Forestry Commission

THETFORD FOREST PARK
The Ecology of a Pine Forest

Edited by Philip Ratcliffe and Jenny Claridge

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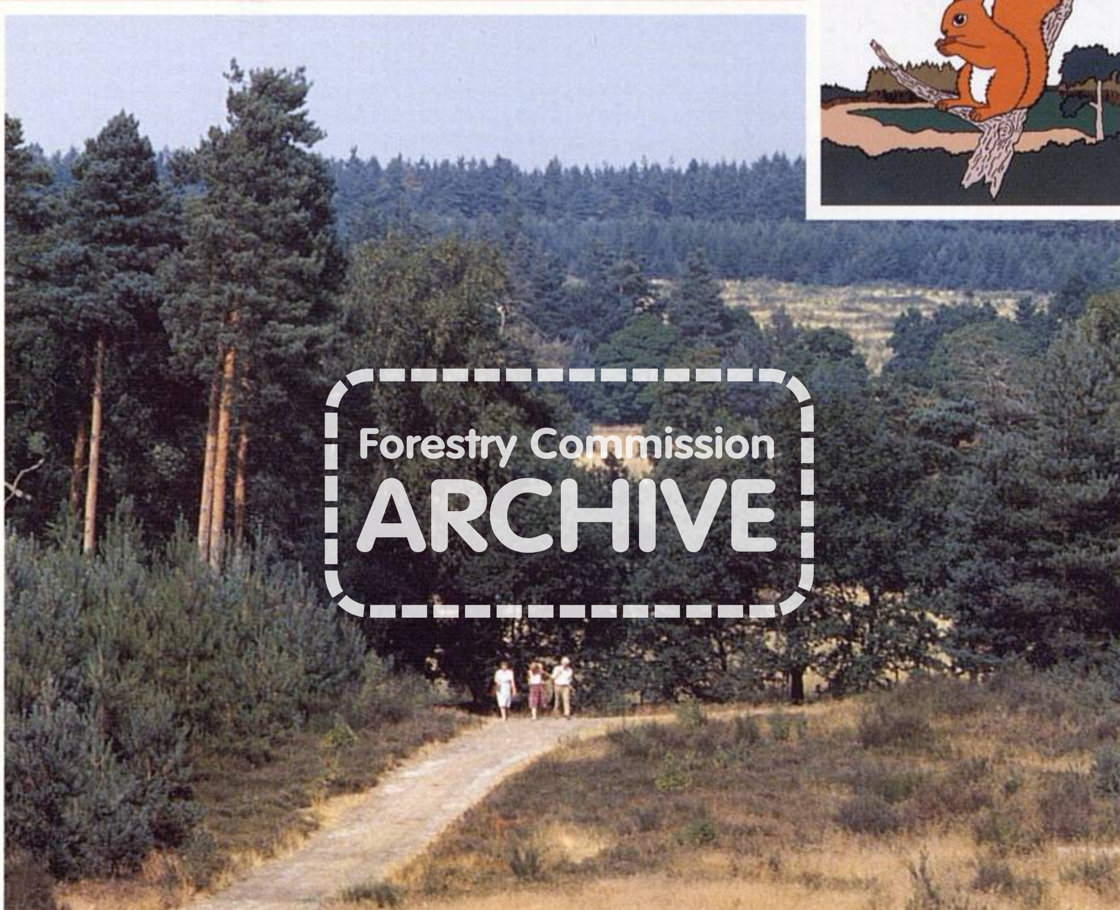

Technical Paper 13

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Thetford Forest Park: the Ecology of a Pine Forest

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Front cover: A Forest Walk in Thetford Forest Park (Forest Life Picture Library: 1006320.02).

Back cover: The position of Thetford Forest (shown in green) in the Breckland of south-west Norfolk and north-west Suffolk.

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Preface

The establishment of Thetford Forest by the Forestry Commission in the 1920s and 1930s on the sandy mobile soils of the Breckland was a challenge to the foresters of the day. It concentrated research on the silviculture of a range of tree species and their establishment on Breckland soils and on the pest problems caused by pathogenic fungi, insects and mammals. The Forestry Act of 1919 provided the objective of promoting forestry to repair the ravages of war. In 1957 the Zuckerman Committee introduced commercial and social objectives.

Subsequently there has been a great deal of interest in the Breckland flora and fauna and their adaptation to forest conditions, and forests have become increasingly important for recreation and for their wildlife. The Wildlife and Countryside (Amendment) Act, 1985 gave mandatory support to the multi-objective management of forests for the public good and a restatement of Forest Policy in 1991 emphasised the management of forests for the range of diverse benefits which they provide. Recent research has therefore addressed wider aspects of the ecology of Thetford Forest.

Since the Thetford symposium in 1991, the Rio summit (1992) and Helsinki (1993) resolutions have led to even greater emphasis on multiple benefits, sustainable management and the maintenance of biodiversity. Continuing research and modification of management objectives and strategies are necessary to underpin these.

The symposium which led to this publication was designed to gather together the results of a wide range of research which collectively have added greatly to our understanding of this pine forest ecosystem and influenced its management.

The intended audience is woodland managers and ecologists and anyone with an interest in forest wildlife including the many visitors to the Forest Park. As well as providing a wealth of information about Thetford Forest, the abundance of comparative information included should also be of value to those interested in other woodland types.

Philip R. Ratcliffe

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Chapter 1

Why Thetford Forest? The human and natural history of Breckland before the early 20th century

Roland Randall and David Dymond

Summary

The Breckland is an area of geologically similar sandy soils, approximately 1000 km^2 in extent, in south-west Norfolk and north-west Suffolk. It is mainly 15-30 m above sea level and is underlain by a chalky-sandy glacial drift over chalk. Soil development is cyclic and results from the breakdown of the drift material. At its most acid stages, the soil becomes unstable and liable to windblow, exposing the underlying drift to further pedogenesis. Relict patterned ground from periglacial times is still present and can be reflected in present-day vegetation. Over the last 10 000 years, climate and then man have changed the natural vegetation of Breckland from an open herbaceous landscape,through birch and pine forest to alder-mixed oak with elm, and back to open heathland. The last 8000 years have seen several main phases of human exploitation. First, prehistoric settlers cleared the land of its natural scrub and

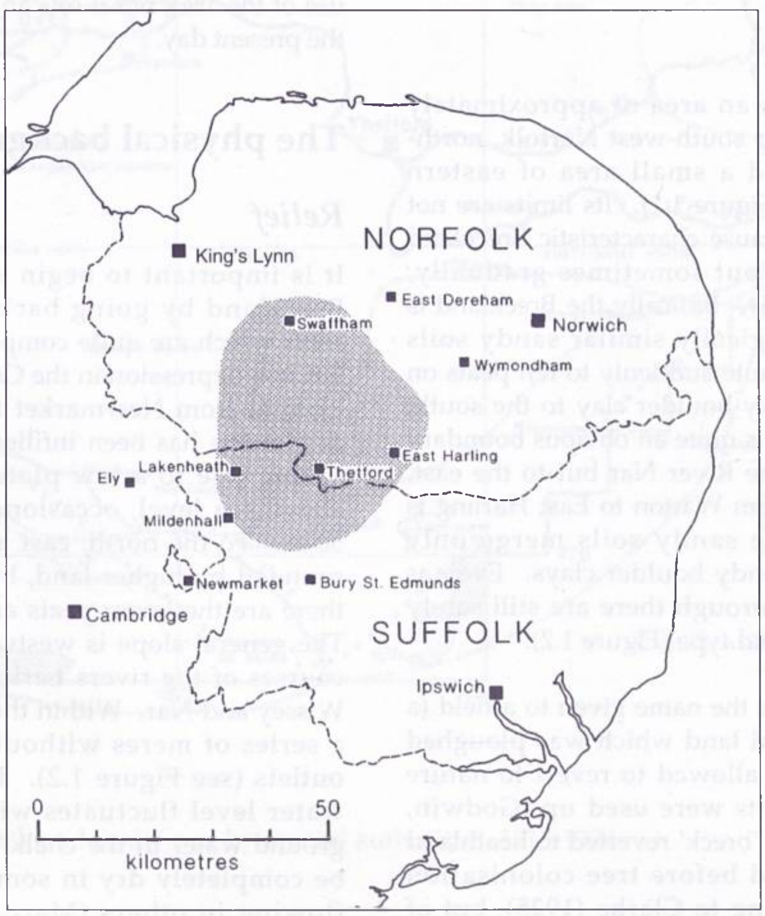

Figure 1.1 The position of the Breckland (shaded area) in East Anglia

farmed it productively. By later Anglo-Saxon times the region had been divided into parishes bearing English names which have persisted to the present day. The complicated landscape of the Middle Ages was dominated by extensive arable open fields, rabbit warrens and vast areas of common and heath. After the Black Death in 1349, however, many settlements shrank and some were totally deserted. This gave the surviving population new economic opportunities, and led ultimately to the development of major agricultural estates dominated by large houses and parks. The Breckland was to be given a significant transformation in the late 18th and early 19th centuries, when high prices encouraged a spate of Parliamentary and private enclosure. For a time farming remained relatively prosperous, but then from the 1880s, when foreign competition began to undermine English agriculture, the region was particularly badly affected. The price of land plummeted and the Breckland came to be valued more for its game and shooting than for its farming. After the First World War, the Forestry Commission bought and leased huge areas of former arable and heath at very low prices and initiated another radical transformation of the region.

Introduction

The Breckland is an area of approximately 1000 km^2 covering south-west Norfolk, north-west Suffolk and a small area of eastern Cambridgeshire (Figure 1.1). Its limits are not easy to define because characteristic Breckland components die out sometimes gradually, sometimes abruptly. Basically the Breckland is an area of geologically similar sandy soils which give way quite suddenly to fen peats on the west and sticky boulder clay to the south. In the north there is quite an obvious boundary at the valley of the River Nar but to the east, although a line from Watton to East Harling is often drawn, the sandy soils merge only gradually with sandy boulder clays. Even as far east as Attleborough there are still sandy loams of a Breckland type (Figure 1.2).

The term 'breck' is the name given to a field (a break) in marginal land which was ploughed up regularly and allowed to revert to nature when the nutrients were used up (Godwin, 1944). After use a 'breck' reverted to heathland for a long period before tree colonisation occurred according to Clarke (1925), but of course the rabbit influenced this from Norman times and further ploughing frequently interrupted the succession. The distinctive landscape of this area has been noted by travellers (e.g. Blomefield, 1739; Whitaker, 1893) for several centuries when it had been known as the Fielden and in the 19th century the area was known as the 'Breck District' (Newton, 1866). In 1894, Clarke altered this to Breckland, a name which has become generally accepted. This regionalisation indicated that by the early 20th century the peculiar features of the area as a whole had attracted scientific attention.

As well as W.G. Clarke's classic book, *In Breckland Wilds* (1925), which was revised in 1937 by R.R. Clarke, there are general texts on the area by Schober (1937), Cook (1956) and considerable ecological detail in Trist (1979), Chadwick (1982) and Webb (1986). Because the area is near to Cambridge, the University has played an important role in its scientific exploration. In 1931, a Breckland Research Committee was formed to co-ordinate physical, biological and historical research. This Committee met until 1972, and from 1974 to 1978 *Breckland Research Bulletins* were published. Much of the earlier literature has been greatly outdated by the changing agricultural, military and forestry land-use of the area, but it sets an important scene for the present day.

The physical background

Relief

It is important to begin an examination of Breckland by going back to its geological roots which are quite complex. The Breckland lies in a depression in the Cretaceous chalk that extends from Newmarket to Swaffham. This depression has been infilled by glacial debris, giving rise to a low plateau some 15-30 m above sea level, occasionally rising to over 50 m. To the north, east and south it is surrounded by higher land, but to the west side there are the lower peats and silts of Fenland. The general slope is westwards following the courses of the rivers Lark, Thet, Little Ouse, Wissey and Nar. Within the Breckland there is a series of meres without surface inlets or outlets (see Figure 1.2). In these meres the water level fluctuates with the changes in ground water in the chalk beneath. They can be completely dry in some years and overflowing in others (Marr, 1913; Jones and Lewis, 1941).

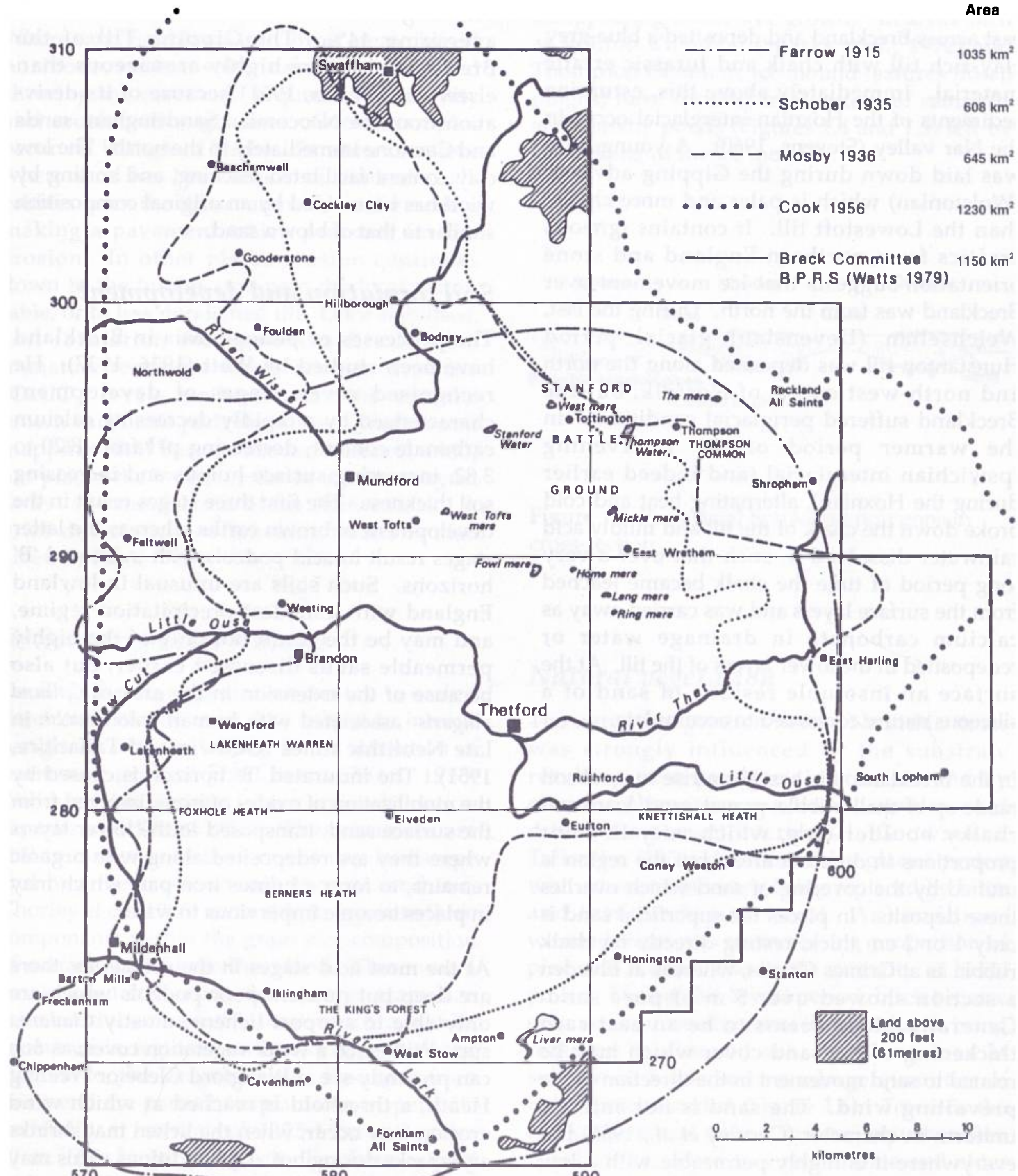

Figure 1.2 The Breckland as defined by several authorities, 1915-1979

Drift deposits

West and Donner (1956) recognised the deposits of three glacial stages in East Anglia, two of which can be identified in Breckland from the stone orientation of the till. The ice advance which laid down the lower Lowestoft till moved east across Breckland and deposited a blue-grey clay-rich till with chalk and Jurassic erratic material. Immediately above this, estuarine sediments of the Hoxnian interglacial occur in the Nar valley (Stevens, 1960). A younger till was laid down during the Gipping advance (Wolstonian) which is paler and more chalky than the Lowestoft till. It contains igneous erratics from northern England and stone orientation suggests that ice movement over Breckland was from the north. During the last, Weichselian (Devensian) glacial period Hunstanton till was deposited along the north and north-west coasts of Norfolk, but the Breckland suffered periglacial conditions. In the warmer period of the intervening Ipswichian interglacial (and indeed earlier during the Hoxnian), alternating heat and cold broke down the chalk of the till and mildly acid rainwater dissolved it, such that over a very long period of time the chalk became leached from the surface layers and was carried away as calcium carbonate in drainage water or redeposited in the lower layers of the till. At the surface an insoluble residue of sand of a siliceous nature continued to accumulate.

