muted. Thus Pinus is at over 30% at NG7 and NG5B, but less than 10% at the others. Once again some local relationship between pine and alder seems possible, for only at the two high pine profiles is alder greatly reduced. Sustained alder frequencies at NG1A and NG6 testify to the limited local impact of disturbance in those areas, and also probably some diversity in the source populations of alder at this time. This vegetation patch effect is also present in the record for the indicators of disturbance. Weed pollen types are important in these disturbances again suggesting that the impact was adjacent to the sampling points along the stream. Melampyrum is abundant at NG6 and NG7 at the head of the transect, but also significant at NG1A, less so at NG5B and almost absent at NG4. Proximity to the centre of disturbed areas could determine the extent of Melampyrum abundance, but degree of canopy opening would also be important. Disturbance saw the end of Rumex abundance at NG4, with its virtual demise, and the rise of Erica-type which, if Erica tetralix, could reflect locally very wet conditions which prevented the establishment of post-burn Melampyrum dominance. Damp grassland types were common in several disturbances at this time and of these Potentilla, also common at NG6, seems to have adopted the response role at NG4 usually filled by Melampyrum. Potentilla is an accepted indicator of post disturbance damp grassland and has figured in pre elm decline disturbance phases elsewhere on the North York Moors, for example at Glaisdale Moor (Simmons and Cundill 1974). It has been most abundantly present in such a disturbance context, however, in the Pennine upland (Turner and Hodgson 1983), and most significantly so at Soyland Moor (Williams 1985). At North Gill it has been commonly present, but not always as a clearly diagnostic indicator, but rather as a member of the wetland herb community. The paucity of Melampyrum at NG4, while important at NG1A and NG5, may be interpreted as reflecting locally differential response to disturbance among the more common weed types. The behaviour of *Pteridium* supports this view, as spore frequencies differ strongly from profile to profile, suggesting that expansion of the fire-tolerant bracken (Vogl 1964) into burned areas where it could achieve local dominance (Rymer 1976) was limited by variations in the severity of burning in different disturbances. Bracken abundance tends to mirror that of *Melampyrum*, being poor at NG4, higher at NG1A and NG5B and very important at NG6 and NG7. The more open vegetation at the higher site would in any case tend to encourage bracken representation, and the better drained soils of the plateau edge zone around NG7 would be more suitable for *Pteridium*, especially where it had to compete with *Calluna*. Below NG6, *Pteridium* would perhaps have expanded vigorously only where fire had removed the plant cover almost entirely, so that bracken could sprout quickly from surviving buried rhizomes (Ahlgren 1974). As shown by several ecological indicators, the lower parts of the stream valley experienced lighter or less close disturbances than the higher profiles. *Pteridium* spores in the lower profiles at this stage may reflect vigorous bracken growth along the fringes of surviving shrub woodland patches, stimulated by higher light levels after canopy opening, rather than dense bracken fern colonisation of open ground.

The severity of disturbance seems to have been appreciably greater at NG5B, where the reduced *Alnus* values point to a very local impact of disturbance, and a more complex regeneration flora. The woodland canopy may not have been seriously broken at NG1A and NG4, for heliophyte regeneration shrubs do not respond positively there, while at NG5B *Corylus*/*Myrica*, *Salix* and *Calluna* significantly rise, while other less abundant types are also present, especially *Prunus*. D zone pollen curves below NG5 are smooth, suggesting some degree of transport, but frequencies at NG5B are more erratic, indicating very local sources for the disturbance type pollen. Inspection of the curves for Corylus/Myrica, Salix and Calluna at NG5B, NG6 and NG7 are most instructive regarding the ability of FRPA to detect differences in post disturbance plant succession. It would appear that in the d zone around NG5B hazel, willow and heather all increased, while only hazel and willow expanded in similar circumstances at NG6 and at NG7 only hazel gained ground after disturbance, and then only marginally because of its already abundant local distribution.

Stable ecological conditions after each disturbance are characterised by the restoration of oak woodland, so that oak frequencies are once again high, although at NG5B regeneration of Quercus - Alnus communities was the least successful of all the profiles. This contrasts with NG7 in particular, where quite dense oak - alder - hazel woodland apparently enclosed the permanent Callunetum which occupied the spring-head area itself. The denseness of the forest at the upper edge of the site is shown by the fall to very low values of Pinus at NG6 and NG7, for the pine curve is probably a sensitive reflector of the relative ease of transport of airborne pollen and thus of the density and filtration capacity of the woodland canopy (Tauber 1977). Thus at the less severe disturbances at NG1A and NG4, pine pollen is uniformly low up to and including zone E for this reason. At NG5B, however, the regeneration of woodland which took place appears to have been only partial, for while Corylus/Myrica, Pinus and Calluna frequencies do fall appreciably, they remain at a substantially higher level than in previous stability conditions. In contrast to all other profiles Betula values are sustained at a high level in this 's' zone E at NG5B, and it seems that birch had joined oak in the stable, regenerated woodland. Alnus increases only slightly and clearly no longer formed local stands but is represented as a general local woodland component. This is in great contrast to NG1A and NG6 where smooth, abundant alder frequencies show the maintenance of prolific local Alnus growth.

Although the evidence for more wooded conditions at NG5B in zone E is unmistakable, that the vegetation remained very open is also shown by the continued presence of ruderal herb pollen. A reduced, but still continuous, Melampyrum curve and sporadic records of damp grassland weeds including Urtica, Potentilla and Plantago lanceolata show that areas of rough grassland persisted in this central part of the site, although direct disturbance pressure was not present, perhaps due to incomplete canopy closure. Failure to regenerate woody vegetation around NG5B, in the way apparently achieved after disturbance elsewhere at North Gill, could be due to a number of reasons, one being a possible acidification of soils and general ecosystem degeneration to the point where tree regeneration was no longer possible (Simmons and Innes 1985). The replacement of oak by birch in the local woodland has already been noted, and may be evidence of such a trend. Other acid tolerant types, like Calluna and Sphagnum, are not greatly favoured in this zone, however, and another cause of retarded tree regeneration may be more likely. Perhaps grazing and trampling activities of animals may have served to prevent tree growth and maintained grass areas in this part of the site. Buckland and Edwards (1984) have discussed how concentrated grazing pressure can prolong the existence of open ground, while Plantago lanceolata is stimulated to germinate by trampling (Sagar and Harper 1964) and can indicate rough pasture (Vuorela 1970). Peaks for

Potentilla, Ranunculus and Succisa, and for Gramineae itself, support this hypothesis as similar grazing phases have been reported by Williams (1985) from the central Pennines, although on a greater spatial and temporal scale than at North Gill. No such effect is seen at NG6, and any persistence of grassland must have been an effect very local to NG5. Other grassy glades may have existed in parts of the woodland away from the sampling profiles, however, and the proportion of the landscape which failed to maintain woodland can not be estimated from the present evidence.

The later zones of disturbance in the FRPA record have perhaps the clearest indications of major impact although there are distinct differences between profiles in the magnitude of its ecological effects. Only at NG7 is disturbance less intense than in the previous 'd' zone, with Alnus unaffected, Quercus reduced much less than in the earlier example, and Pinus and Betula only moderately increased. Corylus/Myrica gradually declines throughout zone F at NG7 as Quercus recovers from the initial impact of disturbance, and hazel was either not involved in regeneration or even lost ground during disturbance and subsequent restoration of Quercus cover. NG7 certainly experienced local disturbance however, as Melampyrum and Succisa values are almost as high as at any stage in the profile and other probable fire indicators like Epilobium occur.

The response to disturbance at NG6 is much more complex and produced vegetation patterns quite different to the situation at the head of the site. Although the fall in Quercus is less pronounced than in preceding 'd' zones, significant expansion of shrub communities occurred and these included a range of the less abundant heliophyte taxa. A more substantial removal of the oak canopy seems likely, for increased flowering of Corylus/Myrica and Salix and better pollen transport of Pinus took place, and perhaps a real expansion in ground cover of hazel and willow in the regeneration of the burned area. The peaks and variety of weeds in this zone point to a very substantial increase in the amount of grassland in this area, although the high levels of Alnus pollen at NG6 remain unaffected and so local carr populations persisted either around NG6 or within stream transport distance. The Potentilla, Rumex and other grassland weed values suggest that this disturbance may have added to the nucleus of grassland which had persisted throughout the previous 's' zone E at nearby NG5B. Incipient replacement of that small open area by heath or scrub vegetation may have prompted some renewed disturbance at NG5B.

Disturbance in zones F at NG1A and NG4 was much more damaging to the local woodland than hitherto for the lower parts of North Gill seem for the first time to have been subject to major impact. At NG4, for example, the third zone of disturbance includes Melampyrum and Pteridium curves of such magnitude that they must reflect local fire and recolonisation of open ground close to the sampling profile, a feature not previously recorded here. Similarly the oak fall is much greater than previously while removal of local Alnus, fluctuating erratically during its decline, occurred for the first time. The positive responses of Pinus, Betula, Salix and Corylus/Myrica all confirm that this event at NG4 records severe disturbance of the oak - alder woodland. Similar disturbances occurred at NG1A for the Quercus fall is very pronounced, but some doubt must remain as to whether some deforestation or merely canopy removal took place as far downstream as this. There is no expansion of Salix or Corylus/Myrica, for example, and these actually fall within this zone. Replacement of oak pollen is by Betula and Pinus mainly, with a little Ulmus and Tilia, which is due to the nature of the forest at this lower edge of the site. That birch expands where hazel does not reflects both the more primary, less scrubby character of this woodland around NG1A, not locally diversified by burning, and also that even this substantial fire event may have had only limited effects. Although consistently present Melampyrum is not abundant, while Pteridium is virtually absent. Clearly there were no large areas of open ground created here, providing the opportunity for seral successions to dominate the pollen flora. Perhaps the most interesting aspect of the pollen record at this profile is the sudden fall in Alnus from high to moderate values which occurs in mid zone, at the time when oak values begin to recover. Reduced charcoal values in this second part of zone F suggest that burning was reduced locally, and the fall of alder runs counter to the other pollen evidence of the beginnings of woodland recovery. The presence of silt inwash in the sediment suggests that destabilisation of stream side communities during this erosive period, perhaps coupled with changes in edaphic conditions and water regime, could have given rise to the removal of alder from part of its local habitat, and to which it was unable to return. The other FRPA data from NG1A suggest that the permanent decline of alder at this time is an indirect, post disturbance effect caused by changed environmental conditions, and it need not provide evidence that the edge of the burned area passed beyond the location of NG1A.