In the Breckland this has given rise to a subsoil made up of chalk rubble, gravel, sand, loam and chalky boulder clay, which vary in their proportions in different areas, but the region is unified by the covering of sand which overlies these deposits. In places the superficial sand is only 1 or 2 cm thick, resting directly on chalk rubble as at Grimes Graves, whereas at Elveden a section showed over 5 m of pure sand. Generally, there seems to be an eastward thickening of the sand cover which may be related to sand movement in the direction of the prevailing wind. The sand is not entirely uniform in character (Chorley *et al.*, 1966) but everywhere it is highly permeable with a low water-retaining capacity which contrasts greatly with the surrounding fen and chalky boulder clay. The sands of the Breckland act as a filter-bed, absorbing water with great rapidity and performing like a mulch with minimal evaporation over the chalk water-table.

Where the Breckland soils are only centimetres deep over the chalk, they are alkaline, highly calcareous and have a specialised lime-rich flora (see Barkham, Chapter 5). Elsewhere, there are highly acid, often podzolised, soils (Perrin, 1955) resulting from decalcification of the till by percolating rainwater (Clarke *et al.*, 1938; Watt, 1936). According to Perrin (1957) the Gipping Till ranges from 30-70% calcium carbonate, averaging 44%. The Gipping Till of the Breckland is more highly arenaceous than elsewhere (Perrin, 1961) because of its derivation from the Neocomian Sandringham sands and Carstone immediately to the north. The low clay content facilitated leaching, and sorting by wind has been aided by an original composition similar to that of blown sand.

Soil formation and development

The processes of pedogenesis in Breckland have been studied by Watt (1936, 1937). He recognised seven stages of development characterised by a rapidly decreasing calcium carbonate content, decreasing pH from 8.20 to 3.82, increasing surface humus and increasing soil thickness. The first three stages result in the development of brown earths whereas the latter stages result in acid podzols with indurated 'B' horizons. Such soils are unusual in lowland England with a modest precipitation regime, and may be the result not only of the highly permeable sands discussed earlier, but also because of the extension in the area of *Calluna vulgaris* associated with human colonisation in late Neolithic times (Godwin and Tallantire, 1951). The indurated 'B' horizon is caused by the mobilisation of oxides of iron dissolved from the surface sand, transposed to the lower layers where they are redeposited along with organic remains, to form a humus iron-pan, which may in places become impervious to water.

At the most acid stages in the soil series, there are deep but nutrient poor podzols which are only able to support lichens, mostly *Cladonia* spp. With such a weak vegetation cover, as one can presently see at Wangford Glebe or Weeting Heath, a threshold is reached at which wind erosion may occur, when the lichen mat shrinks and cracks during hot, dry conditions. This may occur either frontally, by prevailing winds, or by blowout formation caused by whirlwinds or 'dust-devils' (Watt, 1937). The seriousness of the erosion is dependent upon the coincidence of suitable vegetation and climatic conditions. In general, this has resulted in greatest erosion on the west side of Breckland with deposition towards the north-east but locally it has resulted in infill of the river valleys. One of the most famous 'blowouts' occurred in 1668, at the height of the Little Ice Age conditions, when so much sand was driven by the wind 8 km from Lakenheath Warren to Santon Downham that the Little Ouse was diverted and part of the village buried (Wright, 1668).

Where sand has blown into lower areas old soil horizons, paleaosols, can be excavated showing the continued sequences of stability and erosion through time. Good examples occur on Wangford Glebe. In some locations where sand has been removed, flints or chalk cobbles from the till accumulate on the surface making a pavement which prevents further erosion. In other places erosion continues down to the humus iron-pan, the local water-table, or to less decalcified till. Once stabilised, soil formation recommences firstly with immature rendzinas where calcium carbonate ($CaCO_3$) levels are high and then with the brown earth and podzolic series. Modern soil mapping (Soil Survey Research Board, 1960) has placed the brown earths in the *Worthington Series* and the podzols in the *Santon Series.* A brief description of Breckland soils is also given by Pizer (1979).

Relict periglacial features

During the last glaciation no ice invaded Breckland, but the area was subject to intense periglacial activity leading to the formation of patterned ground phenomena (Watt, 1955; Williams, 1964), frost heave and solifluction (Sparks and West, 1972). These features are still in evidence in the present day landscape and have been a local influence on land use. Chorley *et al.* (1966) were able to separate three components within the grain size composition of surface sand of the Breckland. There was a weak trend indicating decrease in grain size from north-east to south-west which might be explained in regional variations of, and glacial attrition to, the arenaceous till. Residuals from this trend are partially explainable by periodic variability at intervals of 0.125-1 km and under 10 m. The larger periodicity has been related to parabolic dune forms of very low relief (under 2 m) developed by periglacial wind action (cf. Maarleveld, 1960), whereas the most local variability may be associated with the stripe patterns at 7.5 m average wavelength and the polygons with 10.5 m mean diameter (Williams, 1964). These patterned ground features result in alternate strips of calcicole and calcifuge features that are still widely visible in present day vegetation (Figure 1.3). Particularly fine examples exist on Bromehill Heath, Norfolk and at Grimes Graves and Lakenheath Warren, Suffolk, but many sites are disappearing under tree growth. In areas such as Walton Common (Sparks *et al.*, 1972) and Thompson Common, ice mound features (fossil pingos) have resulted in a pattern of ramparts and marshy ponds (Figures 1.4 and 1.5) left by the melting of the ice mounds.

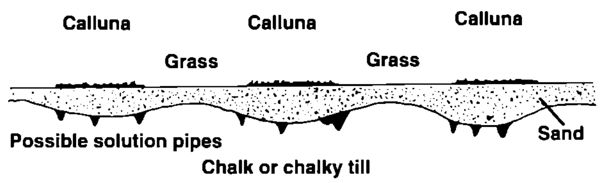

Figure 1.3 Periglacial Breckland polygons in cross-section

Natural vegetation

The natural vegetation before Neolithic times was strongly influenced by the substrate resulting from periglacial processes and by climatic change as conditions ameliorated during the present interglacial. Godwin and Tallantire (1951) describe a late-glacial period with an open landscape being replaced by birch and then birch-pine forest. As conditions warmed there was an increasing proportion of pine and a quick rise in the quantity of hazel pollen. During the Boreal period, birch became only a minor constituent of the woodland, being replaced by elm and oak, pine continued at substantial levels and very large quantities of hazel were recorded (Figure 1.6). Towards the end of the Boreal period, moister, equally warm conditions resulted in a rise in lime and alder and a marked reduction in pine, whereas oak remained common. The Atlantic period was characterised by an alder-mixed-oak forest in which elm suddenly declined around 6000 BP, marking the involvement of Neolithic man in the landscape (Rackham, 1980). The elm decline corresponds very closely to a marked rise in

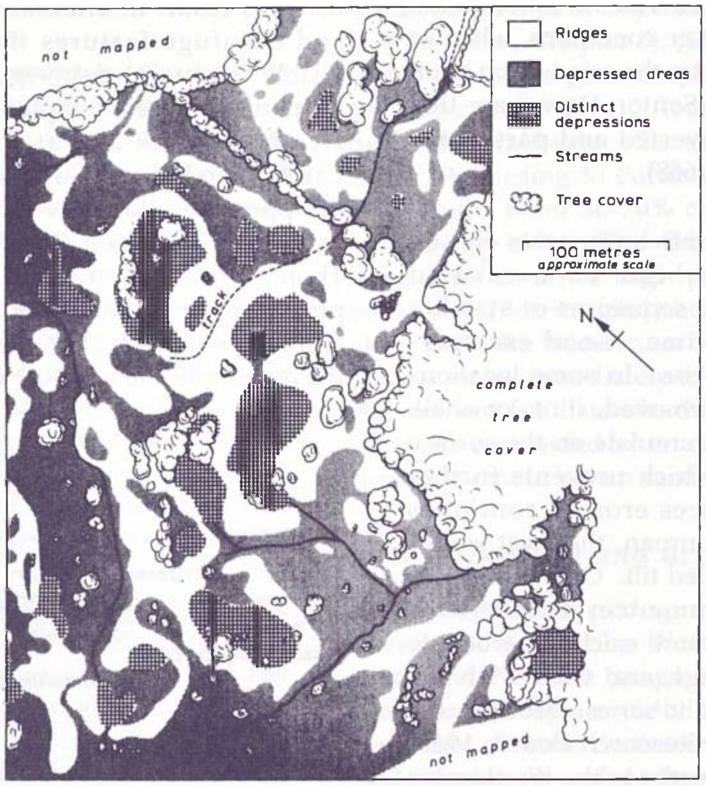

Figure 1.4 Ice mound features on Walton Common, near King's Lynn (after B.W. Sparks, R.G.G. Williams and F.G. Bell, *Proceedings of the Royal Society A* **327**)

grass, heather and herb pollens, especially plantains (Figure 1.7) thought to be associated with cultivation. Hence, there is convincing evidence that in general the Breckland area had a wooded landscape for much of the present interglacial but that anthropogenic heath developed in Neolithic times. The increasing presence of sphagnum moss in Atlantic times suggests that, locally, wetland such as fossil pingos was significant, whereas the continued presence of grass and herb pollen throughout the sequence suggests some areas of Breckland did not have a closed canopy of woodland, even

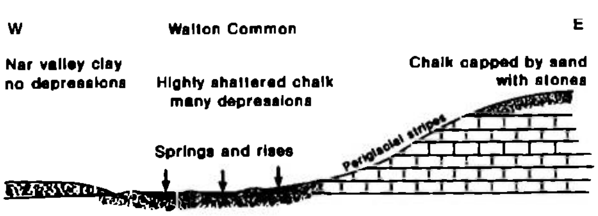

Figure 1.5 Ramparts and marshy ponds at Walton Common, near King's Lynn, Norfolk (after B.W. Sparks, R.G.G. Williams and F.G. Bell, *Proceedings of the Royal Society A* **327**)

in moister periods, because of excessive soil drainage. Evidence of this can still be seen in the continued presence of early interglacial species such as *Silene otites, Veronica spicata* and *Artemesia campestris.*

The human landscape of Breckland

Because of its geology, dry 'blowing' sands filling a depression in the chalk escarpment, and its comparatively dry climate, the Breckland has usually been regarded as agriculturally marginal. That has not prevented the development of distinctive patterns of human settlement and land-use. Five main phases are worth summarising in turn:

- Prehistoric clearance and farming
- Anglo-Saxon settlement
- The Medieval landscape
- Population decline and readjustment
- The new Breckland landscape

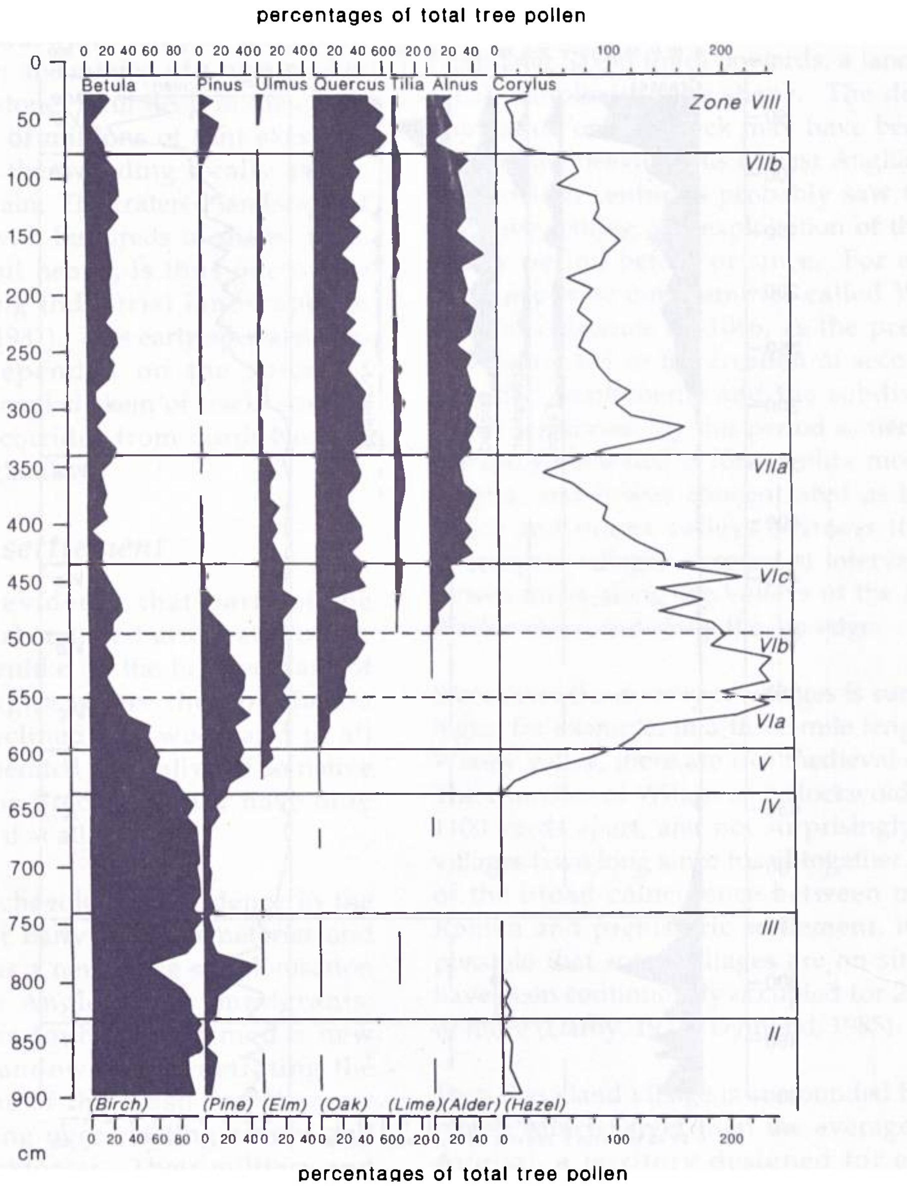

Figure 1.6 Percentages of total tree pollen at Hockham Mere, Norfolk

Prehistoric clearance and farming

It has been estimated that the Breckland yields a million worked flints to the square mile. At any event, generations of archaeologists have recorded large concentrations of archaeological finds and sites from the Palaeolithic onwards, underlining that the region was highly attractive to early man (Barringer, 1984). However, the open heathland regarded as characteristic of the region was first created in Neolithic and Bronze Age times, probably making its greatest impact from the middle of the 3rd millenium BC when metal tools were first available. Over many generations settlers using primitive hand-tools gradually cleared away the woodland and scrub which had clothed the landscape since the end of the Ice Age. Not until the later 18th century did the Breckland again grow trees in any numbers. In 1939, when Harry Godwin sampled the bed of Hockham Mere, he gave the first palaeo-botanical demonstration in Britain of the sequence of vegetation in post-glacial times and the impact of prehistoric man (Godwin and Tallantire, 1951; Murphy, 1984; Sims, 1978).

These prehistoric farmers created temporary and permanent settlements, usually in river valleys and along the edge of the fen (Martin and Murphy, 1988). A regime of mixed farming (arable with livestock) was established on the valley soils, while higher and drier areas were opened up for grazing. On the higher, remoter ground beyond their settlements, stock enclosures and fields, Bronze Age inhabitants

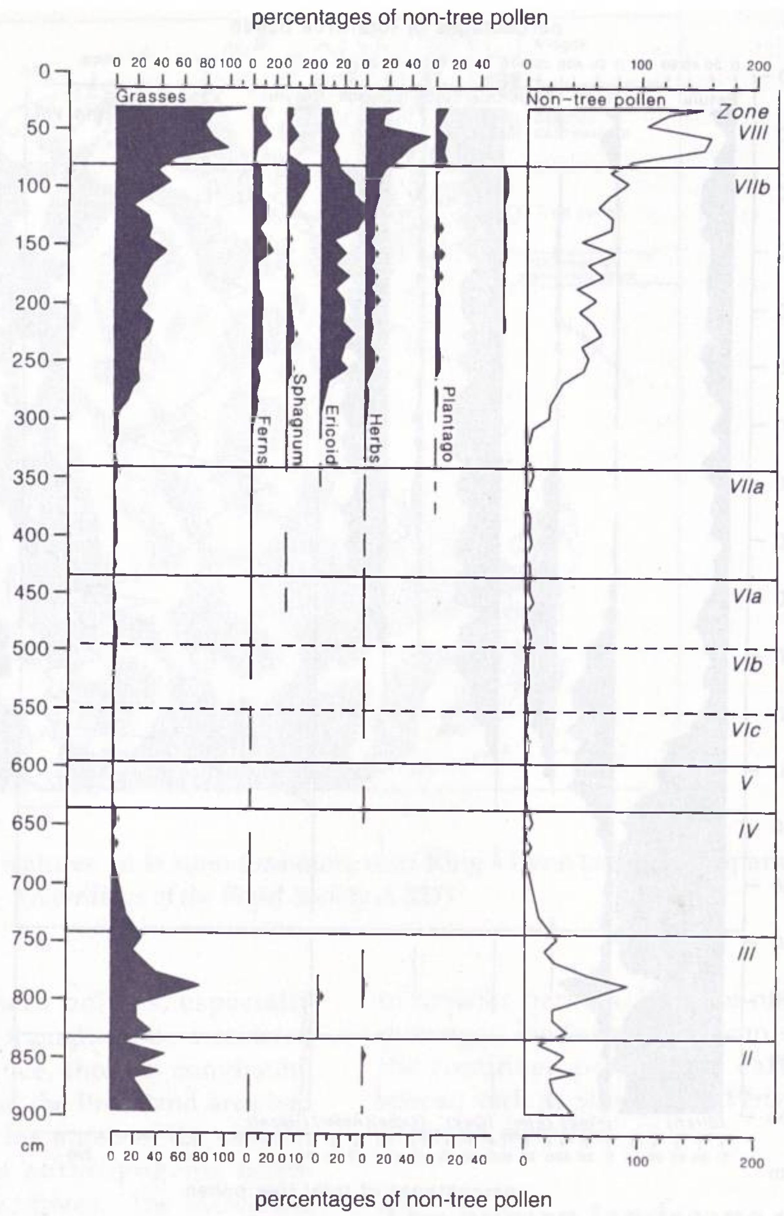

Figure 1.7 Percentages of non-tree pollen at Hockham Mere, Norfolk

built burial mounds or 'barrows'. Scores of these have survived either as still appreciable mounds or as ploughed-out ring-ditches (Lawson *et al.*, 1981). One of the best surviving groups is the so-called Seven Hills at Brettenham, originally at least 13 barrows strung out along a commanding ridge, no doubt serving settlements in the valleys on each side. During the Iron Age, the distribution of coins suggests that the Breckland had become one of the three political centres of the Icenian kingdom (Allen, 1970; Webster, 1978). This, for example, helps to explain the existence of a large Iron Age fort underneath Thetford Castle, commanding the point where the Icknield Way crossed the rivers Thet and Little Ouse, and of other defensive enclosures at Gallows Hill, Thetford and at Barnham (Gregory, 1981).

These major developments in prehistoric times were continued or even accelerated during the Roman period, largely by the same native people of Celtic or British stock living in scattered farmsteads and hamlets. On the western edge of the Breckland, against the fens, the density of Romano-British settlement was very thick, farmsteads occurring every half-mile or less, on or close to their Iron Age predecessors. At Hockwold, a Roman villa and native village seem to have had an economic and tenurial relationship, and were surrounded by a complicated grid of enclosures, fields and droveroads (Gurney, 1986). The higher and drier parts of the region were no doubt cleared and exploited for their grazing, but they were not suitable for living in because of the lack of water (Moore *et al.*, 1988).

In the Late Neolithic period (*c*. 2700-2000 BC), Breckland also illustrates another important human enterprise: the mining of a high quality flint called 'floorstone' from deep in the chalk, the manufacture of millions of flint axes and other tools, and their trading locally and to other parts of Britain. The cratered landscape of Grimes Graves, with hundreds of shafts, adits, tunnels and spoil heaps, is thus one of the earliest surviving industrial landscapes in Europe (Mercer, 1981). This early specialisation undoubtedly depended on the so-called Icknield Way, a tangled skein of tracks leading along the chalk corridor from north Norfolk into southern England.

Anglo-Saxon settlement

We have little evidence that parts of the Breckland were abandoned at the end of the Roman period (unlike on the heavier clays of central East Anglia where the population undoubtedly declined and woodland in all probability regenerated naturally). The native population of the Breckland may have only slightly declined, if at all.

Furthermore, archaeological evidence in the form of Pagan or Early Saxon cemeteries and settlements attests a new wave of colonisation by Germanic or Anglo-Saxon immigrants. These people undoubtedly formed a new aristocracy of landowners, penetrating the region by means of the Wash and its river system and taking over existing estates and their native workforces. Their military and political power is revealed by Anglo-Saxon place-names which dominate the modern map, to the almost total exclusion of earlier Latin and Celtic names.

In 1965-72 Stanley West excavated the now classic site of West Stow. This was a complete Early Anglo-Saxon village sited on a small sandy hillock in the valley of the river Lark. It consisted of some 70 small timber huts (see Figure 1.8) and about 10 larger 'halls', occupied from the 5th to the early 7th centuries by an average of three to four extended families. The economy of this community was based on the growing of wheat, barley, rye and pease, the keeping of sheep, cattle, pigs, horses and goats, supplemented by fishing, wildfowling and some hunting of red and roe deer. It is no accident that this early village stood on a site which had previously been occupied by Roman kilns, an Iron Age farm and other occupations going back to the Mesolithic period (West, 1985; Crabtree, 1989).

The medieval landscape

From later Saxon times onwards, a landscape of great complexity took shape. The density of population on the Breck may have been lower than on the heavier soils of East Anglia, but the 11th to 13th centuries probably saw the most intensive settling and exploitation of the region at any period before or since. For example, three separate communities called Wretham were in existence by 1086, as the pressure of population led to the creation of secondary or daughter settlements and the subdivision of earlier territories. By this period settlement was markedly nucleated in form, unlike most of East Anglia, and it was concentrated as before in major and minor valleys (witness the string of compact villages close-set at intervals of one to two miles along the valleys of the Lark and Blackbourne) and along the fen-edge.

Sometimes the density of villages is surprisingly high: for example, in a three-mile length of the Wissey valley, there are five medieval churches. The churches of Wilton and Hockwold are only 1100 yards apart, and not surprisingly the two villages have long since fused together. Because of the broad coincidence between medieval, Roman and prehistoric settlement, it is quite possible that some villages are on sites which have been continuously occupied for 2000 years or more (Darby, 1971; Dymond, 1985).

Each Breckland village is surrounded by a large parish (much larger than the average for East Anglia), a territory designed for economic purposes and containing a good cross-section of locally available soils from low-lying valley silts and gravels to high dry sands. Two of the most astonishing convergences of parish boundaries in Britain can be seen at Ringmere in Norfolk (Figure 1.9(a)) and at Rymer Point in Suffolk (Figure 1.9(b)). Six and nine parishes, respectively, meet to take advantage of Breckland Meres, those rare natural ponds where water could be found on sandy uplands (Munby, 1968).

The medieval farming landscape contained three main physical components, which are described in manorial surveys and illustrated on good manuscript maps surviving from the 16th and 17th centuries.

- First, under pressure of local population from Late Saxon times onwards, open arable fields had developed which were subdivided into scores of furlongs and thousands of long thin strips. Even as late as

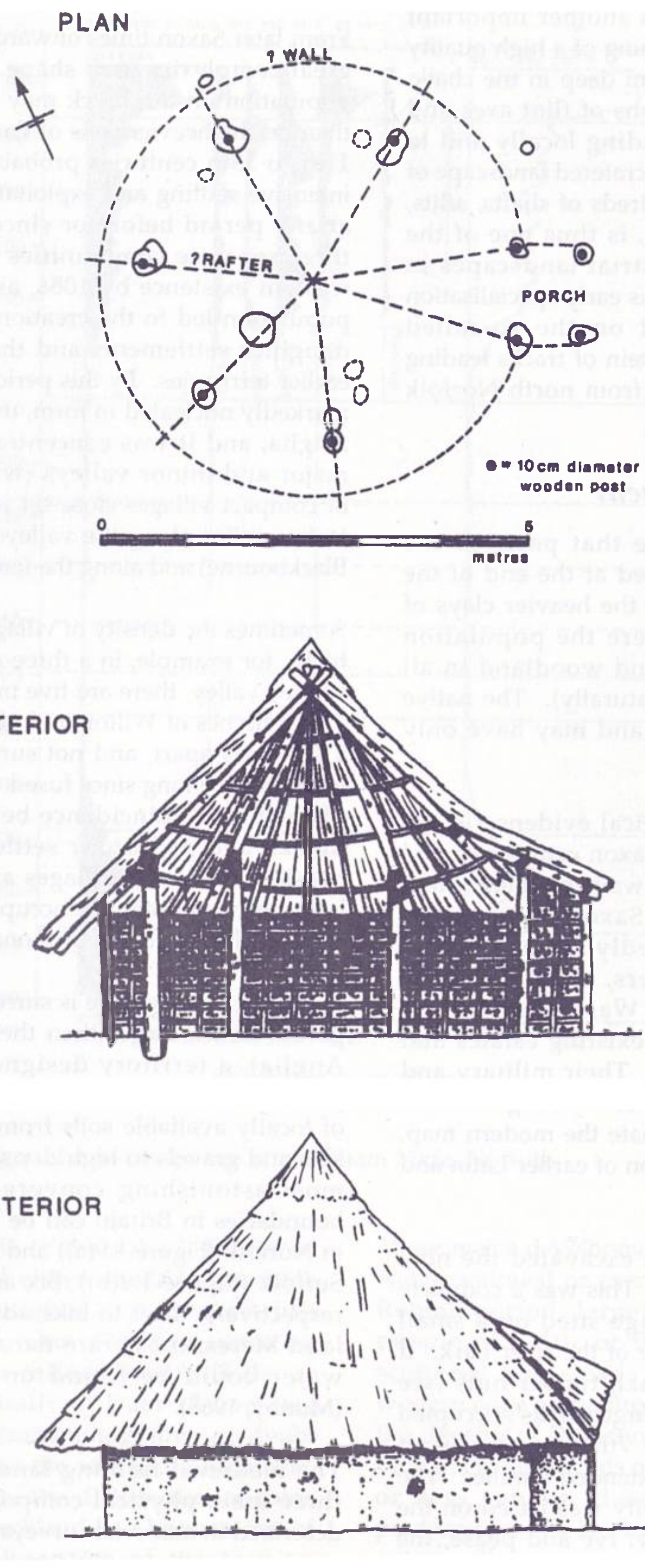

Figure 1.8 Timber hut of 2000-1500 BC, excavated in 1982 at West Row, Mildenhall, Suffolk

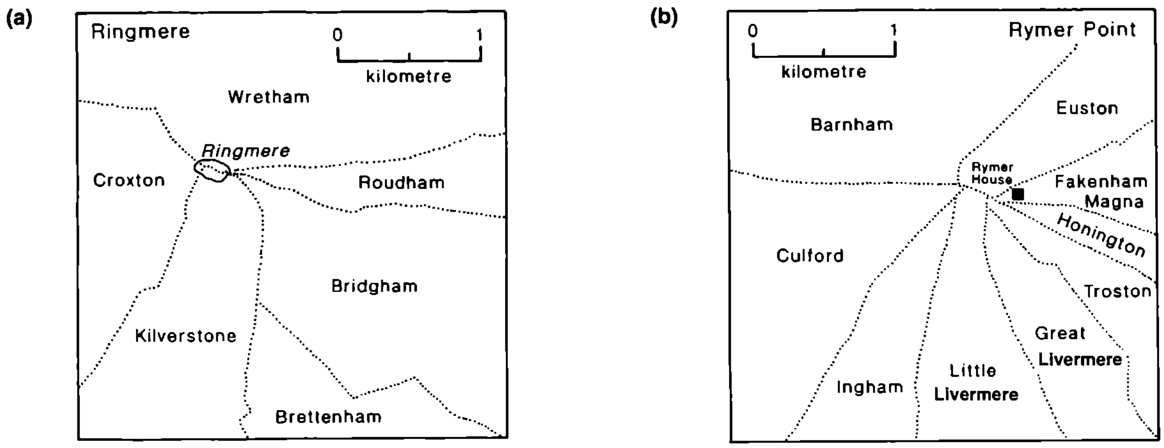

Figure 1.9 Two Breckland Mere and related parish boundaries: (a) Ringmere, Norfolk, (b) Rymer Point, Suffolk

1764 John Kirby referred to most delicious Champayn Fields' across a great sweep of western East Anglia, from Bury St Edmunds to King's Lynn.

- Second, on the poorer and generally higher soils of the Breckland, beyond these arable fields, were extensive 'commons' and heaths, the haunt of the bustard which became extinct in the 19th century and largely used for the grazing of sheep. These medieval sheep were ancestors of the later Norfolk sheep which were horned in both sexes, had black faces and legs, and grew a short but fine fleece.

- The third component, certainly in existence by the mid-13th century, comprised large turf-walled enclosures or warrens for the systematic breeding and farming of rabbits, usually situated in the higher and remoter parts of their parishes and containing a small defensive house for the warrener and his family to live in (Bailey, 1989).

On the lighter soils of East Anglia, and particularly on the Breckland, a special institution called the 'foldcourse' emerged to regulate the grazing of sheep on all kinds of land, including the arable fields after harvest and during fallow periods. This was the system whereby, in Eileen Power's words, 'the little golden hoof turned sand into rich soil'. More prosaically, Eric Kerridge referred to the sheep as 'animated muck-spreaders' (Bailey, 1990).

So buoyant was this medieval economy, in a so-called marginal area, that several major trading and marketing centres developed in it and around it, like Thetford, East Harling, Mildenhall and Brandon. Other places too, now regarded as no more than villages, once had weekly markets or annual fairs, such as Feltwell, Methwold and Market Weston.

Population decline and readjustment

The fearsome Black Death of 1349 was the first of many outbreaks of disease in the later 14th and 15th centuries which not only cut back the population but also reduced its basic fertility. At Northwold in the early 15th century, 43% of manorial tenants died childless and 47% left no sons. As a result, the pattern of human settlement was markedly thinned out as tenements were abandoned and villages shrank or became progressively deserted. Nowhere in East Anglia was this decline more obvious than on the Breckland. In 1940, while preparing to write a famous article on England's late medieval population, John Saltmarsh excitedly visited five ruined churches on the Breckland in one afternoon – with no more than a bicycle (Saltmarsh, 1941). Still today we see a high number of abandoned and ruinous churches as at Gasthorpe and Eriswell St Peter, and can see the archaeological evidence of shrunken and deserted villages like Wangford, Wordwell and Roudham. At Thuxton one farm now occupies the site of a sizeable linear village which once had over thirty tofts lining its main street (Butler and Wade Martins, 1989). Even where sizeable villages still survive today, as at Icklingham, frequent gaps in their streets indicate that they were once more populous and tightly packed. Not unnaturally, these demographic trends were accompanied by fluctuations of wages and prices and by major changes in the occupation of land and manorial administration.

However, there is another side to this coin. The decline of population from the 15th century onwards gave the survivors more space and offered unprecedented economic opportunities to those who were enterprising or had capital, particularly to landlords and major tenants or leaseholders. Gradually they were able to get more land under their direct control and to eliminate vestiges of earlier, more communal farming. At Sturston, a 16th century landlord called Edward Jermyn typically took over where the Black Death left off: he bought in land (including the parson's glebe), ploughed up former boundaries, seized control of the rector's foldcourse, converted commons to his own use and pulled down houses in the village. Policies such as these led to a steady weeding out of small owners and occupiers, already marked by the 17th century and accentuated in the 18th, and to the development of ever larger agricultural estates (Dymond, 1985).