Once again, as in previous zones, severe fire disturbance seems to have affected the land around NG5B, for the fluctuations in disturbance type taxa are of greatest magnitude in this area. The widest range of ruderal and grassland herbs occurs here, particularly in the first part of zone F, and the consistently high curve for Plantago lanceolata and other disturbance indictor points to substantial areas of grassland around this site. The mosaic of seral regeneration communities was most complex at NG5B. All of the heliophyte shrubs which are major components of this mosaic are present in their highest frequencies of the diagram, although the Salix maximum does not approach the abundance recorded at NG6 after disturbance, where dense willow carr must have been established among aquatic environments. The Calluna curve at NG5B is comparable to that achieved by the long standing heather area at NG7, however, and pine, birch and hazel must have been present in large populations to produce pollen maxima of the type recorded. These taxa may have been involved in seral regeneration of a substantial area, for increased flowering by forest edge communities alone could not account for such an assemblage. The ability of FRPA to detect micro-scale ecological change may be seen in the first half of this zone, where initial colonisation of the burned area by Pteridium gives way to rough grassland with Plantago lanceolata. This itself is then replaced, for in the second half of the zone some restoration of oak and alder reduces the dominance of regeneration type flora, and taxa denoting open environments gradually cease to be recorded.

The differences in the intensity of disturbance between NG5B and NG6 are very great and reflect the major differences which existed in vegetation structure over quite short distances at North Gill as a consequence of individual disturbances. Each of the five profiles are distinctive in several ways which appear to be dependent upon the distance of each profile from the centre of its disturbance impact.

Final post disturbance pollen assemblages at all profiles are similar in recording the decline of regeneration pollen types as mixed oak woodland gradually became re-established around North Gill. Some differences occurred however, due both to natural diversity of forest type and, even more especially, to local successions resulting from repeated disturbance. Quercus is dominant at around 60%, a little more at NG1A and slightly less at NG7 reflecting the altitudinal gradient in forest density at the site. Closed oak woodland of a fairly homogeneous character and without significant breaks seems to have developed everywhere below NG7 and even at that profile there is little indication of persisting open areas. The Calluna maximum at NG7 is even more pronounced however, and heather heath across the mire area at the spring head, causing locally abundant pollen production, seems probable. Some expansion of heather onto the drier sandy soils away from NG7 itself may have occurred. The frequencies for Corylus/Myrica are similar in all profiles at this stage and the revertence of hazel to an understory role in the oakwood is possible, with the hazel thicket of previous disturbance zones diversified, except perhaps above NG7. Few herb indicators of open grassland persist, with Melampyrum only significant at NG1A. Local mire herbs do not show any real spatial patterning, and only the low Pteridium curves at NG1A and NG7 suggest that small areas of degenerating grassland still existed.

The main differences between profiles lie in the local distributions of Alnus and Salix, and associated indications of local mire conditions. NG6 evidently remained a local centre of swamp and carr communities and Salix, hardly represented elsewhere, continues to dominate the local stream side vegetation. Alnus also appears to have been locally abundant near NG6, for values rise to their highest of the diagram, a feature shared with NG7, and some expansion of alder at these higher locations seems likely. In contrast in the lower area of North Gill alder was unable to recover the ground lost, particularly after the third zone of disturbance at each profile. Alder carr did not become re-established between NG1A and NG5B and the still substantial alder values recorded there must represent alder populations within the general oak woodland. Some bog expansion and perhaps acidification may have contributed to this, as Sphagnum increases at these sites but is not important at the upper profiles.

10.2.4 Conclusion

The major conclusion to be drawn from the comparison of the fine temporal North Gill data is that, even at this very high level of resolution, there were very significant differences in floral development after disturbance between the five sampled profiles. FRPA has allowed them to be observed distinctly and interpreted in terms of ecological change. The more precise FRPA data enable pollen assemblages which are aggregate features at the centimetre level of analysis to be evaluated as successional events. The recognition that phase D2 is composed of many individual episodes of disturbance is critical to its understanding, for it means that contrasts in vegetation history need not be explained in terms of a unitary cause, but result from a succession of environmental impacts, perhaps of varying scale, located in different areas of North Gill. Each disturbance brought specific ecological changes to that part of North Gill where it was located. Thus similar but separate disturbances produced very different vegetation patches over distances of only a few tens of metres. For example in zones D at NG5B, NG6 and NG7, local vegetation was dominated by hazel, willow and heather respectively. This seems to represent real vegetation diversity due probably to different ecological responses to disturbance across the site. Many other similar examples of local differences in community development have been noted above, and this very sharp diversity in the patterning of vegetation is a feature which persists throughout the FRPA profiles, but which was not apparent in such ecological detail from the composite centimetre level assemblages. Each profile appears to have had its own local environmental factors which influenced the way in which the vegetation responded to disturbance stimuli. The background environmental gradient linked to altitude and natural forest density remained of influence throughout the successive disturbances. The disturbances of each 'd' zone were small enough to be centred upon a single or possibly two profiles, and the centre of disturbance was at different places in different zones. This may well explain the behaviour of the Alnus curve in phase D2, for in the centimetre diagrams the Alnus decline, if it occurs at all, varies between profiles. The FRPA evidence suggests that the spatial location of the small disturbance events will have determined the precise time of the removal of local Alnus growth in each profile.

Thus early FRPA disturbances appear to have had appreciable local effects only around the NG5 area, and Alnus falls irrevocably during disturbance zone B only at NG5B, although NG6 also shows a temporary fall and other disturbance evidence. The second disturbance at NG7 must have been located very close to that profile, perhaps mainly to the west of the stream as suggested by the stratigraphic charcoal evidence. The continued high Alnus at NG6 could partly reflect that profile's more easterly location and the presence of undisturbed Alnus carr along the easterly tributary stream which enters North Gill not far above NG6. The later disturbance events at NG1A and NG4 were the most effective there, and it was then that the permanent fall of Alnus pollen occurred at these profiles due to removal of local Alnus carr. Zone F was also the most intense period of disturbance at NG5B. Recurrent disturbances clearly caused major variability in landscape development at various spatial and temporal scales at North Gill. The consequences and origin of these disturbance impacts are discussed in the next chapter.

CHAPTER ELEVEN

DISCUSSION

11.1 Introduction

The fine spatially and fine temporally precise ecological data assessed in the preceding chapters have shown that the North Gill site supported a mosaic of environmental patches comprising mire, heath, grassland, regeneration communities and several types of woodland, and have allowed the development of these ecological features to be traced at several spatial and temporal scales. In this final chapter the consequences of disturbance for the late Flandrian II ecosystem will be discussed, and the role of man in this process will be considered.

11.2 Disturbance and Mire History

11.2.1 The North Gill mire

The highly precise nature of the fine resolution data make them ideally suited for the study of localised mire development (Van Geel and Middeldorp 1988) and how it was influenced by local environmental disturbance. Fine resolution concentration data in particular, being in most cases directly influenced by mire sedimentation rates, have proved most illuminating especially allied to lithological evidence. It has been shown (Moore 1985, 1988, Moore *et al*. 1986) that the impact of disturbance upon the mire flora can be very great due to hydrological changes after burning of the catchment vegetation, as well as to direct disturbance of the mire surface. Water which is no longer intercepted by the woodland ecosystem will drain into the mire, providing an excess which can lead to rapid growth of peat, change in peat type, inwash of extraneous material and changes in the mire flora. The severity of disturbance determines the degree of hydrological change (Moore *et al*. 1986) for while tree removal can cause soil erosion into the mire, opening of the canopy may lead only to input of extra water without destabilisation of catchment slopes.

Disturbance in the wet Atlantic climate regime of Flandrian II, with increasing rainfall at the end of that period (Lamb 1974), would have had major hydrological impacts in mire systems and the North Gill evidence illustrates that very strongly. Inwash stripes of mineral soil or charcoal are common. These occur even at the FRPA scale, for at NG1A three very thin stripes occur within the stratigraphy of phase D2, showing the multi-impact nature of that phase, with which the charcoal curves agree.

The concentration evidence is most instructive of the effects of increased input of water into the mire. In almost every case total pollen concentration is much higher during d zones or phases than in their s counterparts. Water levels certainly rose during disturbance, as many sites have shallow water gyttja deposited at these levels, but even in _turfa_ peats the concentrations rise. Opened canopies may have greatly increased flowering and pollen production which, allied to inwash of any pollen in humus deposits on the forest floor, would have increased pollen input and concentration in the short term. As regeneration followed and pollen productivity fell, the high water levels in the mire would accelerate bog growth, so that pollen concentration in the stable conditions after disturbance would be much reduced. These high d and low s concentration levels are a pattern often repeated in the North Gill profiles, and just as evident in the shorter time span of the FRPA zones. Zone G at NG4 is a good example of a major fall in concentration due to increased bog growth following disturbance, although the previous d zone NG4-F has higher concentration in the initial disturbance impact.

Zone G at NG4 is also a good example of the effects of disturbance on local mire flora, for while increased peat accumulation rates depress concentration values, Sphagnum is unique in showing greatly increased concentrations at this time. The increased sediment wetness clearly promoted local expansion of Sphagnum on the bog surface. At North Gill the effects of the post disturbance hydrology changes on the mire flora are often clearly seen in the pollen curves for taxa like Gramineae, Cyperaceae, Calluna, Sphagnum and wetland herbs of varying type. Their relationships do not always follow the same pattern, but differ according to local factors. For example in the NG7 FRPA diagram rises in Gramineae and Calluna, and a fall in Sphagnum, point to local drying of the mire, whereas in the NG5B FRPA diagram Gramineae and Sphagnum both rise as Calluna falls, indicating wetter conditions. Perhaps different grass communities, with Molinia or Phragmites, may be represented here. At NG6 Gramineae and Sphagnum act in a reciprocal way as monitors of bog wetness, and this is the most common relationship at North Gill, suggesting that Molinia may have been more usually present. That these mire taxa concentration values often rise or fall against the trend of the overall concentration values shows that they represent actual local plant abundance changes in the mire flora. Calluna in NG1A-7 and NG1A-5, Sphagnum in NG1A-6 and Gramineae in FRPA zone NG1A-G are good examples from the same profile. That such mire flora responses are as visible at the FRPA level as at the centimetre level shows them to be a direct response to the effects of disturbance on local hydrology, rather than induced by some autogenic succession or by a larger scale process like climate change.