At the top end of the social scale, local gentry and squires frequently built grand houses for themselves and laid out ornamental parks consisting of grassland, trees, lakes and structures such as boathouses and temples. By the end of the 18th century, the well-known maps of Faden and Hodskinson show the Breckland thick with parks, large and small, with large numbers of newly planted trees in the form of clumps, belts and coverts. For example, Sylvanus Bevan who purchased the Riddlesworth Estate in 1785, planted a million trees in his park and around his estate. Major houses and parks have indeed remained major features of the Breckland until modern times, even when in decline (Barringer, 1973; Dymond, 1972).

One of our best examples is at Euston where the modest holdings of the Rokewood family were by the end of the 17th century expanded into a great, aristocratic estate belonging at first to Lord Arlington and then to the Dukes of Grafton. The Elizabethan manor house was remodelled and extended into what contemporaries called 'a palace' in the French style; pleasure gardens and a huge park of about 1500 acres were laid out with the help of nationally known advisers like John Evelyn and William Kent; and the farming estate which was the economic base of the whole enterprise was expanded to cover at least eight neighbouring parishes. At Euston and elsewhere, the church now lying securely within the park is the only obvious reminder of the ordinary village and farming community which preceded the transformation (de Beer, 1959).

The new Breckland landscape

Against the background of lower population and increasing control by landlords, the Breckland witnessed a major phase of parliamentary enclosure in the late 18th and early 19th centuries. For example, in the Norfolk Breckland alone 49 Acts of Parliament were passed for the enclosure of 115 000 acres. This process, driven by agricultural economics and new ideas of efficiency, eradicated the old open fields and brecks which had frequently covered thousands of acres and led to the break-up of many of the heaths, commons, sheep-walks and rabbit warrens. Instead, there emerged a new planned landscape of large geometrical fields, defined by banks, hedges and tree-belts (usually of Scots pine), new plantations and coverts for the keeping of game, straight roads and tracks of standard widths, and marl pits where heavier soils enclosure had happened centuries earlier, usually in a much more piecemeal way (Dymond and Martin, 1989).

Today's inheritance

It appears therefore that the Breckland landscape of today is above all the result of *four* major phases of human endeavour: prehistoric clearance, Anglo-Saxon settlement, medieval settlement, and the emergence of major estates in the 17th and 18th centuries and parliamentary enclosure in the early 19th century. Of course, that is not the end of the story. To explain dramatic 20th century developments such as afforestation, the creation of military air-bases, or the designation in 1940 of the Stanford Battle Area which swallowed five complete villages and their territories, one must appreciate what happened to the farming industry after the great period of enclosure.

During the middle decades of the 19th century, a period of so-called 'high farming', the mixed agriculture of the Breckland remained reasonably profitable. Landlords, for example, were still investing in improvements such as new cottages, tree-belts and covered yards for cattle. Then the situation changed: from the late 1870s farming fell into serious depression as foreign grain (and later on, animal products) flooded the English market and undercut the home producer. As prices fell, so did incomes and rents. In an area of light sandy soils like the Breckland the results were particularly devastating: land was progressively abandoned, fields tumbled down to rough pasture or reverted to heath and farm buildings crumbled with neglect (Haggard, 1902).

Some farmers survived by diversifying into such crops as asparagus, blackcurrants, cabbages, sugar beet and lucerne, but by the early 20th century the Breckland was valued not so much for its farming as for its game and shooting. Some of the largest 'bags' ever made in England were recorded in the region during this period. On the Elveden estate described in 1902 as 'a game property where bona fide agricultural conditions did not prevail', the record year was in 1899 when the final count came to 103 392 head of game, including 21 053 pheasants. The biggest bag in a day came on 5 November 1912, when King George V, Lord Iveagh and three other guns killed 3247 head (Martelli, 1952).

Thus, in trying to answer the question 'Why Thetford Forest?', one must put heavy emphasis on persistent agricultural depression between the 1870s and 1930s, on the break-up of landed estates after the First World War and, above all, on the low price of land. This gave the Forestry Commission, a state-controlled body set up in 1919 and granted £3.5 million for its first ten years, an excellent opportunity. At very low prices it was able to buy and lease large areas of Breckland, much of it heath and abandoned arable, and to embark on the commercial production of timber on an unprecedentedly large scale. For example, in 1927, just before his death, the 1st Earl of Iveagh agreed to let 3000 acres to the Commission at a rent of 2 shillings and 3 pence per acre. Not surprisingly, by 1950, the Commission had created the King's and Thetford Forests on about 56 000 acres of the Breckland.

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Chapter 2

The history of the rabbit in Breckland

John Sheail and Mark Bailey

Summary

This study outlines the way in which the rabbit was introduced to, and conserved in, Breckland from the medieval period onwards. The impact of rabbit-keeping on the local economy and the effects of the marauding animal on the wider environment are assessed.

Introduction

In a sense, the Breckland landscape is very modern. Large-scale afforestation dates from the inter-war years. The Stanford military training area was established in the Second World War, and the designation of land for nature reserves is a post-war development. In another sense, these forms of land-use represent only the latest phase in a long history of land-use and management that has taken close account of the distinctive qualities of Breckland. It is the purpose of this chapter to relate the present to the past through the history of the rabbit.

While the Romans and their predecessors may have brought rabbits to the British Isles, the present population appears to be derived from stock introduced during the 12th and 13th centuries AD from Normandy and other parts of present-day France, Spain and the Low Countries to islands and coasts. Until the 18th century, the adult was called a coney, and only the young was known as a rabbit (in this study, old and young alike will be referred to as 'rabbits'). For the greater part of their history, the animals were largely confined to 'coneygarths' or 'coneywarrens', where they were conserved for their meat and fur (Sheail, 1971).

When rabbits were introduced, Breckland was an infertile and largely treeless region, dominated by vast tracts of heathland. Because the agricultural history of Lowland England has been written largely from the perspective of cereal cultivation, modern historians have tended to view Breckland as a 'marginal' region. The history of the rabbit reveals that heathlands have at times been regarded as a valuable resource. During the medieval and post-medieval periods, they were consciously managed for rabbit farming and for such purposes as fuel gathering. The rabbit in turn helped to conserve the heathland. It grazed close to the ground, loosening the light soil and increasing its infertility, thus creating a unique habitat within which the species characteristic of heathland, such as stone curlews, wheatears and the spiked speedwell, could flourish.

An optimal use of land: the medieval rabbit warren

We know desperately little about the way in which the rabbit, during its 800-900 year sojourn, has adapted genetically to the British environment. The medieval animal may have been significantly less resilient to the damp climate, and therefore even more averse to water-retentive clays and loams. The deep, porous sands, low rainfall and undulating heathlands of Breckland would have been a much more suitable habitat, particularly as those self-same conditions made the land marginal for crop-growing. In 1563, a lease for Brandon warren noted how it was 'very Wyde and Large but of very Baren Soyle and nevertheless very good for brede of Conyes'.[1] Far from being a subsidiary or peripheral activity, the conservation of the species may have represented the most valuable use of the land.

Rabbit-keeping did not simply develop in the absence of alternative uses for the land: it was a dedicated and skilled business. The warrener might be the highest paid manorial officer. For much of the year he worked alone, guarding the rabbits against both predators and hunger. At times, poaching made it a dangerous job, and hence a wooden watchtower was erected on Lakenheath warren in 1365, and a stone lodge at Methwold in 1413. Considerable discretion had to be exercised over the numbers to be culled for their meat or fur (or both) so as to maintain sufficient breeding-stock, and leasees for Swaffham warren had to leave it 'sufficiently stocked' on pain of a penalty of £10. Yet the warrens were still vulnerable to devastation by disease. In 1483, the Methwold warrener was pardoned the year's rent because of 'murrain' amongst his animals, and in 1491 a further £11.1.5d was allowed due to 'a great mortality in the winter'. In 1435, £5 had been spent on restocking and another 60 live animals were bought in 1439, while gorse had to be specifically planted as winter feed in 1437 (Bailey, 1989).

Prior to the Black Death of 1349, rabbit production was a distinctly low input-output concern. Cullings varied widely from year to year, but seldom exceeded a couple of hundred. A net financial loss in many years meant it was essentially an indulgence enjoyed only by the wealthy for their household consumption. The drastic fall in the human population in the late 14th century and the reduced pressure on the land for basic foodstuffs brought about a remarkable change in fortunes. On the one hand, the grain market collapsed and arable cultivation contracted severely. The occasionally cropped 'outfield' of Oxwickfield in Brandon became permanent warren pasture. On the other hand, there was also more incentive to keep rabbits where labour costs were low compared with grain farming. Because cullings could be sharply increased without a big rise in labour inputs, unit costs might actually fall. The rise in human living standards and purchasing power induced changes in taste and fashion. The eating of rabbit meat and wearing of rabbit fur descended the social scale. The fur of the most common rabbit, the common grey, was used for warmth, and that of the silver-grey and black rabbits for fashion (Bailey, 1988).

The commercial rabbit warren may be regarded as an unlikely, but successful, growth industry in the 14th century which presented a wide range of employment opportunities. Skinners and barkers were prominent in Thetford and Bury St Edmunds, and were also located in many smaller settlements. Yet, with other late-medieval 'growth' industries, there may eventually have been a tendency to over-supply. Prices fell from their peak of 4d to about 2d per animal for most of the 15th century. A concurrent rise in wages and transport costs must have resulted in lower profit margins. On many manors, however, rabbits remained the largest single source of income at the end of the Middle Ages, thus maintaining their relative importance in the region's farming.

The early-modern rabbit warren

Whatever their views on the incidence and timing of an Agricultural Revolution, historians of the post-medieval period have tended to portray innovations in farming as a response to economic malaise. Writing of the period 1660-1750, E.L. Jones described how falling grain prices encouraged farmers to introduce legumes and root crops to crop rotations on the light, fertile and well-drained soils of East Anglia (Jones, 1967). However, such a course of action was not open to farmers on the very light or very heavy soils. For those in Breckland, the solution was to increase further their dependence on the rabbit. While Adam Speed suggested resort to turnips, clover-grasses, potatoes, liquorice and saffron, it may be significant that his book, *'Adam out of Eden, or an abstract of diverse excellent experiments touching the advancement of husbandry'*, begins by advocating the 'improvement of ground by rabbits' (Speed, 1659).

Rabbit warrens were not perceived as something inimical or separate from the advances made in post-medieval farming (Sheail, 1978). By the 18th century, up to 15 000 acres of Breckland may have been occupied by warrens. There was as much concern for the well-being of the rabbits as for any other livestock. A prospective tenant at Sturston insisted on the inclusion of the warren in his lease, and his landlord demanded that he should leave a breeding stock of 1400 dozen rabbits at the end of the tenure, together with 90 hectares of summer ley for the sustenance of the next tenant's cattle, sheep and rabbits. It was considered part of the Grand Design of Nature. As Richard Parkinson asserted in his

Treatise on breeding and management of livestock, published in 1810, 'the land was given to man for his use and amusement, with plants and animals proper for his benefit and support'. As part of that Design, 'there are many thousand acres of land in this Kingdom that Providence seems to have appropriated to the breeding of rabbits' (Parkinson, 1810).

The warren constituted an outstanding example of how the advances and successes in one sector or region of farming could confer benefits on another. Rabbits benefited as much as sheep from the introduction of new crops and rotations to the better ground. As soon as the bottleneck of too little winter fodder for the farmstock was removed, rabbits could be given the hay previously reserved for sheep. In 1722, the tenant of Elveden warren ploughed up and planted 12 acres of the outfield with turnips, which were grazed by rabbits until the following 20 March. Perhaps as a further step towards sustaining higher numbers of rabbits, the warrens at Lakenheath and Eriswell in the 1740s were covered with marl for the first time, in order to prevent the 'blown up sands' from being further impoverished and eroded (Crompton and Sheail, 1975).

The marauding rabbit

If the history of the rabbit highlights the resourcefulness of landowners and occupiers in responding to the constraints of arable husbandry, so too does it draw attention to their failure and incompetence in preventing the rabbit population from damaging other forms of land-use.

Animal husbandry had evolved out of the integrated use of the three habitats characteristic of Breckland, namely the few tracts of arable, the meadows along the shallow valleys, and the extensive grass-heaths. The interdependent nature of this system was demonstrated by a lease of 1662, whereby the landlord undertook to provide his tenant with '360 wheather lambes wheather hoggs or wheathers which shall be foulded in seasonable wheather and convenient times of the yeare yearely', and the tenant covenanted not to 'sowe the arable landes . . . disorderly or out of course and thereby hinder the ffeede of the sheep belonging to the fouldcourse' of the landlord.

Whereas sheep provided landlords and tenants with the opportunity of integrating those three types of habitat, rabbits made it possible to exploit the heaths even more intensively. There is evidence that, as the rabbit population acclimatised to its new surroundings and grew so dense, it began to disrupt the prevailing pastoral economy. While normally gregarious, the rabbits left the warren more often as food ran out and such stress developed as to lead to a breakdown in the animals' normal behaviour. An inquisition at Methwold in 1522 declared that 'much of the Corne of the said londe is distroyed yerely with Conyes which be so greatly encreased' (Postgate, 1961). At Freckenham in 1551 rabbits were described as 'increasing and multiplying on the common land'. A lease for Brandon warren in 1589 commented on the 'growth and renewal' of stock outside the warren.

The damage caused by the marauding rabbit narrowed the options available to landowners and occupiers during periods of high grain prices, and tilted the Breckland economy further towards pastoral farming. When economic conditions were favourable, farmers sought to increase the area under cereal cultivation by 'annihilating' the warrens and placing 'the whole country under tillage' and plantations. Yet the rabbit was by now too well established for these options to succeed. William de Grey, the first Baron Walsingham, complained in the 1770s of how the expense of improving is much greater than is generally understood' (Sheail, 1979).

The success of rabbiting further restricted Breckland's potential as an arable farming area. Consequently, a multiple form of land-use evolved, where the intention was to use each part to its optimum, whether for grain crops, plantations or rabbits. This soon led to even greater frustration and expense as the rabbits destroyed crops and saplings, even where fences were erected. When a farmer offered an area of Sturston for tree-planting, the bailiff warned of how 'there is a greate hazard of theire being destroyed by the rabbits and so there is all over the premises'.

Even where the warrens were displaced by cultivation and woodlands, some rabbits survived. By the 18th and early 19th centuries, viable breeding colonies could survive in a feral state. The presence of root crops, clover and an early 'bite' of grass made it easier for some animals to survive late winter and early spring. Game preservation led to the large-scale destruction of natural predators, which might otherwise have eliminated, or at least checked, the growth of the initially small feral colonies. More significantly, sportsmen actively conserved the animals so as to increase the size of their game bags.

It was through the exploitation of the wild rabbit, as part of a wider interest in game preservation, that many Breckland estates survived the 19th century and particularly the period of agricultural depression that lasted, almost without break, from the 1870s until the late 1930s. For all the problems it created for farmers, the rabbit provided economic diversification, which bolstered Breckland's resilience to the depression. The most famous sporting estate was that of Elveden Hall, which included Eriswell, Wangford and Lakenheath. It was purchased by the Maharajah Duleep Singh in 1863. His bag for a season could include 9600 pheasants, 9400 partridges, 3000 hares and 75 000 rabbits (Turner, 1954). In 1894, the first Earl of Iveagh bought the estate and managed it entirely for game. Farming became an adjunct to the shooting (Martelli, 1952). By 1909, half the estate consisted of warrens of 'wild' rabbits. They had become so well established that their abundance was turned to good advantage.

It was the annual harvest of *wild* rabbits that now sustained the local industries, based on the processing of their fur. A cottage industry became increasingly factory-based. The Hatter's Furrier Company had been founded in 1790, and was joined by another, S.P. Lingwood, at Brandon in the early 19th century. In his field notebook for the Brandon and Icklingham district (1877), the geologist, S.B.J. Skertchley, made detailed notes of the processes employed. In the pulling room, the skins were chalked 'to keep the fur down', carded, 'pulled' so as to remove the hairs, 'carrotted' with a composition of 'secret character' which was rubbed into the fur, and then left to dry. A machine invented in Brandon, and driven by an 8 horsepower engine supplied by Burrell of Thetford, brushed and pared the fur from the skins, which were then shredded. It could process six times as many skins as by hand. Girls were employed as 'lookers' to sort the fur into its five different types, the most important being the dark brown central portion of the back. Each type was packed into paper bags weighing 5 lbs each, marked and arranged in crates or cases. Nothing was wasted, much of the felt being sold to the cloth districts for sizing, or used in the manufacture of glue. The annual stock of some 200 000 dozen skins taken in by early spring, together with imported skins of the hare and beaver (or musk rat) provided employment for up to 400 hands.[2]

Conclusions

There has clearly been no precedent for the role of Government and statutory bodies in determining the use and management of land since the 1920s. In Breckland, a state forest has been laid out, military training facilities imposed, and tracts of land acquired or scheduled for nature conservation purposes. The motives have, however, much deeper roots, namely to exploit the distinctive opportunities afforded by a region which has always been marginal for arable farming.