The fine spatial data from North Gill show that the start of peat formation was also often a consequence of disturbance and time - transgressive across the site.

The mechanism involved in the processes of peat inception in the uplands of Britain has been considered by several authors (Moore 1975, Moore _et al_. 1984, Chambers 1981, 1984, Maguire 1983). Moore (1975) has discussed the origin of upland mire, concluding that the process of woodland disturbance is likely both to increase water input _via_ run-off and favour its retention within the ecosystem, thus changing the hydrological balance and promoting peat inception. His finding of evidence of clearance at the base of upland peat deposits had tended to support this view (Moore 1972, 1973, Merryfield and Moore 1974, Wiltshire and Moore 1983), and it is a feature recognised elsewhere in this context (Simmons and Cundill 1974, Atherden 1979, Bostock 1980). Most authors however, regard the interplay between a number of environmental factors as deciding whether peat inception takes place or not. Having recognised the influences of hydrology, climate and pedology, Edwards and Hirons (1982) conclude that variations of slope and local topography may most often be the decisive factor regarding peat formation, with inception taking place earliest in isolated centres, perhaps of very limited extent, where topographic conditions were particularly favourable, and often after human activity had provided a stimulus for local hydrological changes.

North Gill is typical of this sort of mire centre, which may be classified as upland 'basin' peat and categorised as having wood remains in the lower layers, overlain by well humified amorphous peats and then by fresher _Eriophorum_ - _Sphagnum_ 'blanket' peats. Topographic factors are most important at this type of site, peat forming characteristically in Flandrian II in water-retaining depressions, often within wet birch-alder woodland (Moore 1972). These basin mires are thus non-climatic in origin, and hence diachronous in date of inception. Their lower amorphous and wood peats may be referred to as soligenous or 'pedogenic' (Taylor and Smith 1972) to differentiate them from the overlying Eriophorum and Sphagnum blanket peats which are 'climatic'. Since topographic factors are so fundamental to basin mire formation, however, it may also prove useful to employ the classification system of Hulme (1980) which is based upon topographic considerations, and recognises 'confined', 'partly-confined and 'unconfined'.

In areas of basin peat, the location of earliest peat formation (primary basin peats) will have been decided by minor variations in pre-peat topography and the existence of microbasin features in the hillslope, and the importance of including a sub-peat topographic survey as part of the sampling strategy, as at North Gill, has been stressed by several authors (Hafsten and Solem 1976, Edwards and Hirons 1982). Tallis (1964a) did so and recorded considerable differences in dates of peat inception over short distances at Dean Head Hill in the southern Pennines, dependent upon variations in local topography, with the earliest peats confined to basin areas along the pre-peat stream courses. The same author (Tallis 1973, 1985) reported considerable peat-depth variation at Featherbed Moss, Derbyshire, and found that the two areas of deepest peat related directly to the sub-peat contours, having formed in depressions in the mineral surface at stream heads. Pre-peat topography, particularly angle of slope, was critical regarding date of peat formation and subsequent growth. Maguire (1983) reached a similar conclusion in a hillslope situation on Dartmoor, while Chambers (1983) has reported contrasting dates of peat initiation between nearby upland sites of differing topographical character. The value of surveying the pre-peat topography is clearly illustrated at North Gill, where a series of areas of negligible gradient have been recognised in the pre-peat stream valley. It is likely that these contain true microbasins of confined type which acted as early foci for peat growth during Flandrian II. The basal Polytrichum moss peat at North Gill may represent an early phase of deposition, and its discontinuous nature may well reflect the localised distribution of these pre-peat microbasins which are likely to have been only a few metres in extent. It seems likely that this primary moss peat may have followed an even earlier phase of burning at North Gill, given the fire-responsive character of Polytrichum commune (Ahlgren 1974) and that charcoal pieces appear in the mineral soils. It has been noted (Johnson and Dunham 1963) that Polytrichum moss is also favoured by running water, so that natural paludification within wet woodland may be involved here. A summary of the environmental history of North Gill is shown as figure 143.

The considerable but still variable extent and thickness of the lower charcoal unit shows that the effects of fire on the site was to increase greatly the area within the North Gill valley within which organic accumulation occurred, for the reasons outlined by Moore (1975, 1988). Although still a 'primary' basin deposit, this lowest charcoal-rich peat evidently spread to fill much of the stream valley basin, forming the basal biogenic stratum on points of slightly steeper gradient. By this stage of mire history almost all of the floor of the basin area, except for minor protruberances in its surface, plus the lowest slopes containing it, had been covered by peat.

Peat continued to spread during the next stage in mire history, which is represented by Unit NG-L5 and is correlated with the high alder phase at much of North Gill, a time of local environmental stability. Pollen concentration evidence shows that growth proceeded slowly, but peat cover seems to have expanded in area as well as increasing depth in the centre of the basin. In particular, peat seems to have spread laterally up the shallow slopes which formed the basin sides, as well as across any small mounds remaining in the basin floor. There is a case here for redefining the mire during this period as 'partly-confined' (Hulme 1980), beginning to spread beyond its original confines and depositing 'secondary' basin peat of the well humified amorphous variety of unit NG-L5. On the shallow slopes of the outer basin it seems probable that, although still paying regard to topography, peat formation may have become influenced less by factors of ground-water than by paludification after changes within the soil profile itself, and was therefore pedogenic (Taylor and Smith 1980) on these more water-shedding slopes. While periodic surface waterlogging might have occurred, studies on similar situations (Taylor and Smith 1972) suggest that soil processes independent of topography are more likely to be causative. It may be that external influences triggered such pedological changes. A process of acidification which began following the fire-removal of woodland and its replacement by open communities may have had paludification as its conclusion, so that pedogenic peat would spread outwards from the primary basins of the North Gill valley up the shallow slopes which enclosed them.

A feature of these secondary basin peats is the presence of macrofossil wood remains, mainly birch and alder. These occur mainly within the stream channel area in the central and lower parts of the site, but are locally abundant and occur throughout the amorphous peat, although the largest pieces are in the lower levels. These wood remains testify to the re-establishment of woodland within the upper slopes of the basin at the fringes, or perhaps even on, the expanding but thin amorphous pedogenic peats. Much of the wood in the stream channel peats is detrital, having been transported and introduced into the mire, and the densest wood remains occur in the basin area of lowest gradient. Some tree growth within the stream channel itself occurred, however, since tree stumps apparently rooted *in situ*, have been recorded. The pollen evidence presented strongly suggests the existence of damp carr - woodland, mainly alder but also with willow and birch, at least around the lower part of the site at this stage.

A second feature of these secondary basin peats is the presence in their upper layers of inwash horizons which extend almost the whole length of the site. Upper charcoal layers and a mineral band composed mainly of sand and silt but in places with a high clay fraction, are evidence of renewed fire disturbance of woodland followed by the instability and downwash of soil material. The detection of the limits of this charcoal horizon between twenty-five and forty metres to the west of the present stream (figure 6) probably shows the limit of spread of the amorphous peats of the subjacent unit, upon which it was deposited and retained. Even allowing for possible erosion of the thinner outskirts of the amorphous peats in the fire event, their rate of lateral spread was clearly slow, like their rate of vertical accumulation. The size of the mire was still very small. The inwash of allochthonous material and pollen changes in the mire flora even at FRPA level, however, do demonstrate that at this stage the site hydrology still could be heavily influenced by factors of topography, slope and changes in ground-water supply. The effects of disturbance in the mire catchment, and subsequent alterations in water-balances and sediment transport, could clearly still be expressed as profound changes in mire hydrology and deposition. Wherever these Flandrian II woodland disturbances exactly took place, they were near enough to cause a major input of exogenous material into the North Gill mire. The mineral horizons are the clearest evidence, but a great increase in water supply to the mire also took place during the post deforestation periods, giving a great impetus to peat growth. The peat deposited is much less humified than the previous amorphous peats, having accumulated much more rapidly. The general change in peat composition to a *turfa herbacea* with macrofossil remains of *Eriophorum* points to a basic change in mire character, although this change varied in timing across the site. The mire flora became more acidic, perhaps through the acceptance of water discharged from soils which may have had a strong tendency towards acidification, following repeated disturbance. Increases in *Sphagnum* spore frequencies, as noted above, at several profiles confirm a move towards an acid bog flora.

The rapid growth in the *Eriophorum* peats of late Flandrian II and early Flandrian III would have markedly increased the depth and extent of the peat cover around North Gill and it is possible that by this stage it may have filled the North Gill basin and spread on to the hillslope proper. The upper part of the *Eriophorum* peats and the overlying *Sphagnum* - *Eriophorum* peats represent a transition to true blanket peats which are both climatic (Taylor and Smith 1980) and unconfined (Hulme 1980).

11.2.2 Analogous sites

Upland peat sites with features analogous to these found at North Gill have been reported from elsewhere upon the North York Moors and also from other regions of Britain. Although perhaps a particularly good example, therefore, the North Gill site is in many ways typical of upland basin peat mires as a whole. In particular its geographical situation, centred upon a depression at the head of a stream channel just below water-shedding high altitude terrain, is one shared by many other examples. The correlation between spring-head and early peat formation seems a real one, and the erosive action of the stream itself may have created these micro-relief basins which later filled with organic deposits.