Not only would it have been difficult, if not impossible, to accommodate the extensive sheepwalks, rabbit warrens and sporting estates on the more fertile parts of lowland England, but, paradoxically, it was the very qualities which made Breckland unsuitable for cereals that made the region so important for these other uses. As Mortimer commented in 1721, 'Rabbits are very profitable creatures for their great increase and their being kept on dry barren sand or gravel that will maintain nothing else, which the dryer 'tis the better for them' (Mortimer, 1707).

If the story of the rabbit in Breckland draws attention to the resourcefulness of generations of land users, so too does it highlight the penalties of incompetence in land husbandry. Historians of the Great Plains of America and other marginal lands for farming have emphasised how nature deals harshly with ill-conceived and poorly resourced 'improvement' schemes. While the rabbit brought wealth to Breckland, a failure to prevent its spreading from the warrens caused it to become a pest, which significantly reduced the scope for landowners and occupiers to turn to other forms of husbandry.

There are lessons too for the conservationist. It is not enough to designate reserves and schedule sites as a means of preserving heathlands. Their characteristic species may still disappear as the vegetation becomes lush with perennials and rank grasses. The reserve areas may be over protected from disturbance. If the species of the open heath are to survive, ways must be found of reintroducing what was historically the 'shifting mosaic of disturbance' that arrested plant succession (Dolman and Sutherland, 1991). The grazing, scraping and burrowing effect of the rabbit was important in halting successional change in the days before myxomatosis. There is mounting evidence that the rabbit is an important management tool for the management of heathland habitats. The rabbit may be an alien species, but its 800-900 year sojourn has given it a prominence that few other wild species enjoy.

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Chapter 3

Thetford Forest: its history and development

Norman Dannatt

Summary

The history of the effects of man on the area we know as the Breckland has been well researched and documented. The objective of this chapter is to describe briefly how 20th century foresters tackled the challenge of creating a forest on this very poor abandoned agricultural land.

Introduction

The Forestry Commission was formed in 1919 following the recommendations of a Parliamentary Committee chaired by Sir Richard Acland. The objective was to create a strategic reserve of timber for use in the time of war or other national emergency. At that time much of the woodland had been devastated to provide timber for the First World War and the overall area of woodland (including woods and forests felled for the War effort) covered a little under 5% of the land surface of Great Britain. This figure is currently (1995) just over 10% but it still compares unfavourably to the major EEC countries, France, Germany, Italy, Spain, each of which has between 23% and 31%.

The marginal agricultural land in the southern part of Norfolk bordering Suffolk, known locally as the Brecks, was offered to the newly created Forestry Commission for tree planting. The area had rarely enjoyed agricultural prosperity: the soil, being mostly sand overlaying chalk, was very poor and liable to wind erosion. The principal value of the estates in this area was for sporting and at that time there was no market for sporting estates because shooting was readily available for rent. At the turn of the 19th century the Breck enjoyed a period of agricultural prosperity and many of the windbreaks or shelterbelts of Scots pine were planted at this time. However, the agricultural depression following the Napoleonic Wars saw a steady decline in cereal cropping and later in stock rearing so that by the time of the First World War much of the land was covered with rough grass and heath vegetation. The depressed state of agriculture led to some estates falling into the hands of speculators who liquidated the assets and then offered the land to the fledgling Forestry Commission. Other estate owners/executors wished to realise their assets and so many large areas were offered. At that time more land was available than the Forestry Commission had funds to buy.

Contemporary description showed the sorry state of the land: fields were uncultivated, little or no stock was kept, they were overrun by rabbits (see Sheail, Chapter 2) and in many areas the unstable sandy soil had formed sand dunes. Nearly 59 000 acres (some 23 000 hectares) were acquired between April 1922 and February 1939, of which about 75% was bought and the remainder leased, usually for 999 years. Over 400 acres (162 hectares) were planted in 1922, and in the years following the annual planting programme rose to a peak of over 4000 acres, in 1927, and then fluctuated between 1000 and 2000 acres until the late 1930s. There was a considerable reduction during the Second World War but the rate increased in the late 1940s, finishing with a flourish of over 6000 acres (over 2400 hectares) in 1950. The total area planted amounted to nearly 45 000 acres (18 000 hectares), the balance of the land being farms, forest workers holdings, nurseries, etc.

The topography of the area is gently undulating with shallow river valleys with some associated fen/carr wet areas, but the vast majority of the area is overlaid with sand which gives rise to soils varying from deep acidic to shallow alkaline over the underlying chalk. Some of the soils in the east of the area have a small clay content and are slightly richer. Many areas were 'marled', especially during the early 19th century, and these are also alkaline. The area experiences high winds and an almost continental climate with high summer and low winter temperatures. Frosts occur every month of the year and the average rainfall is only about 24 in (610 mm).

Tree establishment methods

The basic methods of establishing trees on these soils has not changed greatly over the years. Initially the first priority was to rabbit fence suitably large areas, 100 to 500 acres, from which the rabbits were then cleared. Thereafter a planting position was prepared by a plough. From the earliest planting it was recognised that the vegetation growing on this derelict dry farmland, mostly grasses, would compete with the trees for moisture and should be removed. Shallow mould board screef ploughs, some single and some double throw, were used and within 5 years a twin plough to give two planting furrows at one pass was developed. The planting distance was 4.5 ft x 4.5 ft (1.37 m x 1.37 m) and the normal method was the L notch using 2 or 3-year-old planting stock. Plants were raised in local Forestry Commission nurseries.

Species choice

The detailed considerations given to the choice of species makes fascinating reading.

Conifer species

Evidence from previous and existing woodland clearly pointed to Scots pine as the most successful species to be grown in these dry, sandy conditions. It is frost hardy, easy to establish, and produces a moderate volume of good quality timber. Over the years a number of disadvantages have been discovered, the major ones being susceptibility to the Fomes root/stem rot (*Heterobasidion annosum*) especially on the alkaline sites, and to the stem rust (*Peridermium pini*) fungus (see Gibbs *et al.*, Chapter 4). Scots pine is attacked by a variety of insects but none has been of the same order of economic significance as these two fungi. A series of trials was begun in the late 1920s to discover the best origin of Scots pine for planting in East Anglia. Plants were raised from seed collected from five native sources including East Anglia and Deeside, and from 15 European sources including the Balkans, Italy, France, central and eastern Europe. The origin which performed the best in terms of height growth and stem and branch form was the local East Anglian strain; the Deeside strain also performed well. According to geneticists, this result would argue that the strain had been present in the locality for millennia, that is, since the last Ice Age, but this view is not supported by some authoritative botanists. There are other strands to this argument; in East Anglia there are a small number of beetles associated with a dead pine and conifer wood which are rare and have such slow dispersal rates that it is likely that they are remnants from the post-glacial era when pine was dominant (but see Welch and Hammond, Chapter 9). How have these beetles survived if not on remnants of pine? There is also evidence of pine charcoal from Grimes Graves and of pine wood being preserved in the Fens, notably from Huntingdon Fen. These records indicate that pine may have been present in the region long after it became extinct in the majority of southern England. Furthermore, the detailed analysis arising from attacks of the stem rust fungus showed that the strain of this fungus is not the same as that found in Scotland, but is similar to the European strain. This fact may also indicate that there has always been an East Anglian strain of Scots pine since the last Ice Age: an intriguing conundrum.

Scots pine has not only provided the major part of the initial timber crop but it has also provided the habitat for such animals as the red squirrel and crossbill through its consistent and generous seed production. Incidentally, this property will ensure the continued presence of Scots pine through natural regeneration.

Although Scots pine was the most obvious species to plant on these infertile sandy Breck soils the early foresters laid down experiments in 1927 to determine the best species for the conditions. A number of pine species were included: Scots (*Pinus sylvestris*), Corsican (*P. nigra var. maritima*), maritime (*P. pinaster*), Lodgepole (*P. contorta*), western yellow (*P. ponderosa*), Weymouth (*P. strobus*), Monterey (*P. radiata*); other conifers were the two larches, European (*Larix decidua*) and Japanese (*L. kaempferi*), Douglas fir (*Pseudotsuga menziesii*), the Californian redwood (*Sequoiadendron giganteum*), Monterey cypress (*Cupressus macrocarpa*), Lawson cypress (*Chamaecyparis lawsoniana*), cedar (*Thuja plicata*), and at least one silver fir, the European silver fir (*Abies alba*). Broadleaved species were also represented with both the oak species, sessile (*Quercus robur*) and pedunculate (*Q. petraea*), plus the American red oak (*Q. borealis*), beech (*Fagus sylvatica*) and sycamore (*Acer pseudoplatanus*). Of these 20 species only 7 could be described as being successful. These were four pines: Scots, Corsican, Lodgepole and western yellow, the two larches, European and Japanese, and Douglas fir. None of the broadleaved species was successful.

From the earliest plantings Corsican pine was favoured as the better species because of its superior form and growth potential. Initial trials of direct sowing of seed and using transplants gave variable results and because this species is more susceptible to frost damage than Scots pine the latter was favoured locally. There was a general feeling, not supported by fact, that the timber of Corsican pine was inferior to Scots pine. It was not until the 1960s when the strength qualities of Corsican pine were shown to be similar to Scots, and it also became clear that Corsican pine was more resistant to both the root/butt rot and stem rust fungi (see Gibbs *et al.*, Chapter 4) and also less susceptible to insect attack, that this species became dominant. Although Corsican pine is a little more difficult to establish than Scots, this has been overcome by current techniques using container grown plants and careful weed control. In the early 1930s some bad seed lots were imported and by 1936 this rough, heavily branched, coarse type had been recognised (called ursuline) and the seed source identified as undesirable. Otherwise there are some very finely branched vigorous stands in Thetford from which seed is now harvested and used for current restocking programmes.

Lodgepole pine, although successful in the experiments, was never favoured over either Scots or Corsican, it was easier to establish than Corsican but slower growing and this has proved to be the case where many of the trial plots have shown an annual growth rate less than Scots pine. The western yellow pine has been a strangely neglected species, the early trials showed that it was slow to establish but then grew quickly. One of the earliest experiments compared six sources, all of which gave acceptable growth rates. This may be a species which could add an element of diversity in the future.

Neither of the two larch species has grown particularly well, both the alkaline soil and the dry climate are unsuitable to their optimum growth. In particular, both are more susceptible to the fomes butt rot fungus than either of the two major pine species. The species are, however, favoured by one of our rarest raptors, the goshawk. Larches being deciduous conifers give colour diversity in the spring and the autumn and so it is likely that for these two reasons that they will continue to be planted in small quantities.

On the deeper soils, Douglas fir (the green variety) has grown well and in spite of the seed destroying insect (*Megastigmus spp.*) natural regeneration has been successful. The major problem with Douglas fir is that it is difficult to establish but on the correct site it merits consideration both from the viewpoint of its superior timber qualities and the diversity it adds to the forest.

Broadleaved species

Broadleaved species were considered by early foresters to be the 'natural climax' for the area and beech was thought to be the most likely candidate. However, it was recognised that the climate of the region was very unfavourable to the establishment of beech. It was too dry and too frosty. In consequence, it was thought that the best way to establish beech was by using larch and Corsican pine as nurses and in 1926 and 1927 some 1600 acres were planted with these mixtures which represented about 25% of the total planted during those years. By 1929 these large scale plantings were seen to have failed and it was decided to conduct a series of experiments to discover the best methods to successfully establish beech before such large scale plantings were repeated. These experiments continued for the next 12-15 years but the combination of frost, summer drought, competition for moisture from the nurse crops and damage from browsing animals (rabbits, hares and deer) continued to thwart the original intention. It was also noted that there were no particularly good origins of beech, all seemed to fare badly in the Breckland conditions. Beech remains a component of the forest but the recent advent of the grey squirrel does not bode well for the future well-being of this species (see Gurnell, Chapter 13).

Oak was only occasionally planted prior to 1930 but in 1931 this species was planted on a 'large scale'. Several hundred acres were planted on the better agricultural soils using a method prescribed by Dr H.M. Steven (a Research Officer in the Forestry Commission, later to become Professor of Forestry at Aberdeen University). Six oak were planted, 1½ ft (0.5 m) apart, followed by a Scots pine nurse; that is, the nurses were 9 ft (3 m) apart. The Scots pine in adjoining lines were staggered to form diagonals across the plantation. The intention was to remove some of the pine when the oak had grown to 6-9 ft (2-3 m) and replace with beech. The prescriptions were not followed through because of the labour shortages in the Second World War, although post-war much of the pine was removed to leave almost pure stands of poorly grown oak. By the early 1960s these stands had not improved and they were considered a failure and were replaced with pine. No difference was detected in the rate of growth or quality between the two species of oak and even on the better soils it was anticipated that there would be a high proportion of degrade in the timber through star and ring shake.

The American red oak was planted in some of the hardwood belts and in some situations it has grown better than either the native oak or beech. However, red oak has not been planted extensively and is not likely to be in the future because of its poor timber qualities.

Birch has not grown well; it is a difficult species to establish by planting. It was planted to form fire breaks and as a nurse for beech. Surprisingly there have not been any great quantities of natural regeneration. Generally the form and quality of the main stem is poor. Grey alder likewise has produced disappointing results.

Poplars have been planted on a variety of sites, mostly in the river valley 'water meadows' and on Fen soils. None has grown particularly well and many of the clones have suffered from canker attack. Some stands have become unthrifty due to waterlogging. A number of the recently introduced Belgian clones may give better results in the 1990s but generally poplar thrives on more fertile soils. It may be that poplars will be retained to provide habitat for the golden oriole.

From this brief summary it can be seen that very careful consideration was given to the choice of species and that the expectation of a large proportion of the forest becoming dominated by broadleaved trees was not realised because of the very poor nature of the soil and the harsh climatic conditions.

The normal tending operations following planting, that is weeding and cleaning, have been neither difficult technically nor expensive. Hand methods have been succeeded by herbicides applied in very small quantities by tractor mounted sprayers. Indeed, we are now using these techniques on an experimental basis to conserve the habitat for woodlarks in situations where it would be unnecessary for the establishment of trees.

Protection

Protection of the trees from damaging mammals, rabbits, hares, deer and now grey squirrels has been necessary from the first planting in 1922. In the mid-1950s myxomatosis almost eliminated rabbits and so reduced protection costs but they have since become more immune to the disease and active measures are now necessary in some areas. Deer have become much more numerous with the increased areas of available habitat. Both the native species, red and roe, are present together with fallow and muntjac (see Chapman and Whitta, Chapter 14). Muntjac do not cause serious damage but the grey squirrel, which invaded Thetford at about the same time, is potentially a much more serious threat to both broadleaved and coniferous trees.

Multi-purpose interests

Although the pine plantations grew well, none was old enough to provide any substantial quantities of timber to aid the First World War effort, nevertheless, ideas were being developed which laid the foundation for future thinning regimes. Simultaneously markets were explored and developed, beginning with the smaller dimensions for fencing, pitwood, hardboard, chipboard etc., then later the larger dimensions for the sawmilling industry. Thetford was the first large forest to adopt a system of sawlog grading designed to ensure a consistent quality both in terms of physical straightness, size and freedom from large knots and other imperfections. The annual production from the forest grew steadily to the current annual production (1995) of just under 200 000 m^3 at which level it is likely to stabilise for the foreseeable future. There have been a number of gales which have caused considerable damage, notably in 1976 and 1987, but their effects have been minimised by manipulating the clearfelling and replanting programmes.