The presence of wood remains at the base of and within the peat is a feature of North Gill type upland basin sites, as classified by Moore (1972), as though peat inception took place within wet woodland. Many sites in the Pennines exemplify this situation, such as Hard Hill (Johnson and Dunham 1963), Leash Fen and Totley Moss (Hicks 1971), Fountains Earth and Hambleton Dike (Tinsley 1975), and a range of locations recorded by Tallis and Switsur (1983) in their detailed regional appraisal of the subject. Perhaps already under some degree of edaphic or hydrological stress, the demise of this woodland and subsequent paludification seems to have been accelerated in many cases by fire, perhaps human induced. In the North York Moors, as well as at North Gill itself, Collier Gill (Simmons 1969a), Loose Howe (Simmons and Cundill 1974) and May Moss (Atherden 1979) have charcoal present at the peat-mineral junction. Elsewhere, Coed Taf C in Wales (Chambers 1983), Over Wood Moss (Tallis and Switsur 1983) in the Pennines and Postbridge on Dartmoor (Simmons 1964) show a similar association. If charcoal records human activity then the differences in timing of peat inception in these many examples of wooded upland basins may reflect different local dates for woodland disturbance which acted as the trigger for environmental change. Differential dates on peat which seals Mesolithic flint sites in the south Pennines (Tallis 1964b) may indicate a human influence, combined with local topography, as a motive factor in the woodland to peat transition. Dates of peat inception do vary widely between sites, although all are much earlier than the surrounding blanket peat, but most are attributable to Flandrian II although some examples like Valley Bog (Johnson and Dunham 1963) and Quick Moss (Rowell and Turner 1985) are mid Flandrian I. In addition to wood remains in the basal levels, many of these and similar sites incorporate wood at intervals higher up the profile.

At North Gill, the presence of wood remains, including rooted stumps, in amorphous peat at levels many centimetres above the peat base shows that after an interval of time woodland was able to recolonise the basin peat area. The mechanism which removed woodland initially and induced paludification was evidently not irreversible. This would tend to support an external factor such as disturbance as decisive regarding tree growth around the site, so that when disturbance ceased in conspectus pollen phase NG-S2 regrowth of carr woodland was still possible, despite the continuing accumulation of peat. As microscopic charcoal particles have been recovered from this high alder phase at North Gill, although no large pieces, we seem to have evidence here of a kind resembling that reported from the western North York Moors at Bonfield Gill (Simmons and Innes 1981, 1988c), although the succession is not so recurrent at North Gill. Since Tallis and Switsur (1983) have reported tree stump horizons and charcoal layers well up from the base of basin peats at Tintwistle Knarr and Featherbed Moss in the southern Pennines, it may be that this kind of succession is not uncommon. Several of the above sites incorporate inwash horizons of silt, clay or charcoal within their basin peat deposits. Where pollen analysis has been undertaken through such layers, as at North Gill, they seem in most cases to be associated with disturbance of vegetation on areas around the site, leading to soil exposure, erosion and inwash into the mire system. The factors involved in this process over a range of soligenous mire types in the North York Moors have been discussed by Simmons et al. (1975). Mineral inwash layers similar to that from North Gill have been observed by Johnson and Dunham (1963) in the north Pennines at Knock Fell and by Tallis and McGuire (1972) in the south Pennines at Deep Clough. Charcoal layers are far more common, however, as research such as Tinsley (1975), Chambers (1978), Tallis and Switsur (1983), and regional studies such as Jacobi et al. (1976), Simmons and Innes (1987) and Innes and Simmons (1988) make clear. Although there may be a case (Boyd 1982) for the intrusive formation of charcoal in peat, it is more likely (Moore 1982) that charcoal layers at depth may be assumed to be in their correct stratigraphic position. Often an admixture of uncarbonised amorphous peat with the charcoal at North Gill supports this view. Fire seems to have been a major factor in upland Flandrian II ecosystems, for while at many sites abundant charcoal characterises phases of local woodland burning, in intervening periods a reduced charcoal presence still occurs, indicating continued extra-local disturbance (Jacobi et al. 1976, Simmons and Innes 1988c, Sturludottir and Turner 1985).

11.3 Disturbance and Woodland History

While the effects of disturbance on mire development at North Gill were considerable, they were indirect, whereas the effects of fire disturbance upon the local woodland ecosystem directly initiated major changes in woodland composition and structure of both short and long-term importance. The combination of centimetre and fine resolution millimetre scale pollen data allows an assessment of the impact of disturbance upon forest communities to be made at both of these temporal scales. As already noted (Bradshaw 1988, Green and Dolman 1988) fine resolution data are perhaps best suited to the study of vegetation processes and dynamics, and multi-impact fire disturbance as occurred in Flandrian II at North Gill have initiated ecological change, whether of classic succession (Clements 1916, Odum 1969) or a more complex patch mosaic form of community (Shafi and Yarranton 1973, White 1979, Mooney and Godron 1983).

At the short-term scale the disturbances in late Flandrian II and at the Elm Decline initiated a similar process with similar results; the diversification of stable forest communities by the deflection of natural tree successions which proceed very slowly in established forest stands, and the creation of seral plant communities dominated by shade intolerant herbs and shrubs as the vegetation is returned to an earlier, more rapidly changing level of succession. As has been considered in detail in chapters nine and ten, however, the seral communities which arose after individual disturbances in different parts of North Gill were often very dissimilar indeed, and although all exhibit the basic successional trend, this proceeded at contrasting speeds and through contrasting community stages, culminating in re-established woodland of contrasting composition. Indeed, in places succession proceeded so slowly as to be arrested for long periods in sub-climax vegetation, particularly around NG7 where heather and hazel communities had great inertia once established.

The contrasts in post disturbance community composition spring from several environmental factors such as soil, moisture, gradient and the existing vegetation prior to disturbance. Critical, however, were the frequency and character of the disturbance itself. The FRPA evidence at North Gill, in particular, shows that the effects of disturbance were linked very closely to its type. In places disturbance was sufficiently intense to achieve a degree of major devegetation, creating a localised area of bare ground suitable for colonisation by pioneer weeds of ruderal type. Although the ecological affinities of many herbs prior to agricultural land-use remain to be fully established (Behre 1981), Artemisia, Rumex, Cruciferae, Chenopodiaceae, Compositae and Plantago lanceolata probably were the most common of these, although most weed groups include wetland species within them, like Rumex. Several other less common types occurred which were probably of ruderal type. Although probably small in area, such unstable bare ground habitats would have been most important in the ecology of these herbs, for natural areas of this type would have been quite rare in the dense pre Elm Decline deciduous forest. Rich herb associations such as those recorded in most North Gill profiles would have been very rare but for the openings in the forest created by disturbance.

Some disturbance impacts at North Gill had lesser effects, however, with few open ground ruderals present, so that a less severe level of disturbance, which did not involve devegetation of the soil, also occurred. This could have involved removal of undergrowth only, or was even restricted to removal of the tree canopy so that more light reached understory taxa, without killing individual trees or shrubs. In cases such as this tree successions do not occur, merely increased pollen production among non-canopy trees and shrubs until the canopy foliage closes over again. These contrasting levels of disturbance impact should have different pollen signals, and it is one of the achievements of the FRPA technique that these different levels of impact can be distinguished in the pollen record at North Gill, as discussed in the preceding chapters.

A further source of post disturbance vegetation diversity is that fire seems to have been the means of disturbance in most, but not all, cases. Thus post fire colonisers like Melampyrum and Pteridium, and less common ones like Epilobium, figure largely in the North Gill diagrams, except where the charcoal curves show fire not to have been a factor, as at the end of NG1A-5 or at the Elm Decline at most sites. Fire is an efficient releaser of biomass and nutrients held static within the stable, late successional tree cover (Ahlgren and Ahlgren 1960, Rowe and Scotter 1973, Ahlgren 1974, Moore 1982, Patterson and Backman 1988), thus rejuvenating the vegetation community. This seral community is well represented in the d phases and zones at North Gill, in which much of the pollen of shrubs and tall herbs would have come from the successional growth at the edges of and within disturbed areas, with the range of heliophyte shrubs recorded demonstrating the added diversity induced by disturbance (Pickett and White 1985).

The contrasting post-disturbance vegetation units which have been recorded by high precision pollen analysis at North Gill illustrate the point that the major effect of disturbance upon woodland has been to increase its level of diversity at both the spatial and temporal scales (Connell and Slatyer 1977, Mooney and Godron 1983). It is suggested (Grubb 1977) that post-disturbance regeneration habitats are of prime importance in the maintenance of species richness in plant communities, as these represent rapidly changing environments within which all stages in the reproduction and growth of member taxa are represented. In its simplest form, the much greater number of taxa identifications in d phases and zones in the North Gill diagrams, compared to s conditions, acts as an index of this increased diversity (Shafi and Yarranton 1973). Maximum diversity at each site is achieved in the early and middle stages of regeneration after disturbance, followed by a gradual decline as evenness and equilibrium of vegetation was restored. Thus disturbance maintains diversity and a high number of member species, whereas stability represents a low constant number of persistent species (Kimmerer 1984).

Of particular relevance to the North Gill data, however, is that the frequency of disturbance is a critical factor in determining woodland structure and subsequent development. Loucks (1970) has noted that, since only a small proportion of the woodland plant community is adapted to the stable environments of late succession, when trees dominate, recurrent disturbance is required to maintain species diversity at a high level. Rowe (1983) also records that frequent fires are required to favour the maintenance of pioneer invaders and sprouting shade intolerant species within the forest ecosystem. If a high level of diversity is to be maintained within a woodland area, therefore, its structure must be controlled by the sequential disturbance of neighbouring stable forest stands. Such recurrent disturbance causes the creation and maintenance of a complex mosaic of different successional stages (Whittaker and Levin 1977). As noted by Heinselman and Wright (1973) and Cwynar (1978), shifting the location of fire disturbance in this way means that while each individual patch of regeneration vegetation is continually evolving, the ground area covered by patches at a particular regeneration stage remains steady as a proportion of the overall patch mosaic. Thus recurrent disturbance maintains the woodland ecosystem at a high level of community diversity. Such a model fits very well with the North Gill pollen data, for recurrent disturbance occurs in every profile at both the centimetre and millimetre level. It is the realisation that recurrent disturbance took place at the FRPA temporal scale, as almost a continuous process, which demonstrates the value of high resolution pollen data for the precise study of the history of woodland ecosystems. The North Gill pollen data shows that the late Flandrian II woodland there had a highly developed and diverse mosaic structure during times of disturbance which was of extreme local complexity.

It remains to consider the longer term effects of recurrent disturbance upon the North Gill woodland ecosystem. Most disturbance events at North Gill culminated in the restoration of woodland, although it was often of a changed character from the pre-disturbance community, generally being more open with increased lime and ash. Rarer types like beech and holly also became more common. The probable role of disturbance in the creation and spread of mire communities has already been discussed, but it appears (Siren 1955) that repeated fire disturbances may also have led to the degeneration of the woodland ecosystem. While the short term effects of disturbance were the rejuvenation of vegetation communities, in some cases the ecological consequences were severe enough to initiate degeneration of soils so that restoration of tree cover was no longer possible, particularly late in Flandrian II after recurrent burning (Simmons and Innes 1985). Sustained disturbance pressure, with perhaps a short interval between burns and exacerbated by the trampling and browsing effects of game or livestock (Buckland and Edwards 1984), burning of humus reserves and leaching after exposure, could well have encouraged soil acidification and erosion. During and after many of the FRPA d zones at North Gill heather, birch and bracken become very important, followed by major heather expansion. A long term effect of disturbance may have been the local replacement of woodland by heathland on a long term basis (Moore 1988). Sturludottir and Turner (1985) have implicated repeated Flandrian II disturbances in soil degeneration leading to the Elm Decline itself.

Thus while repeated fire disturbance was able to maintain late Flandrian II woodland at North Gill in a high diversity and productivity state, this process led to long-term changes in forest structure and composition and may have led to the degeneration of the forest ecosystem into an acidic heathland sub-climax in places (Dimbleby 1962).

11.4 Disturbance and Mesolithic Ecology

The ecological effects of successive disturbance impacts at North Gill in Flandrian II were considerable, both in wetland and dryland contexts, but while the consequences for the vegetation of the application of fire to the local woodlands is clear from the fine resolution pollen data, any direct link between disturbance and human activity cannot be demonstrated. Natural ignition sources do occur, such as lightning strike, although the wet, humid deciduous woodland of Flandrian II, with the Atlantic climate regime (Lamb 1974) would probably not be prone to natural forest fire, nor would it carry fire well. That the incidence of recorded fire disturbance actually seems to increase in late Flandrian II (Simmons and Innes 1985) suggests that a human origin for these fire events may be more likely. Circumstantial evidence lies in the convergent distribution of flint sites and disturbance sites in the uplands of northern England (Jacobi et al. 1976), and in some cases flints occur in direct association with charcoal and pollen evidence of disturbance (Radley et al. 1974). Thus although a causal link between human activity and disturbance cannot be proven, many authors suggest that the distribution and character of the evidence may most logically be explained as the product of cultural activity, rather than by natural events (Jacobi _et_ _al_. 1976, Edwards 1986, Edwards and Ralston 1984, Simmons 1979, Simmons and Innes 1985).

If the Flandrian II disturbances at North Gill do represent human activity, the radiocarbon dates from the site would suggest that the earliest dated phase, 6300BP at North Gill b, is Mesolithic in age, the 5450 - 4990BP phase D3 at NG5B is Neolithic in age, while the phase D2 date of 5750BP at NG5B may be earliest Neolithic by analogy with Williams' (1985) date from Soyland Moor, or else late Mesolithic. The latter may be more likely since, although negative evidence is never conclusive, the failure of highly detailed FRPA investigation to reveal any cereal type pollen would suggest cultivation was not present in this phase. The possibility of Neolithic activity is discussed below.

Most consideration of fire disturbance in Flandrian II has centred upon the Mesolithic, however, partly because deliberate fire - regeneration of woodland vegetation has formed an integral part of the way of life of many near recent hunter - gatherer societies (Mellars 1975, 1976b), to the extent that fire was 'employed to control the distribution, diversity and relative abundance of plant and animal resources' (Lewis 1982). Such control of food resources is the main reason why Mesolithic activity is likely to have been responsible for the localised fire disturbances at North Gill, for the effect of applying fire to closed deciduous forest would have been to increase greatly the local abundance of food resources for foraging communities during the early and middle stages of post - fire regeneration. The productivity of successional vegetation is much greater than that of undiversified forest, so that fire disturbed areas make attractive feeding grounds for wildlife. Not only is the diversity of both flora and fauna increased, but deer (Leopold 1950, Dills 1970, Vogl and Beck 1970) and other game animals are attracted by the rapid growth of grasses and browse plants (Bendell 1974, Evans 1975, Mellars 1975). Deer populations become concentrated in areas where such favourable vegetation is available, and so become much easier to hunt efficiently, thus increasing resource yield.

As well as increasing quantity and quality of large game animals in post fire areas, the diversity of game resources also rises. Small mammals and game birds are attracted to the improved feeding grounds (Ahlgren 1974), while fur bearing animals would also have been a valuable resource, such as bear and beaver, although the role of the latter in streamside woodland disturbance should not be overlooked (Coles and Orme 1983). The vegetable foods (Clarke 1976) which increase in abundance in these post disturbance areas include crops of berries, fruits and nuts which would have greatly benefited human populations. Hazelnuts would have been particularly valuable in this respect, and were capable of long term storage. The great increase in food resource potential caused by woodland burning makes a human origin for many Mesolithic age forest disturbances highly probable. This aspect of Mesolithic ecology has been discussed in detail by Innes (1981).

When considered in relation to the many cases of Late Mesolithic age forest disturbance from the North York Moors (Simmons and Innes 1982, 1985, 1987, Innes and Simmons 1988), which are discussed above, North Gill seems to be a relatively typical example of a high altitude spring-head site showing evidence of multi - disturbance in Flandrian II, resembling others like Collier Gill (Simmons 1969a) and Bonfield Gill Head (Simmons and Innes 1981, 1988c). That so many such sites exist in this and other regions of Britain, allied to the ecological consequences of such disturbances, has prompted authors to suggest that they may represent the use of fire by Late Mesolithic hunters in the deliberate management of woodland ecosystems to maximise resource potential as part of a conscious economic strategy (Simmons 1975a, 1975b, 1979, Jacobi et al. 1976, Welinder 1983a).

Such a strategy would have been required in the late Mesolithic because the stable deciduous woodland of Flandrian II, although potentially a productive ecosystem, would in practice have been impoverished in food resources. Much of the biomass of the ecosystem was bound up in forest stands of high environmental inertia and homogeneity. Edible vegetation was scarce for much of the sunlight was intercepted by the tree canopy, leaving little to penetrate and provide energy for growth of food plants. For that reason game animals were dispersed through the forest, few in number and hard to capture. Increasing Mesolithic population levels (Newell 1973, Cohen 1976) combined with the loss of lowland territory due to the culmination of postglacial sea-level rise in Flandrian II (Tooley 1978) would have enforced a more efficient yield from the Mesolithic economic resource base. Concentration upon the uplands, particularly in ecotone areas where forest was easier to manipulate such as the tree line or spring-heads, may have been one of the responses adopted by Late Mesolithic societies. Coles' (1976) 'steady state forager in ecological balance with the primary forest' concept of Mesolithic life may have had to change by Late Mesolithic times to a more manipulative and systematic land-use strategy in which fire was used to maximise and concentrate food resources. Jacobi et al. (1976) and Simmons (1975b, 1979, 1983) envisage fire - diversified upland ranges in which favourable locations were managed to yield a staple range of resources which could be cropped in a controlled way as part of a specialised economic strategy. The repetitive burning which took place at several upland sites, either as a succession of distinct events as at North Gill or Bonfield Gill Head (Innes 1981) or as longer periods of disturbance pressure (Simmons et al. 1983, Williams 1985), may represent the long-term management of selected areas of forest to maintain high levels of resource productivity in the landscape.

Whether the Late Mesolithic impact upon the environment by fire disturbance of woodland was similar to the above model, or was perhaps less systematic in its application, the fine resolution pollen data from North Gill allows a more detailed consideration of the role of disturbance at this time to be made. Phase D1 at North Gill, although the dates of most individual disturbances remain unknown, is almost certain to be fully Mesolithic in age, phase D3 is much closer to the Elm Decline, and Neolithic in at least one profile, while phase D2 at NG5B at least falls within the period of overlap between Mesolithic and Neolithic type economies, although there is no evidence for cultivation.

The D1 and D2 phases in each profile show post disturbance regeneration communities, with high hazel in particular, and charcoal remains which would support the model that the attraction of wild game was the object of woodland disturbance. That peat inception follows such disturbance suggests that the attraction and concentration of herbivores in small post fire areas may have brought about soil compaction by trampling which, allied to water surpluses, may have aided the peat inception process, as herbivore activity may suppress tree regeneration and prolong open conditions (Buckland and Edwards 1984). The germination of seeds of Plantago lanceolata may be stimulated by trampling (Sagar and Harper 1964, Harper et al. 1965) and its presence in these disturbances may indicate local concentration of animals, although frequencies are not high enough to suggest domesticates. The high _Plantago lanceolata_ values of late phase D3 and the Elm Decline are more likely to indicate the pasturing of domesticated animals, whereas the low _Plantago lanceolata_ and high _Melampyrum_ type disturbance may represent wild game.

Most instructive, however, is that the D2 disturbance phases are composed of the effects of several, and perhaps many more, small disturbances of limited temporal and spatial extent. Each of these FRPA d zones lasts a few decades (the whole of D2 lasting perhaps a few centuries) during which fire was continually present, and between the d zones the continued charcoal presence and incomplete recovery of oak pollen curves suggest that fire disturbance continued elsewhere at the site. There was no single major burn which produced a very large clearing which then passed through stages of seral regeneration as a unit until forest regeneration was completed. Deer will not readily occupy too large an area of open ground within forest, for such a large clearing does not provide them with the security of nearby cover which they require. Mellars (1976b) suggests that a clearing of diameter rather less than 400 m may be optimal to attract deer.