The first substantial clearfelling programmes were carried out in the early 1960s and at this time considerable thought was being given to the second rotation, the first being regarded as a pioneer crop to establish the forest environment. Not only was there a requirement for a sustained output of utilisable timber to give employment both locally and regionally but there were also considerations of appearance both of the forest within the landscape and of the landscape within the forest. The general public were increasingly seeking access and being invited into the forests. More and more naturalists were showing an interest in both plants and animals within the forest and it is interesting to note that on 24 June 1943 Mr W.L. Taylor, the 'Commissioner with responsibility for East Anglia' met representatives of the Norfolk, Suffolk and Cambridgeshire Naturalist Trust. Unfortunately, I cannot discover the subject of that meeting but it illustrates the interest.

When I first visited and worked in the forest in 1962 I was shown the site of the military orchid which had been protected by surrounding it with a barbed wire fence; it was being managed with agreement by the Suffolk Trust (see Harding, Chapter 6). In 1963 on the first large-scale clear felling area at Redneck (an area to the south-west of Thetford town) we were excited to see the stone curlew nest. Unfortunately, this was the first and last occasion, but it demonstrated that there were opportunities ahead.

Conclusions

The history of the creation of Thetford Forest can be summed up as the dedicated response by foresters to the clear political will and the targets set by Parliament through the very turbulent era following the First World War, the depression in the 1930s to the Second World War and its aftermath. Over 30 years ago, to my personal knowledge, foresters began discussing and planning for the second generation of trees in the forest habitat which their predecessors had created. They recognised that there was a whole range of opportunities which were not available to the original pioneers and much of the subject matter of this publication stems from that recognition. We have created a fascinating ecosystem. We shall discuss and argue how best to manage that ecosystem to give a maximum diversity and benefit, and even in 100 years time our successors will question our decisions today just as we question the decisions of the early foresters who created the forest.

Chapter 4

Tree diseases of Thetford Forest and their influence on its ecology and management

John Gibbs, Brian Greig and the late John Rishbeth

Introduction

Since the late 1930s tree diseases of one kind or another have had a significant influence on the forest. Diseases have influenced choice of tree species, stocking densities, rotation ages, felling practices and replanting policies; and these in turn have affected the forest as a habitat for flora and fauna. This chapter briefly describes the most important biotic and abiotic diseases of Thetford Forest and considers their impact.

Fomes root and butt rot

This disease, caused by the wood-rotting Basidiomycete *Heterobasidion annosum*, was first noted in the young Scots pine plantations in the years immediately preceding the Second World War (MacDonald, 1939), although at that time it was considered that the fungus was probably secondary in importance to drought or waterlogging (Day, 1946, 1948). The first detailed research was that conducted in the period after the war, and from this it was established that *H. annosum* was acting as a very effective pathogen and that climatic factors such as drought had but little part to play (Rishbeth 1950, 1951a, b). Moreover it was established that the fungus was entering stands when airborne basidiospores, produced some distance away, infected and colonised stumps created during thinning operations. The stumps then acted as infection foci, with the fungus spreading from stump to adjacent living trees at points of contact between their roots (Figure 4.1). This resulted in the appearance of circular groups of dead trees which enlarged over the years until, at 40 to 50 years old, some of the crops were very open and under-stocked. A survey of the pine plantations by Wallis (1960) showed that by this time economic loss in the worst affected areas could exceed £50 per hectare (*c.* £575 at 1995 prices) over a 5-year period after thinning. It was soon realised that soil conditions had an important influence on the rate of disease spread, losses being much less serious on former heathland acid soils than on naturally chalky soils or on soils that had been marled during former agricultural use (Rishbeth, 1951b; Wallis, 1960). The cause of the soil effect has never been fully elucidated but it seems to depend, at least in part, on the greater antagonistic activity towards *H. annosum* shown by the microflora on root surfaces in acid soils than in more alkaline ones (Rishbeth, 1951b; Gibbs, 1967).

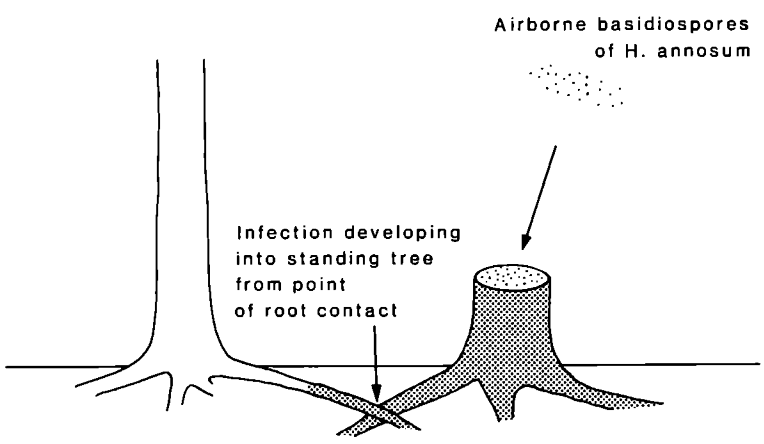

Figure 4.1 Diagram to show the process whereby *Heterobasidion annosum* enters a stand of first rotation pine

The vegetation under the closed canopy of young pine crops is very sparse, but in the openings on calcareous soils caused by *H. annosum*, more vigorous growth takes place. At first, *Holcus* and *Agrostis* grasses, willow herb, nettles and brambles are the main components, but with time, seedlings of sycamore, oak and ash appear, together with some volunteer Scots pine.

In order to reduce mortality, prompt treatment of pine stumps immediately after felling was introduced in 1952 for plantations on high risk alkaline sites and in 1954 for all plantations. Initially the material used was creosote, but, for more than 25 years, biological control with the fungus *Peniophora (Phlebia) gigantea* has been employed. *P. gigantea* is a native wood-rotting fungus that is capable of competing effectively with *H. annosum* for the tissues of freshly-created pine stumps but does not have the ability to attack living trees (Rishbeth, 1963). It is produced commercially in small sachets containing millions of asexual spores (oidia) and these are diluted with water before being applied to the stumps. This can either be via specially designed containers after felling by chain saw (Webb, 1973) or through a device attached to the cutting bar of a harvesting machine. *P. gigantea* fruits readily on the stumps, producing airborne basidio-spores which themselves can compete with *H. annosum* for stumps that, for any reason, do not receive the standard *P. gigantea* treatment. The rapid wood-rotting ability of *P. gigantea* means that care has to be taken not to leave pine logs lying in the forest as these quickly suffer degrade and loss of value.

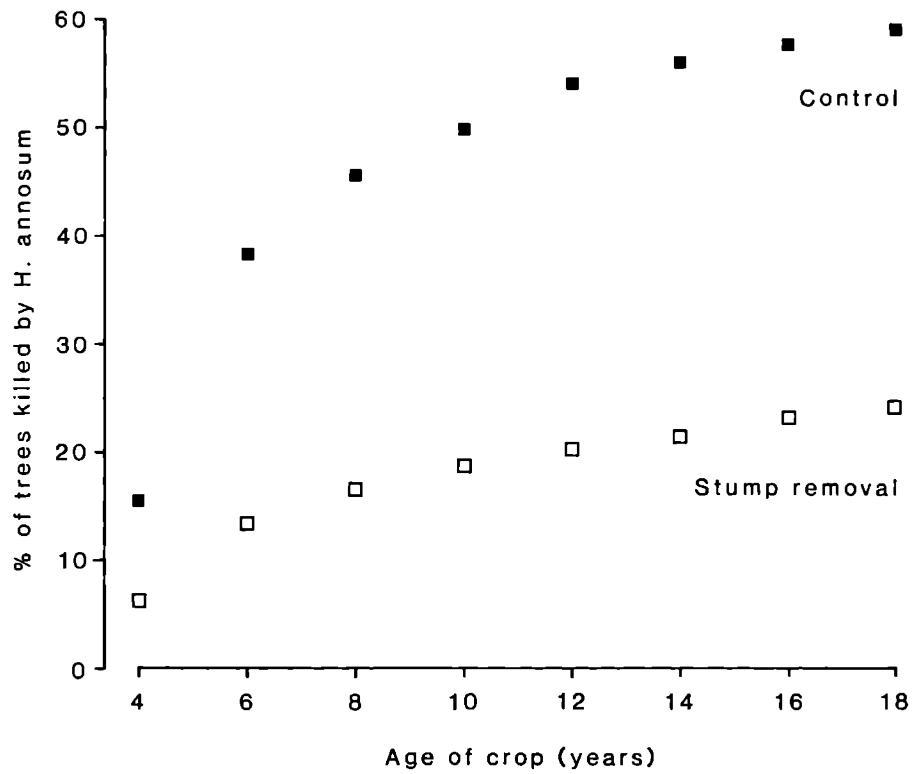

Figure 4.2 Data from an experiment conducted in the 1960s showing the effect of stump removal on losses caused by Fomes root rot in second rotation pine. With the better stump removal techniques used subsequently even lower losses were recorded

By the time stump treatment was introduced into Thetford Forest, *H. annosum* was already well established through much of the area, and because the fungus can commonly remain alive in infected stumps for up to 20 years (Greig and Pratt, 1976), this had a profound significance for the second rotation of pine which was planted in the years after 1970. On acidic sites deaths in these new crops were negligible, but on the more alkaline soils up to 70% of the trees died within the first 10 years (Figure 4.2). This had the effect of creating some areas of young pine which were heavily understocked, and contained quite large glades. Recognising the unprofitability of growing pine plantations in this way, the forest managers gave serious consideration to the idea of removing the stumps of the first rotation crops on alkaline soils before replanting. This technique had been shown to be effective through a series of experiments initiated by the Pathology Branch of the Forestry Commission (Greig and Low, 1975) in the years after 1956 (see Figure 4.2). Since 1972 some 1650 ha have been destumped. This involves the use of a hydraulic excavator, with the upturned stumps being pushed into windrows which initially are some 2-3 m high (Greig, 1984). They provide an unusual habitat for some of the forest wildlife!

Table 4.1 Incidence of Fomes butt-rot in various tree species planted on an acid soil after the felling of a Scots pine crop

Species	Percentage butt-rot[a]
Scots pine	0
Corsican pine	0
Western hemlock	36
Hybrid larch	46
Douglas fir	34
Grand fir	4
Beech	0
Red oak	0
Nothofagus obliqua	0

[a] Data based on an assessment of first and second thinnings in an experiment in the Old High Lodge beat of Thetford Forest.

Heterobasidion annosum has a wide host range. It has been recorded on 74 hosts (38 genera) including bracken, ling and bramble (Greig, 1976). Broadleaved trees are generally more resistant than conifers, although young trees of many species can be killed on chalky sites. Many conifers are principally affected not by killing but by butt rot, a condition in which a decay develops from the roots into the centre of the stem, thereby greatly reducing the timber value. Larch, spruce and hemlock are very susceptible to butt rot and this precludes their consideration as alternatives to pine for second rotation planting at Thetford. It should be noted here that even on the acid soils on which killing of pine does not occur, serious butt rot can develop in susceptible species (Table 4.1). Douglas fir, a possible alternative species in silvicultural terms, is moderately resistant to butt rot but suffers from root killing and subsequent windthrow.

Peridermium stem rust of Scots pine

Peridermium stem rust has also affected the ecology and management of the forest. This rust, caused by *Peridermium pini*, is unlike many rusts in being monocyclic, that is, spores from pine are able to reinfect pine directly. Artificial inoculation experiments have shown that wounds on stems of at least 8 cm in diameter can be infected, but in nature it seems that most infection occurs on very young shoots, possibly via the needles. The disease first becomes visible as a swelling on the shoot and then through the production of masses of orange aeciospores. The fungus develops within the shoot, both proximally and distally, at a rate of about 5 cm per year. Like all rusts, *P. pini* is a highly specialised parasite and can live in the cortex and outer wood of the shoot for many years without causing significant death of host tissue. Eventually, however, the affected tissues do die and, in time, this leads to the girdling and death of branches. If the fungus has progressed down a branch on to the main stem the top of the tree will eventually be girdled and die. The dying tissues on large branches and trunks are characterised by a massive exudation of resin, hence the alternative name: resin top disease.

In Thetford Forest, Peridermium stem rust was first recognised in the old Elveden Beat around 1940, possibly having spread from a pre-1904 plantation in Brandon Park. It subsequently increased in severity in the central part of the forest and also became more common in the outlying areas (Greig, 1987; Figure 4.3). By the early 1980s, forest managers were concerned that trees were dying so rapidly that the disease

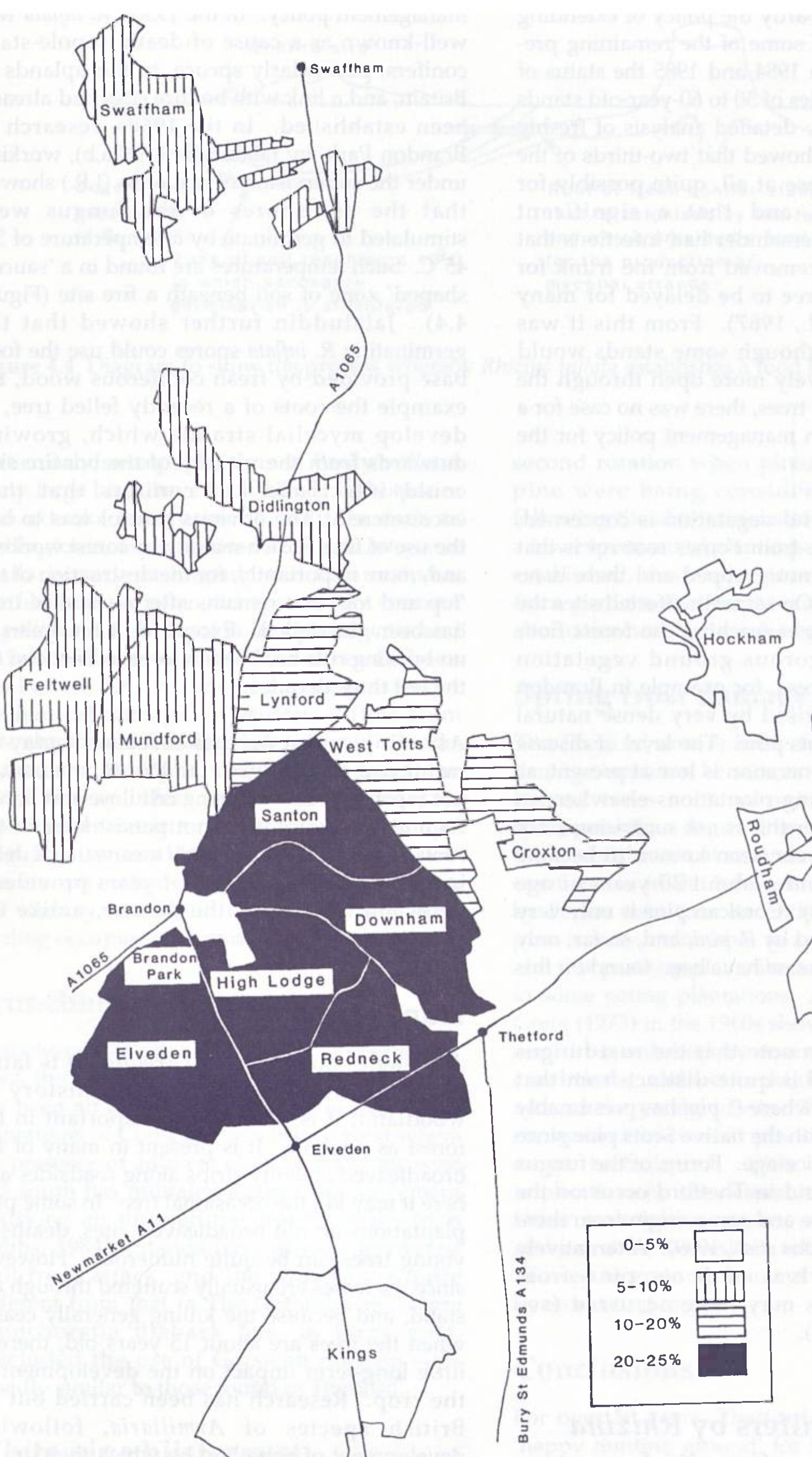

Figure 4.3 Map to show the incidence of Peridermium stem rust in 30 to 60-year-old Scots pine as of 1979

was putting in jeopardy the policy of extending the rotation age of some of the remaining pre-war Scots pine. In 1984 and 1985 the status of the disease in a series of 50 to 60-year-old stands was determined by detailed analysis of freshly felled trees. This showed that two-thirds of the trees had no disease at all, quite possibly for genetic reasons, and that a significant proportion of the remainder had infections that were sufficiently removed from the trunk for the death of the tree to be delayed for many years (Gibbs *et al.*, 1987). From this it was concluded that although some stands would become progressively more open through the death of additional trees, there was no case for a complete change in management policy for the old Scots pine.