The FRPA data, however, suggest that rather than the creation of a clearing or clearings of such a size, during the D2 phase at each North Gill profile a cluster of many small clearings were made by local, controlled fires which made the site as a whole a very complex mosaic of regeneration plant communities at different seral stages. A very high degree of plant diversity would therefore have been maintained throughout the extended phase of activity at the site, which is most likely to be of Mesolithic origin, with an almost continuous gradation between contrasting small patches of successional vegetation. This agrees very well with the pollen evidence of many d zones, which is not strictly successional, but an aggregate of various local vegetation patches at different seral stages, producing more smoothed pollen curves without sharp successional peaks. Maximum vegetation diversity would be achieved in this way, with an ideal combination of grazing, browse and cover (for hunter as well as quarry). Many small burns signify an almost continuous manipulation of the selected site which may be regarded as a form of local management which maintained food productivity throughout that extended period of occupation. With a single large burn, the cleared area would pass through the successional stages as a unit, with a uniform steady decline in productivity as woodland restoration and canopy closure approached. Continuous diversification of the woodland by the regular burning of adjacent small areas, so that maximum control over the vegetation mosaic is maintained, is fully consonant with the high degree of skill in ecosystem management shown by many near recent hunter-gatherer groups (Mellars 1976b, Lewis 1982) and is what one mught expect from the advanced foragers of the Late Mesolithic. The high temporal and spatial precision of FRPA has allowed this Mesolithic fine-tuning of local vegetation patterns and resource distribution to be observed, and revealed the complexity of man - land relationships in that period. Other apparently unitary disturbance phases of Mesolithic age may well prove to be similarly composite under FRPA examination. If so, then the role of disturbance in Mesolithic ecology at the site scale must be interpreted more as process than event.

11.5 Pre Ulmus Decline Cereal Pollen

One of the most significant results of the highly detailed ecological data yielded by FRPA at North Gill has been the recognition of grass grains of cereal type in pre elm decline horizons. These imply early agricultural activity, involving either the adoption of novel food resources by advanced foraging cultures of Mesolithic tradition or a pioneer phase of Neolithic settlement and cultivation (Dennell 1983, Simmons and Innes 1987). Several Flandrian II pollen profiles now exist from the British Isles, and some from North-West Europe, from which cereal-type pollen has been recorded as a result of modern detailed palynological methods such as increased pollen counts and closer sampling intervals. Since cereal pollen production is very low and pollen transport very poor, the increased numbers of pollen sites from small basins or mire edges designed to study very local vegetation history has greatly increased the prospects of finding pre elm decline cereal records (Edwards _et_ _al_. 1986, Groenman-van Waateringe 1988).

Grass grains of the correct size and morphology (Andersen 1979, Dickson 1988) of both _Triticum_ and _Hordeum_ type occur from sites in Belgium (Heim 1979, Beyens 1984), Sweden (Nilsson 1961, Goransson 1986) and Denmark (Stockmarr 1966) and these sites are discussed by Kalstrup (1988) with respect to her recovery of cereal-type pollen from the pre elm decline levels at Trundholm in Denmark. Such records are consistent with the evidence for major Flandrian II deforestation at sites in other areas of Western Europe collated by Roux and Leroi-Gourhan (1964). Of the Irish examples, perhaps the best evidence is that presented by Lynch (1981) from Cashelkeelty in Kerry, where _Triticum_ type grains occurred in the context of a major 'landnam' type forest clearance episode at 5845±100BP, followed by a second phase with both _Triticum_ and _Hordeum_ at around 5350BP. Hirons and Edwards (1986) also report twin phases of cereal cultivation with associated signs of deforestation at _c_. 5740BP and _c_. 5450BP from Weir's Lough, Tyrone, both well prior to the _Ulmus_ decline. Other examples estimated to be of around 5800BP age are Newferry, Antrim (Smith and Collins 1971) and Ballynagilly, Tyrone (Pilcher and Smith 1979). A cereal type grain was reported from pre elm decline levels at Carrowmore in Sligo (Goransson 1984) and at Dolan in Connemara (Teunissen and Teunissen-van Oorschot 1980), while recent work in two profiles near to Dolan by O'Connell (1987) has also yielded Flandrian II cereal pollen. In this case one Triticum-type example was dated to about 5830BP, and is comparable with the evidence from other sites. Other morphologically acceptable grains, one of Triticum type, were recorded from much earlier levels, however, casting doubt upon the reality of the records as evidence of human agricultural activity. Dates of c. 6900BP and c. 7500BP would appear unacceptable for early agriculture in the British Isles, and throw doubt upon the more acceptable late Flandrian II examples. The presence of large but uncultivated grass grains from natural grassland taxa seems a likely explanation, particularly in coastal areas where taxa like Glyceria, Agropyron or Elymus may be contained within the Hordeum type group. Some of the early cereal profiles are from such coastal areas, such as Trundholm in Denmark and Dolan in Connemara. Contamination can also never be excluded entirely as an explanation, although the presence of cereals within unmixed, 'landnam' type spectra would be unlikely in that case.

The validity of cereal type pollen as a true indicator of agriculture cannot be taken for granted therefore, and this must be borne in mind in consideration of the several examples which exist in Britain, and with which the North Gill evidence may be most comparable. Almost all of these, for reasons of distribution of suitable deposits, are from northern England and Scotland, although one example is forthcoming from Rimsmoor on the South Downs in southern England (Waton 1982). A number of cereal grains occurred there at a time estimated as about 5500BP, four centuries prior to the Ulmus decline. Rankine and Dimbleby (1960) recorded a phase of forest clearance with a single cereal grain at Oakhanger in Hampshire, but considered that it must represent contamination due to its very early date of around 6300BP. It may be supposed that the introduction of a pioneer Neolithic agricultural phase would be manifest in the south of England earlier than elsewhere in the British Isles due to proximity to mainland Europe, but such an early appearance for cereal cultivation seems rather too far in advance of the other dated examples to be acceptable at present.

One of the most convincing early cereal phases is that recorded by Williams (1985) at Soyland Moor in the Central Pennines where four cereal grains, one of Hordeum type, occurred during a short lived but very clear period of deforestation. A wide range of clearance indicator pollen was present, with both pasture and arable types (Behre 1981) which could be interpreted as representing mixed farming with grazing and limited cultivation in a 'landnam' type sequence culminating in forest regeneration. Williams considered the sequence of pollen changes to be too ecologically sensible to be explicable as the product of contamination, and the radiocarbon date of 5820±95BP accords extremely well with other dated examples. Similar pollen evidence has been recorded by Innes and Tomlinson (forthcoming) from Bidston Moss and Flea Moss Wood in Merseyside, with dates of 5840±70BP and 5920±50BP respectively, although of a less well marked nature than the Soyland Moor data. The Irish Sea lowland seems to have been a focus of early agriculture, for cereal-type grains have been identified at Hillhouses and Martin Mere by Tooley (1978, 1985) although with little accompanying evidence of forest disturbance. Much more like the Soyland Moor evidence in terms of its structure as a clearance - farming - regeneration sequence is a Flandrian II episode of deforestation with much ruderal and grassland herb pollen at Little Hawes Water in north Lancashire (Taylor et al.1988). Although not dated precisely, this early farming phase contains Triticum type pollen and is probably of mid to late Flandrian II age. It is most interesting as it is in fen peat deposits adjacent to wetland edge hillwash sediments containing very clear, and perhaps contemporaneous, evidence of major deforestation. If the presence of cereal pollen signifies the local existence of human settlement as much as actual cultivation (Vuorela 1973, Williams 1985, Groenman-van Waateringe 1988) with pollen liberated in quantity during winnowing of grain, this location of a terrestrial analogue to a bog deposit may be most interesting.

That pre elm decline cereal type pollen may be present with a much greater distribution than hitherto suspected is demonstrated by Edwards et al. (1986) who have been able to find such pollen grains in several late Flandrian II levels at Aros Moss, a Scottish site previously known to have pre elm decline clearance evidence but without cereals, by a rapid prospecting technique of scanning microscope slides. Such evidence was also found in quantity from nearby Machrie Moor, on Arran, where Flandrian II cereals had previously been reported (Robinson and Dickson 1988). That cereal-type grains may therefore be much less rare in Flandrian II clearance contexts than previously thought to be the case raises questions as to their interpretation and significance as ecological indicators (Groenman-van Waateringe 1983, Edwards and Hirons 1984, O'Connell 1987). It may be that small scale cereal production as part of a pioneer mixed agricultural phase in the second half of

Flandrian II was a common phenomenon in Britain. Low degrees of resolution and lack of direct pollen research may account simply for its lack of recognition up to the present time. It may be, however, that these cereal type grains are likely to be commonplace because they originate from natural, uncultivated members of the grass component of wetland herb communities, either grasses of coastal habitat like Elymus or Glyceria or perhaps genetic variants of grass taxa which produce abnormally large grains (Beug 1986, O'Connell 1987). While the latter can hardly be disproven, it should be possible with careful observation (Andersen 1979, Dickson 1988) to distinguish large non-cereal pollen types such as Glyceria from the Cerealia type; probably from the Hordeum group and certainly from the Triticum type. At this early stage it is only these two cereal types which were likely to have been involved in agriculture in the British Isles. O'Connell's (1987) revelations from the west coast of Ireland, however, with secure Triticum type identification at 7500BP and 6900BP, might suggest that some natural grasses, even if aberrantly, may produce pollen indistinguishable from that of Triticum. Even if such grains refer to wild, cereal type grasses, they are surely too early to represent deliberate agriculture unless of a remarkably precocious type by indigenous hunter-gatherer groups. It is more likely that they must be disregarded as cereal records in the same way as the early post glacial and even late glacial records of similar grains from central and southern European sites discussed by Barker (1985) and O'Connell (1987).