As far as the ground vegetation is concerned, the chief difference from Fomes root rot is that the dead trees are not grouped and there is no effect of soil type. On severely affected sites the extra amount of light reaching the forest floor means that a vigorous ground vegetation develops. Some areas, for example in Brandon Park, are characterised by very dense natural regeneration of Scots pine. The level of disease in this natural regeneration is low at present, as indeed it is in young plantations elsewhere in the forest. However this is not surprising since the disease has never been known to become severe in crops under about 30 years of age (Murray *et al.*, 1969). Corsican pine is only very occasionally affected by *P. pini*, and, so far, only two cases of the disease have been found on this species in Thetford.

It is interesting to note that the rust fungus found in Thetford is quite distinct from that found in Scotland, where *P. pini* has presumably been co-existing with the native Scots pine since the end of the last ice-age. Forms of the fungus similar to that found in Thetford occur on the mainland of Europe and some origin from there seems possible (Gibbs *et al.*, 1989). Alternatively some local survival of Scots pine from prehistoric times may have occurred (see Dannatt, Chapter 3).

Killing of conifers by *Rhizina inflata*: the bonfire site fungus

Although the Ascomycete *Rhizina inflata* has never killed large numbers of trees in Thetford Forest, the threat that it might be a serious problem has had a significant effect on management policy. In the 1950s, *R. inflata* was well-known as a cause of death in pole-stage conifers, particularly spruce, in the uplands of Britain, and a link with bonfire sites had already been established. In the 1960s, research in Brandon Park, by Jalaluddin (1967a,b), working under the supervision of one of us (J.R.) showed that the ascospores of the fungus were stimulated to germinate by a temperature of 35-45°C. Such temperatures are found in a 'saucer-shaped' zone of soil beneath a fire site (Figure 4.4). Jalaluddin further showed that the germinating *R. inflata* spores could use the food base provided by fresh coniferous wood, for example the roots of a recently felled tree, to develop mycelial strands which, growing outwards from the vicinity of the bonfire site, could infect and kill conifers that they encountered. The obvious control was to ban the use of fires for tea-making by forest workers, and, more importantly, for the destruction of the 'lop and top' that remains after a stand of trees has been clearfelled. Except for a few years, a no-burning rule has been in force in Thetford for the last three decades.

As a final point on this disease, it may be mentioned that *R. inflata*, unlike *H. annosum*, is not capable of decomposing cellulose and lignin. As a consequence it cannot persist long in the roots of the trees it kills. This means that a delay in replanting of a couple of years provides a sufficient control for the disease, unlike the situation with *H. annosum*.

Honey fungus

Although honey fungus (*Armillaria*) is fairly common on sites with a long history of woodland, it is relatively unimportant in the forest as a whole. It is present in many of the broadleaved amenity strips along roadsides and here it may kill the occasional tree. In some pine plantations on old broadleaved sites, deaths of young trees can be quite numerous. However since the losses are usually scattered through the stand, and because the killing generally ceases when the trees are about 15 years old, there is little long-term impact on the development of the crop. Research has been carried out on British species of *Armillaria*, following development of a method by which they can be recognised in culture (Korhonen, 1978). In Thetford Forest, as in much of southern England, three species are commonly present (Rishbeth, 1982). *Armillaria mellea* attacks broadleaved trees, some species of which are

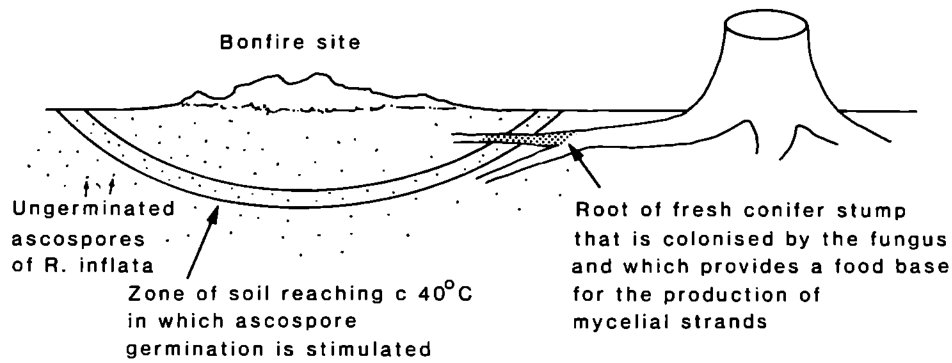

Figure 4.4 Diagram to show the process whereby *Rhizina inflata* establishes a food base in a forest site

particularly susceptible; thus in Emily's Wood many large birch have been killed. This species also attacks less resinous conifers such as Wellingtonia, as at Lynford Hall. *A. ostoyae* is similarly very pathogenic and kills resinous conifers such as pine and spruce. By contrast *A. gallica* (= *A. bulbosa*) is less pathogenic and mainly kills trees that have already been weakened, for instance by suppression or mechanical damage. *Armillaria* differs from *Heterobasidion* in forming differentiated strands, termed rhizomorphs, that grow through the soil and may infect roots of living trees or exploit other nutrient resources such as stumps. *A. gallica* generally forms more extensive rhizomorph systems than the other two species; one such system found in plantations at West Harling occupied an area of 11 ha.

Brunchorstia dieback

Brunchorstia dieback caused by *Brunchorstia pinea*, the asexual stage of *Gremmeniella abietina*, has been an occasional problem in pole-stage plantations of Corsican pine, being worst where the presence of adjacent older crops to the west and south has militated against the movement of drying air through the crowns of the trees (Gibbs, 1984). Stands have always recovered well from attack, and the situation is quite different from that in The Netherlands, where Brunchorstia dieback has, in large part, precluded the use of Corsican pine on sites broadly similar to those found in Thetford.

White pine blister rust

Another disease meriting mention is stem rust of white pine caused by *Cronartium ribicola*. Without the existence of *C. ribicola*, white pines such as Weymouth pine, (*P. strobus*) would have been strong candidates for extensive use in the second rotation when pines other than Scots pine were being considered. In practice, following the observations of Chard (1962), only a few experimental plantings of white pine were established, these being located at sites remote from gardens that might contain currants, the alternative host for this disease.

Spring frost damage

The Thetford area is liable to spring frosts and damage can often be seen on susceptible broad-leaved trees such as oak, beech, ash and sycamore. To a degree this damage must delay the establishment of secondary woodland in the open spaces in the forest, such as those created by Fomes root rot. Recently planted Corsican pine is very vulnerable to spring frost damage and this partly explains the low level of stocking in some young plantations. Work by Low and Greig (1973) in the 1960s showed how this effect could be reduced by maintaining bare soil conditions, and hence higher temperatures, around the young plants. The value of this is recognised in current planting and establishment techniques, with no doubt some implications for the natural history of the forest. Other frost-tender species, such as Douglas fir and grand fir, can only be established if they are allowed to grow up under the shelter provided by an existing crop.

Conclusions

For over 50 years, Thetford Forest has been a 'happy hunting ground' for forest pathologists. Although diseases have taken a considerable economic toll, methods of managing them have been developed where necessary. The impact of some of them and the remedial treatments used have significantly influenced the ecology of the forest and are likely to continue to do so.

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Chapter 5

Nature conservation management of the Breckland flora

John Barkham

Summary

Historical changes to the landscape and ecology of Breckland are described in order to provide the context for a definition of aims for the conservation of its flora. Central to this is an awareness that the 'traditional' grassland and heathland is the result of thousands of years of degradation. Nature conservation aims are suggested which embrace a broader view of what is of value in the Breckland flora. Basic principles of the management required to meet these aims are discussed.

Introduction

Breckland has no fixed boundaries and varies in area from 608 to 1350 km^2 (Trist, 1979). Of the 940 km^2 of the Breckland Environmentally Sensitive Area (ESA), 7.4% (70 km^2) is covered by heathland (Lambley, 1990a), approximately 25% is covered by coniferous plantation, and the remaining 65% by arable farmland and development.

Anybody familiar with the area and interested in its vegetation would probably consider the most valuable flora of Breckland to include:

- flower-rich calcareous grass-heaths
- plants of open ground; annual weeds and ruderals
- heather-dominated acidic heathland
- flora of meres, pingos, fens and riverine grasslands.

The flora under closed stands of coniferous trees and intensively managed arable land is considered of little value. In the forests as they now are, floristic interest is focused on two components: firstly, the rides; secondly, the felling coupes until the re-establishment of closed canopy. In arable land, it is confined to field margins, verges and trackways.

The area of semi-natural heathland has declined by something like 76% from about 290 km^2 in 1900 (Lynne Farrell, data in Lambley, 1990c). Most of the substantial heather and grass heathlands are now protected in 25 Sites of Special Scientific Interest, of which six are nature reserves. With the establishment of the Breckland ESA and changes in the policy and objectives of the Forestry Commission, the climate towards overt nature conservation objectives is more favourable than ever before.

Doubtless over the century to come, there will be significant changes in land-use in Breckland, unless history is not to be repeated. However, at the present time major changes in the balance of forestry farming, Ministry of Defence, and nature conservation land are unlikely in the foreseeable future, even if the changing political climate is resulting in greater priority being given to nature conservation objectives. The principal questions facing conservationists are to do with managing sites rather than securing them, as well as advising owners about their management.

The aim of this chapter is to take a broad view and a historical perspective in identifying aims and strategies for conserving the Breckland flora.

Historical changes

Breckland is a low chalk plateau covered by glacial drift which varies in depth and composition, and consists of chalk, clay, sand and gravels in variable proportions. In some areas, periglacial sorting of surface materials has given rise to patterned ground (Watt *et al.*, 1966). On top of the drift is a deposit of blown sand of post-glacial origin, varying in depth from a few centimetres to as much as 2 m (Pizer, 1979). Substantial surface sand movement has been a feature of Breckland up until the end of the 19th century (Duffey, 1975). This geomorphological history has given rise to a very variable growing medium for plants, with significant variations not only from one heath to another but over a few centimetres, especially where chalky substrate is close to the surface.

The post-glacial colonisation of the Breckland area by plants followed a course typical of lowland England (Godwin, 1944), with a forest of oak and alder replacing birch and pine as the climate warmed. Pigott and Walters (1954) and Watt (1971b) believe that, because of the particular combination of dry, semi-continental climate and drought-prone soils, species characteristic of open ground survived through this long period of woodland history, in areas unable to sustain more than open scrub and along river banks. An alternative hypothesis is that many of these species arrived in the period following neolithic forest clearance with the waves of human colonists from the continent over several thousand years. It is likely that a number of Breckland rarities, including *Medicago sativa* ssp. *falcata*, *Herniaria glabra*, *Alyssum alyssoides*, *Apera interrupta*, *Bromus tectorum* and *Muscari atalanticum* owe their presence to this process (Watt, 1971a; Clapham *et al.*, 1987). However, there is a catalogue of biogeographical evidence (Pigott and Walters, 1954) to suggest that perhaps eight of the rare Breckland species have a continuous history in the area since late glacial 'steppe tundra' conditions.

As elsewhere in southern England, neolithic people selected light soils for their initial clearance for cultivation and sheep grazing. Once cleared, it seems that organic matter content declined and nutrient status was reduced through successive cultivations (Dolman, 1991). A period of about 4000 years, from the entry of neolithic man until the Norman Conquest, provided a long time for vegetation response and change. The pollen record (Godwin, 1944) suggests continuous human occupation through this period. The climate was warmer and drier during the first 2500 of these years, then cooler and wetter in the latter 1500. Leaching of nutrients and acidification of the deeper sands would have been assisted by periodic cultivation. It is through this period of time that the Breckland heaths and grasslands evolved from deciduous woodland, and it is important to remember that grazing by rabbits only became significant during the last 800-900 years since their introduction by the Normans (Crompton and Sheail, 1975; Dolman and Sutherland, 1991; Sheail, Chapter 2).

From the Norman Conquest to the early 20th century, the land use was predominantly large agricultural estates upon which farms were tenanted. Arable crops, sheep and rabbits were the main outputs. The balance between these shifted in relation to an interplay between economics and weather (Sheail, 1979). Streamside meadows probably remained the most constant feature. Otherwise, the relative proportions of land given over to sheep-grazed grass-heath, arable and warren varied. At times of low wool prices and low summer rainfall, rabbits were the most valuable crop. Greater areas of 'breck', that is, grass-heath ploughed a few times every 12-15 years (Sheail, 1979), were cultivated when crop prices were high, and then returned to grass-heath when they were low. From 1870 to 1905 the area of arable land in Breckland fell from 286 to 183 km^2, while the area of permanent pasture rose by only 3%. It can be seen from Figure 5.1(a), (b) that arable reverted to grass-heath at such times.

From an ecological point of view, we can regard the period from 3000 BC until about 1920 as one of exploitative use and continuous reduction in ecological capital. A combination of nutrient leaching, nutrient loss through the cropping of plants, sheep and rabbits, and windblow of exposed, over-grazed grass-heath, arable and warrens reduced large areas to a state of desert-like degradation, such that a 17th century traveller wrote, 'Nothing was to be seen on either side but sand and scattered vegetation; a mere African desert. In some places this sandy waste occupied the whole scope of the eye. In many places we saw the sand even driven into ridges, and the road totally covered' (Dolman and Sutherland, 1991).

The inter-war depression of agriculture and land prices, coupled with anxieties about the low availability of home-grown timber, provided an economic climate favourable for the rapid expansion of forestry, while in the later 1930s the slow beginnings of agricultural modernisation became evident. There followed the requisitioning of the Stanford Practical Training Area in 1942, the almost complete loss of sheep grazing from remaining heaths, and the acquisition of heathland remnants as nature

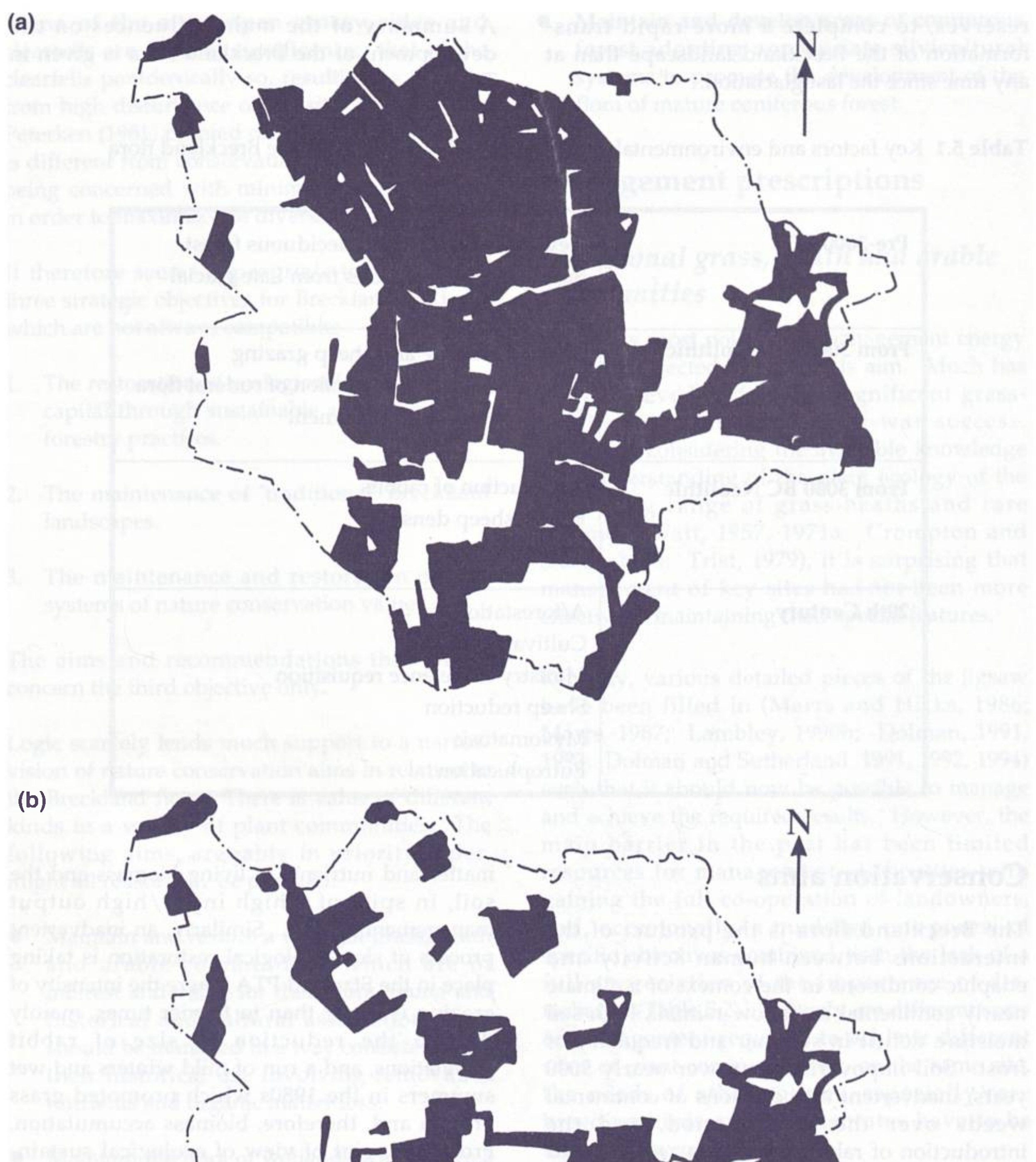

Figure 5.1(a), (b) The change in the amount of rough and heathy pasture in the Stanford Training Area between about 1883 and 1904 (after Sheail, 1979); arable areas shown in black

reserves, to complete a more rapid transformation of the Breckland landscape than at any time since the last glaciation.