If Triticum type grains were being produced by uncultivated grasses, then all Triticum records whether late, pre or even post Ulmus decline must be viewed with some circumspection, for these grasses would presumably continue to be members of natural, perhaps marshland, grass communities in late periods when cereal pollen would be acceptable without question. On the other hand, that these cereal type grains very often occur in association with unequivocal pollen indications of forest clearance and perhaps grazing would support their origin as part of a human, agricultural process. Such grains tend not to be scattered through profiles, but are concentrated within clearance phases as part of an open ground clearance assemblage. The 'landnam' evidence of Lynch (1981), Taylor *et al*. (1988) and Williams (1985), the latter with duplicate profile counts as confirmation, are excellent examples of the juxtaposition of cereal-type grains and major forest clearance, although it is just possible to argue that increased transmission of grass pollen from natural sources due to the opening of the forest cover during clearance for hunting or pasture could account for the phenomenon. It is just this kind of problem that the FRPA work at North Gill is designed to elucidate, and the 'landnam' type successions at the end of phase D3 at NG1A place the site very firmly within the category where cereal-type pollen occurs as a member of a heavy clearance suite of indicator taxa. As with Soyland Moor, North Gill is an upland site and so coastal marsh grasses cannot complicate interpretation, the background grass pollen at North Gill being mainly dryland Poaceae or mire types like *Molinia* and *Phragmites*, neither of which produce large grains, although *Glyceria* could be present. The cereal-type record at NG1A at the FRPA level allows a much clearer appraisal of the relationship of cereal-type pollen with the other clearance indicators and with the changes in tree pollen frequencies. This in turn provides a better understanding of the kind of land use operating at the time of this early agricultural activity (see below section 11.6). Thus, although early FRPA zone H at NG1A contains clear indicators of deforestation, no cereals occur, suggesting that better pollen transmission of natural large grass grains is a poor explanation for the appearance of cereal-type pollen, as does their absence in the earlier clearances of the site phase NG-D2. The major 'landnam' clearance of late FRPA zone H at the end of phase D3 shows the classical presence of cereals with high Plantago lanceolata and a host of other ruderal and agricultural types. As interpreted in chapter six, the cultivation of land in very close proximity to NG1A seems certain here. Most important, however, is the continuation of cereals and Plantago lanceolata, with associated ruderals, into zone I when oak pollen has recovered to non-disturbance levels. Eased pollen transport cannot explain these data, since clearly tree canopies had been restored around North Gill 1A, leaving a very small area near to the profile where cultivation carried on for a short period until it too was abandoned. It seems certain that these cereal type grains of NG-D3 at NG1A must represent actual cereal cultivation, for the clarity with which the FRPA reveals successive clearance phases and plant communities does not sensibly allow for their explanation by other means.

The age range of phase D3 at NG5B, between about 5400BP and 5000BP, means that if phase D3 at NG1A is of similar age this cereal cultivation, although a few centuries prior to the Ulmus decline, is well within the accepted time range for early Neolithic settlement in northern England. As remarked upon above, some Ulmus decline dates from lowland northern England are contemporaneous with it (Simmons and Innes 1987), and so the recognition of cereals in this phase would be no great surprise. The other evidence from northern England which shows comparable, although less finely sampled, agricultural phases is dated half a millenium earlier, however, with Soyland Moor (Williams 1985) and Bidston Moss and Flea Moss Wood (Innes and Tomlinson forthcoming) dated between 5800BP and 6000BP. This age range is contemporaneous with that of the Irish data discussed above. The coincidence in age of early cereal records, within a few centuries, is circumstantial evidence that these grains may indeed be evidence of a pioneer phase of agriculture around the Irish Sea basin at the start of the sixth millenium BP, for random identification of natural large grass grains could hardly produce such a convergent age pattern. The evidence from North Gill 1A is of a later, more developed phase of agriculture, more akin to the later pre elm decline phases noted at other sites like Weir's Loch (Hirons and Edwards 1986) or Cashelkeelty (Lynch 1981), which also date to about 5400BP. At North Gill, however, the early, pioneer phase seems to be absent as, despite exhaustive FRPA analyses, no cereal type grains have been recorded within any phase D2 at North Gill. The characteristics of all cereal type grains recorded at North Gill are listed in Appendix 4. No other pre Ulmus decline cereals have been reported from the North York Moors, with the possible exception of Jones (1978) at Tranmire Slack, although the cereal type grains there occur so late in Flandrian II that they may be regarded as associated with the elm decline rather than preceding it.

11.6 Neolithic Ecology and Land-Use

The several records of cereal pollen from North Gill (listed in Appendix 4), both from pre Elm Decline and later contexts, occur in association with other pollen evidence of forest clearance and show that the agricultural activities of early Neolithic populations were a major influence in modifying the woodland ecosystem. The data from NG1A are particularly instructive on this subject, for early agricultural practices are recorded there before, at and after the Flandrian II-III transition, with detailed FRPA data available from the pre Elm Decline disturbance phase NG1A-5. That profile therefore allows the comparison of the character of three successive phases of early Neolithic activity, the second of which, the Elm Decline itself, is recorded in all the other profiles also. The North Gill data may therefore shed some light upon the nature of the development of land-use methods during the introduction and establishment of Neolithic societies in the area.

11.6.1 Pre Elm Decline Activity

Perhaps the most interesting result of FRPA at North Gill has been not only the recognition of pre Elm Decline cereal cultivation, but the realisation that this phase of pioneer agricultural activity, NG1A-5 or NG1A zone H, contains probably four and perhaps more separate disturbance impacts of quite distinct ecological character. There are at least three peaks in the Melampyrum curve, the first also with some bracken and ruderal weeds, which point to repeated opening of the woodland by fire. The final part of zone H (figure 68), however, contains little evidence of the use of fire, but has cereals, ruderal weeds and high Plantago lanceolata. These indications continue into zone I, after tree pollen values have recovered to their pre disturbance levels. The recurrent peaks in many of the major taxa during phase H, for example Calluna, but consistently high or low values for trees involved in disturbance, like Betula and Quercus, suggest that reductions in tree cover took place almost continuously through the phase, providing a composite pollen assemblage representing the amalgamated effects of forest disturbances. Rather than a single regeneration which would proceed through birch and hazel to forest trees (Iversen 1973), a blurred and indistinct picture of several regeneration communities is being observed.

There are parallels between the NG1A successions and Iversen's model of early farming within a forested environment, as both include a phase of burning prior to the taking of a cereal crop from the cleared land. The use of fire to prepare woodland for cultivation is a well known phenomenon (Montelius 1953) and Iversen (1973) suggests that successful cultivation requires the preparing of the soil in this way as a first stage in the process. The persistence of charcoal and Melampyrum until near the end of the zone of disturbance, however, again shows that a single burning event was not involved at North Gill, but a number of short term cycles of forest clearance, with renewed burning at regular intervals. This pioneer phase of agricultural activity therefore perhaps comprised a form of shifting cultivation based upon slash-and-burn techniques, as described by Huttunen (1980), Vorren (1986) and Vuorela (1986). These authors suggest that the successive creation of small clearings through fire may have been an efficient way of exploiting a forested environment, in which cereal yield could fall after only a few years (Reynolds 1977), without the need to establish permanent fields. Such a land-use pattern could easily produce a composite pollen record as in zone NG1A-H. Rowley-Conwy (1981) has effectively argued against the existence of shifting cultivation as part of the 'landnam' phase of early Neolithic agriculture, and he is probably correct in this view. The post Elm Decline 'landnam' at North Gill resembles many other examples in being a more emphatic clearance of the woodland, probably involving established fields. Landnam phases have been shown to last three or four centuries in Denmark (Rowley-Conwy 1982) and the landnam from Hatchmere in Cheshire (Birks 1975), for example, has been shown to be of four hundred years duration. The pre Elm Decline cereal phase at North Gill 1A does not represent landnam farming, but is a pioneer phase of Neolithic agriculture of much shorter and more ephemeral type. The duration of zone H is not known exactly but its twenty-five millimetre thickness may well, if an estimate of four or five years per level is used, have lasted about a century. This estimate may even be generous, for it is more than double the duration per millimetre recorded in disturbance phases at NG5B. A period of shifting cultivation of about a century would compare well with the estimate for the duration of forest slash-and-burn phases produced by Vorren (1986). The North Gill data suggest that the shifting cultivation model may be more appropriate for the Flandrian II pioneer Neolithic than it is for the later 'landnam' events.

An alternative approach to the problem concerns the possible role of domesticated animals in the pre Elm Decline Neolithic economy. The considerable frequencies of Plantago lanceolata in the cereal phase at the end of zone NG1A-H could be interpreted as a pastoral indicator but Groenman-van Waateringe (1986) suggests that ribwort plantain may well have been an arable weed at the start of the Neolithic, and so the agricultural phase at the end of NG1A-H may have been entirely arable. It is quite possible, however, that the Melampyrum characterised levels of the majority of NG1A-H represent the creation of open patches in the woodland to encourage the forest grazing of stock, primarily cattle. The enhanced fodder resources after light forest burns which may have encouraged wild game for Mesolithic hunters would presumably have increased the carrying capacity for domestic beasts also, with any continued attraction of wild ungulates presumably an added bonus. That the burning ended before arable cultivation began makes good sense, for the attraction of wild animals to areas where crops were being grown would not have been to the advantage of the agriculturalist.

The North Gill 1A FRPA data therefore support a model of pioneering Neolithic agriculture in which the exploitation of the forest, rather than its removal, by stock grazing and browsing was the primary economic objective. Regular burning maintains productivity for extensive forest grazing (Goransson 1982), and will continue to sustain this resource base for several decades. After this time, however, the presence of the animals causes the woodland to become increasingly open, until its productivity declines and clearings are formed. It is at this stage that burning must be stopped, so that the forest may be allowed to regenerate, and its exploitation by grazing ceases to be viable. Goransson regards the regenerating forest as a form of coppice wood, rather than fully restored dense tree cover. Goransson's (1982) pollen diagrams from the early Neolithic period in Sweden, however, show that it is during this regeneration of woodland, after fire-grazing has been discontinued, that cereal pollen becomes recorded in the pollen spectra. The open areas within the regenerating woodland were used for arable cultivation once cattle were no longer allowed to graze within it. Even when tree recovery was complete, cereal cultivation could persist under the new lighter canopy until total canopy closure was achieved or soils became unable to support it further.

Goransson's model of an early Neolithic strategy for exploiting forest ecosystems, which consists of a period of fire supported grazing of animals, followed by the exclusion of fire and stock, and a shorter period of cereal cultivation while woodland regeration was completed, is one which explains the pattern of the FRPA pollen and charcoal evidence from zone NG1A-H extremely well. If this model does reflect the economic strategy of the Flandrian II pioneer Neolithic at North Gill, it would form a natural progression from the fire ecology strategy of the Mesolithic, with domesticated animals substituted for wild game and the novel resource of cereals added to the process as its final element. It could form part of the gradual adaptive process envisaged by Simmons and Innes (1987), wherein continued management of the forest ecosystem, rather than its clearance, characterised the transition from the Mesolithic to the earliest Neolithic economic systems of land-use.

11.6.2 The Elm Decline

Although the Elm Decline has long been regarded as probably an effect of the agricultural activities of early farming communities (Iversen 1941, 1949) the precise nature of such activities has never been satisfactorally demonstrated. The anthropogenic importance of the phenomenon has diminished with the realisation that agricultural activity had been present for some centuries before it took place, so that the Elm Decline does not represent the start, or even the intensification, of Neolithic farming (Groenman-van Waateringe 1983). That soils and climate (Sturludottir and Turner 1985) or disease (Girling and Greig 1985) may have been the cause of the decline of <u>Ulmus</u> are also viable theories, and Perry and Moore (1987) have shown that not only can modern elm disease result in elm pollen decline similar to that of Neolithic age, the more open canopy can cause an increase of weed species pollen analogous to that attributed to Neolithic forest clearance. It has also been suggested (Groenman-van Waateringe 1983) that the decline of Ulmus may be mainly a palynological artifact caused by filtration and other pollen transport effects.

The anthropogenic origin for the Elm Decline has included theories that a pastoral economy involving forest grazing and collection of leaves for animal fodder was responsible, while the selective felling or ring-barking of elms to make available the best soils for cultivation has also been put forward as the cause. At many sites, including North Gill, elm frequencies reach their maxima immediately prior to the Elm Decline itself, often in sharp peaks, and this may support the ring-barking hypothesis as Goransson (1982) has pointed out that this process often stimulates the profuse sprouting and flowering of the trees for several years before eventual death. Rowley-Conwy (1982) has presented evidence, however, which makes pollarding and fodder collection an unlikely single cause to the event.

The recognition of cereal pollen grains together with other major forest clearance indicators, many of arable type, confirms an agricultural contribution to the fall of elm, however. Cereals occur in Elm Decline horizons at many sites, and three of the North Gill profiles, NG1A, NG5A and NG10, contain them. Scaife (1988) judged that cereal cultivation was the major factor involved, but also felt that the opening of the woodland may have assisted the spread of an elm disease, perhaps introduced by Neolithic settlers.

FRPA has been used by a number of authors to investigate the possible causes of the Elm Decline (Turner and Peglar 1988). Garbett (1981) examined pollen fluctuations across the Elm Decline at temporal intervals of only one or two years, in trying to study the behaviour of

Hedera as a proxy indicator of standing dead elm trees, which may have been common if disease were the major factor in the Elm Decline. This did not work, perhaps due to poor Hedera pollen transport, but he did identify a series of stages which he interpreted as leaf-fodder collection, followed by more systematic leaf gathering, and finally increased forest clearance to encourage grazing for animals.

Scaife (1988) and Moore (1980) however have both presented FRPA diagrams in which a form of rotational cereal farming was involved, either under light forest canopy or within cleared areas. Scaife also postulates a period of woodland-based pastoralism concurrent with this, thinning the forest cover and allowing increased representation of less well transported taxa in the pollen spectra.

Sturludottir and Turner (1985) prefer the effects upon soils of a prolonged period of Mesolithic burning of the local vegetation as the major cause at their site in the Northern Pennines, where no signs of agriculture accompanied the Elm Decline. This absence of agricultural indicators is the case in many Elm Decline pollen horizons, so that its association with Neolithic settlement in many cases may not be true.

The Elm Decline is therefore a most complex feature which may have been caused by different factors in different places, or a combination of many factors (Turner and Peglar 1988), since temporally precise FRPA work has revealed great variations in its character between sites, allowing contrasting interpretation of its origin.

Close comparisons between the above FRPA studies and the data from North Gill are difficult because FRPA diagrams involving the Elm Decline were not prepared at North Gill as the feature was not central to the aims of the research and time did not permit what would have been a most interesting exercise. The late Flandrian II agricultural activity described above, however, forms a natural link between the earlier forest disturbances and the events at the Flandrian II-III transition, and so some consideration of the Elm Decline at North Gill is necessary.

Little can be said regarding the disease hypothesis from the North Gill data, but there are aspects which support each of the other possible contributory factors. The prolonged pre Elm Decline fire disturbance of the forest at North Gill is closely comparable to the evidence of Sturludottir and Turner (1985) from Pawlaw Mire and the effects of repeated burning on soils and ecosystem has already been considered (Simmons and Innes 1985).

The cereal and weed pollen data from the various North Gill profiles, however, resembles the small rotational farming and clearance hypothesis (Scaife 1988) in many respects. The absence of cereals from some of the profiles may be due merely to taphonomic factors. The absence of very clear 'landnam' type successions may well be due to the aggregation of pollen input from a spatially complex range of land-use activities around North Gill at the time of the Elm Decline. Neolithic activity of a mixed arable and pastoral kind carried out within woodland of varying density over a period of time may have led to the type of pollen data recorded at North Gill, rather than major forest clearance.

More like the results of major clearance of 'landnam' type are the early post Elm Decline clearances of late phase NG1A-7 in which great increases in taxa like Plantago lanceolata, Calluna and Pteridium occur with cereals, arable weeds and major falls in tree pollen frequencies. Betula responds very positively in this phase, as in classical 'landnam' fashion, due to its ecological characteristics as a regeneration tree (Gimingham 1984). Major 'landnam' phases of this kind may last for a few centuries (Rowley-Conwy 1982) and may represent long-term, settled farming activity, perhaps with permanent fields, in contrast with the more transient effects of the earlier agricultural practices of the Elm Decline and late Flandrian II.

11.7 Conclusion

The research presented and discussed in this thesis has addressed the hypothesis that fine resolution pollen analysis, both spatial and temporal, has the potential to provide reliable, precise ecological data which can elucidate problems in prehistoric archaeology and palaeoecology which are too detailed or complex to be resolved by less precise analytical techniques. Several research aims within this broad hypothesis were listed in chapter one, and the results from North Gill, FRPA and multi-profile, have shown the fine resolution technique capable of meeting the requirements of these aims very successfully. FRPA has been shown to be reliable up to the limits of its application and to yield ecologically valuable data at these fine scales of resolution. The use of fine resolution concentration analyses and charcoal analyses has been shown to be a valid extension of the technique, in relation to both mire and woodland development. Their use alongside percentage FRPA is recommended. Fine spatial ecological data at the level of individual profiles was most sensitive, allowing the study of very short-term local woodland dynamics. The method seems to be ideally suited to the study of woodland ecosystems, particularly where disturbance has caused short-term vegetation successions to occur, and FRPA has successfully differentiated between the effects of different types of land-use within the similar forested environment and, most especially, has allowed an assessment to be made of the type, location and number of early prehistoric disturbance impacts. It is in the study of this kind of detailed and complex palaeoecological problem that the technique's greatest value may lie. With better chronological control than that available in this research, a better spatial dimension in between-profile correlation should be possible. The scarcity of suitable sediments and the high numbers of levels to be counted mean that the application of FRPA may in practice be restricted, but at critical sites it promises to be a uniquely sensitive technique for the resolution of problems of prehistoric land-use and ecology.

This has been fully demonstrated by the research topic to which FRPA has been applied in this thesis. The study of pre Elm Decline woodland disturbances has until recently remained at the quite general level of documentation of examples and the establishment of ecological models to explain the probable role of Late Mesolithic and early Neolithic societies in bringing about landscape change (Jacobi et al. 1976, Simmons 1979, Simmons and Innes 1985). This has been inevitable due to the ephemeral, low visibility character of most of these disturbances in pollen diagrams, and the coarse sampling strategies usually involved.

The recognition that the second millenium of Flandrian II represents a period of overlap between Mesolithic and Neolithic economies and thus a prolonged period of culture change (Edwards 1986, Zvelebil 1986, Zvelebil and Rowley-Conwy 1986, Simmons and Innes 1987), means that the culture and economic strategy of prehistoric communities during that critical transition period cannot be studied without highly detailed ecological data. The scale, duration and regularity of disturbance, the role of fire or axe, the role of wild game or domesticated animals, and the presence or absence of cereal cultivation all need to be known in some detail at individual sites before further understanding and modelling of prehistoric economy and culture during this period can be attempted. FRPA will almost certainly be required to achieve this aim.

Aa North Gill FRPA has elucidated in detail a progression from Mesolithic age fire manipulation of forest, perhaps designed to control the abundance and location of plant and game resources, to a stage where small scale cultivation was added to the traditional economy of foraging societies, perhaps also with domesticated animals, in a pioneer phase of Neolithic activity. The Elm Decline and the larger 'landnam' clearances which followed it form further stages on the trend away from a foraging to a settled food production economy. At the single location of North Gill, therefore, the second half of Flandrian II formed a period of adaptation in which food production components were gradually added to, and eventually replaced, traditional foraging strategies. Many key elements of each of the stages in this adaptive process, such as the presence of cereals or the multiple nature of disturbance impacts, were only visible and intelligible at the FRPA scale.

The timing and character of cultural and economic change during the Mesolithic - Neolithic transition is likely to have been very different between regions and even between sites within regions, as between upland and lowland situations for example. FRPA may have to be increasingly used in the ecological study of this phase of prehistory although it will also be of value with respect to other periods of vegetation history. The success of the technique at North Gill suggests, however, that FRPA will be of particular diagnostic value in the study of the environmental and land-use history of the period during which the agricultural economy of the Neolithic gradually replaced the foraging economy of the Mesolithic.

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