A summary of the main influences on the development of the Breckland flora is given in Table 5.1.

Table 5.1 Key factors and environmental changes in the development of the Breckland flora

Pre-3000 BC	Development of mixed deciduous forest Survival of relict species from Late glacial
From 3000 BC Neolithic	Forest clearance and sheep grazing Cultivation, and introduction of ruderal flora Grass and heath development
From 3000 BC Neolithic	Introduction of rabbits Rise in sheep densities Desertification
20th Century	Afforestation Cultivation Ministry of Defence requisition Sheep reduction Myxomatosis Eutrophication

Conservation aims

The Breckland flora is the product of the interactions between human activity and edaphic conditions in the context of a climate nearly continental in its low rainfall, high soil moisture deficit in summer and frequency of frost. Soil impoverishment over nearly 5000 years, inadvertent introductions of continental weeds over the same period, and the introduction of rabbits 900 years ago have led to a situation not dissimilar, though perhaps more extreme, than other plagioclimax grasslands and heathlands in the British Isles. It would be hard to imagine a more degraded landscape than the pre-First World War Breckland in comparison with the mixed deciduous forest of pre-Neolithic times.

Yet this is what the conservation effort, beginning in the 1930s (Sheail, 1979), has been directed towards preserving. The Forestry Commission has been inadvertently restoring ecological capital by establishing forests, which has resulted in an accumulation of organic matter and nutrients in living biomass and the soil, in spite of a high input/high output management system. Similarly, an inadvertent process of slow ecological restoration is taking place in the Stanford PTA where the intensity of grazing is lower than in former times, mainly due to the reduction in size of rabbit populations, and a run of mild winters and wet summers in the 1980s which promoted grass growth and, therefore, biomass accumulation. From the point of view of ecological sustainability, the only certain deleterious land-use changes occurring at present are those involving urban, industrial and highway development, though intensive inorganic arable cultivation is contributing nothing positive. However, the ecological sensitivity of forestry practice could be improved.

Despite what must have been considerable losses of biota resulting from Neolithic forest clearance, the biodiversity of the degraded landscape of grass-heaths and disturbed, open ground is now of great interest to nature conservationists. In the forest, the flora and fauna of the more open grassy rides and clearfells are of most significance: that of the clearfells paradoxically so, resulting as they do from high disturbance of the site. However, as Peterken (1981) pointed out, *nature* conservation is different from conservation; the former often being concerned with minimising productivity in order to maximise the diversity of biota.

It therefore seems appropriate to distinguish three strategic objectives for Breckland land-use which are not always compatible:

1. The restoration of ecological/environmental capital through sustainable agricultural and forestry practices.

2. The maintenance of 'traditional' Breckland landscapes.

3. The maintenance and restoration of ecosystems of nature conservation value.

The aims and recommendations that follow concern the third objective only.

Logic scarcely lends much support to a narrow vision of nature conservation aims in relation to the Breckland flora. There is value of different kinds in a variety of plant communities. The following aims, arguably in priority order, might all reasonably be pursued:

- Maintain and restore a range of grass, heath and arable communities which are of interest and value for their flora, fauna and historical and cultural associations, and should be managed in a way consistent with their historical use involving removal of nutrients and organic matter loss.

- Maintain the flora of wetlands which have a long and continuous history and are of national nature conservation importance.

- Maintain and enhance a range of attractive, flower-rich grasslands accessible to the public, including wide forest rides.

- Maintain a shifting system of clearfells in order to perpetuate the ruderal flora.

- Restore some areas of mixed deciduous woodland characteristic of a range of sandy loam soils.

- Maintain and develop areas of coniferous forest adopting appropriate silvicultural systems to promote the development of the flora of mature coniferous forest.

Management prescriptions

Traditional grass, heath and arable communities

Until now most policy and management energy has been directed towards this aim. Much has been achieved and some magnificent grass-heaths bear witness to post-war success. However, considering the available knowledge and understanding of the plant ecology of the remaining range of grass-heaths and rare ruderals (Watt, 1957, 1971a; Crompton and Sheail, 1975; Trist, 1979), it is surprising that management of key sites has not been more effective at maintaining their special features.

Recently, various detailed pieces of the jigsaw have been filled in (Marrs and Hicks, 1986; Marrs, 1987; Lambley, 1990b; Dolman, 1991, 1993; Dolman and Sutherland, 1991, 1992, 1994) such that it should now be possible to manage and achieve the required results. However, the main barrier in the past has been limited resources for management, difficulties with gaining the full co-operation of landowners, and, occasionally, a muddled pot-pourri of specific objectives combined with the lack of a full appreciation of the importance of disturbance (Table 5.2). Not only are different sorts of management required to achieve different sorts of plant community but, on the same site, the needs of other species, especially rare breeding birds and invertebrates have to be taken into account too.

This leads naturally to the conclusion that the suite of Breckland grass-heath sites needs to be considered as a whole to ensure that appropriate objectives are assigned and achieved in appropriate places. Such co-ordination has long been necessary and is now being achieved through English Nature's Breckland Advisory Committee and appropriate liaison on the ground between English Nature, the Norfolk Naturalists' Trust, the Royal Society for the Protection of Birds and the Suffolk Wildlife Trust.

Table 5.2 Disturbance factors affecting Breckland flora (after Watt 1971a, Crompton and Sheail, 1975; Sheail, 1979; Dolman, 1991; Dolman and Sutherland 1991), some of their effects and current status

Activity	Effects on plants through:	Current status of activity
Flint mining	Creation of spoil heaps	Ceased
Traditional arable cultivation	Open ground creation Organic matter and nutrient loss Seedbank movement	Ceased, except at Weeting
Plough-breasting	Light disturbance on sandy heathland	Ceased
Preparation and maintenance of agricultural trackways	Bare ground maintenance	Continuing
Mole tunnelling	Bare ground Excessive soil drainage Seed bank exposure	Continuing
Rabbits grazing, burrowing and scraping	Short turf maintenance Bare ground maintenance Nutrient redistribution	Reduced
Warren building and management	Nutrient removal Turf removal for bank and wall creation	Ceased
Rabbit predation	Reduction in rabbit numbers	Increasing
Sheep grazing	Short turf maintenance Nutrient redistribution Nutrient removal	Much reduced, but now increasing
Other consumers, e.g. heather beetle	Selective grazing and mortality	Continuing
Game management	Ploughing, sown grass	Continuing
Military bombing Bomb disposal Tracks Bulldozing Gun emplacements Defensive banks	Throws up scattered chalk Vegetation destruction Creation of frost hollows Destruction of lichen cover Exposed bare areas of chalk Transport of chalk Turf removal	Continuing in STA and Lakenheath
Modern arable cultivation	Open ground creation Herbicides Fertilisers Heavy machinery, frequent use	Continuing
Roadside verges	Bare ground exposure Compaction Salt Cutting	Continuing
Afforestation	Habitat changes	Much reduced

Specific objectives under this heading include:

- Establishment of a traditional management culture, including shifting cultivation, sheep grazing and warrening.
- Maintenance and re-establishment of populations of rare annuals and short-lived perennials characteristic of arable and other frequently disturbed ground.
- Maintenance of grazed short swards of herb-rich, bryophyte-rich and lichen-rich turf.
- Maintenance of heather-dominated vegetation, and control of bracken.
- Creation of new areas of traditionally composed grass and heath.

As with much nature conservation management, these objectives are all concerned with the management of change. This involves intervening in the natural process of succession to alter the course of outcomes of competition between plants, which, in turn, may require manipulating the plant environment.

We shall never know the precise and different local requirements for every plant species we wish to maintain or re-establish. However, we know enough about the past environment of Breckland to re-create conditions likely to be favourable. Disturbance from a wide range of factors (Table 5.2) has been crucial. Many disturbances were temporary or ceased after a long period of effect. It is therefore necessary to mimic past disturbance in present management practice.

Recent studies (Dolman, 1991; Dolman and Sutherland, 1991) have shown that significant differences in vegetation arise from sheep and rabbit grazing (Figure 5.2). Sheep can effectively maintain short grazed swards of perennial herb-rich turf, while rabbit grazing supports annual herbs and lichens. Sheep, however, prevent scrub encroachment and may promote a sward more favourable for the spread of rabbits. Dolman (1991) also shows that rotavation of short grass swards results in improvement of certain desirable features, such as the cover of lichens, hemicryptophytic herbs, less competitive grasses, and the attractiveness of the sward to rabbits, even as long as 20 years after the event.

Dolman and Sutherland (1991) also highlight the serious and relatively new environmental component of eutrophication, which arises from the twofold increase in nitrates in rainfall over the last century. This, together with the cool, wet summers of the mid-1980s, was the probable cause of enhanced growth of competitive grasses on the remaining Breckland grass-heaths, exacerbated by unfavourable conditions for the maintenance of high rabbit populations. It is important to facilitate the rapid removal of these added nutrients. Regular rotavation, by mimicking the former cultivation practices, reduces nutrient uptake by established plants and increases leaching. Further detail is added by Dolman and Sutherland (1994) who found that ploughing, as opposed to rotavation, while significantly reducing total nitrogen in the top 10 cm of soil, resulted in a greater loss of plant species, requiring a greater reliance on external sources of seed for their replacement. Rotavation combined with rabbit, rather than sheep, grazing is now regarded as essential for maintaining traditional Breckland grass heaths with an abundance of lichens, winter annuals and cushion-forming mosses (Dolman and Sutherland, 1992).

There is still much to be learnt in detail about appropriate timing and intensity of treatment in an environment variable in time, space and vegetation composition. There is much also to discover about how best to maintain rabbit populations at the required density. However, appropriate combinations of sheep and rabbit grazing and rotavation are capable of creating and maintaining the groups of plants most valued in the grass-heath swards. In addition, enough is probably known about the distribution, abundance and ecology of the 20 Red Data Book and 14 nationally scarce species (Watt, 1971a; Trist, 1979; Davy and Jefferies, 1981; Gaffney, 1987; Lambley, 1990) to manage successfully for them, using the same combination of agents, though judicious re-establishments into manageable sites may be required.

Wetlands

These include the fluctuating meres, natural and artificial lakes, pingo systems, valley fens and basin mires, fragments of remaining fen on the edge of the Fens, rivers and wet grasslands associated with them. These are treated fully by Lambley (1990a).

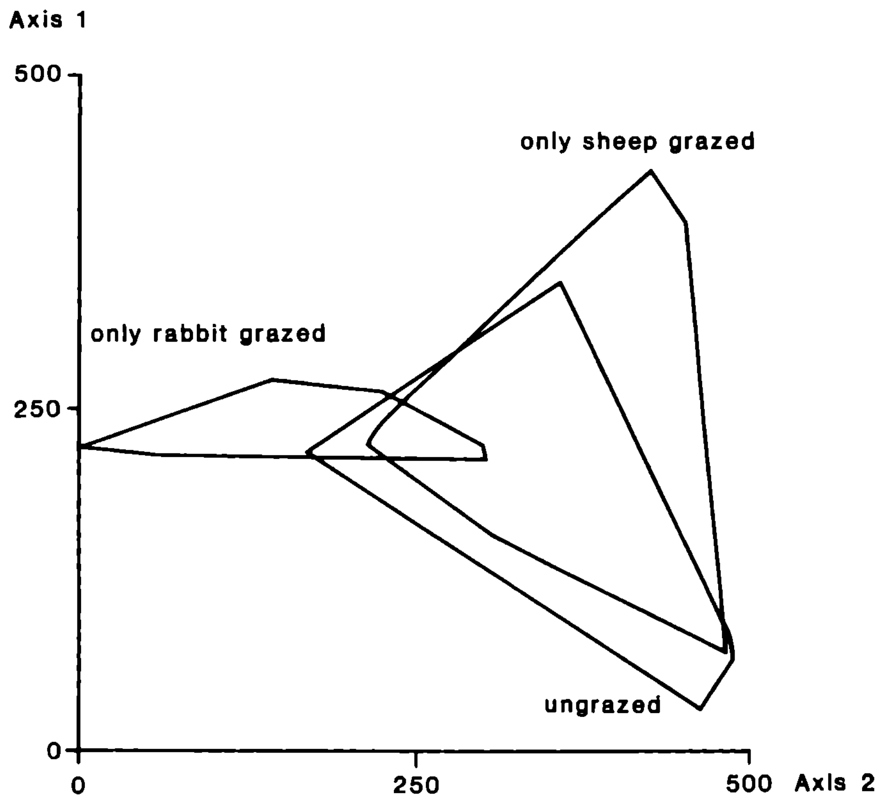

Figure 5.2 The difference between sheep-grazed and rabbit-grazed vegetation as illustrated by the distribution of sites on the first two axes of a DECORANA ordination of quadrat data (from Dolman, 1991)

Attractive flower-rich grasslands

Where it is appropriate in the context of the first aim, sheep-grazing can be timed to achieve this objective over a large area of grassland. Where rabbits are abundant, sufficient control over them during the flowering season is probably impossible to achieve, meaning that the density of flowers in bloom is much reduced. This means that in practice most of the flower-rich grasslands so much enjoyed by the general public have arisen incidentally in association with road construction and maintenance (verges) and forest management (rides) where high densities of rabbits are absent and particularly where the sands overlying the chalk are thin and calcareous.

Regular end-of-season cutting and removal of biomass is essential to prevent organic matter build-up and eutrophication leading to succession towards competitive grass dominance and woodland. The main problems to solve are:

- Provision of a comprehensive site inventory.
- Management costs: mechanical maintenance rather than reliance on rabbits is necessary.
- Provision of access and interpretation.

Clearly, the Forestry Commission has a major role to play here, together with the help of voluntary conservation bodies in site inventory, highway authorities in managing particular road verges, and landowners managing field heathlands with the assistance of ESA payments. Management prescriptions to meet specific objectives are now well rehearsed (Crofts and Jefferson, 1994).

Ruderal flora of clearfells

The basic principles of managing for floristic diversity and attractiveness of felling coupes in the forest area are the same as for the annual flora of disturbed ground elsewhere in Breckland. Different problems arise from the need to integrate a specific form of silvicultural practice with safeguarding nature conservation interests. These problems are discussed later in Chapter 17. It is encouraging to note that attempts to re-create heathland on previously forested land, especially that adjoining existing heaths, may be successful, and more so than similar attempts on soils previously under arable crops (Christopher Clarke, in Dolman, 1993). Approaches to heathland restoration in general have recently been well summarised (Gimingham, 1992).

Mixed deciduous woodland

This requires new ground. It is an exercise in habitat creation. The main requirements are:

- *Harmony with other objectives*: identification of areas and co-operation with other local objectives as appropriate.
- *Funding*: Forestry Authority Woodland Grant Scheme.
- *Promotion*: co-operative and joint. Forest Enterprise leading, with Countryside Commission, English Nature, MAFF, district councils, voluntary conservation agencies, relevant landowners all linking in.
- *A basis of ecological and practical management principles*: initial natural regeneration or planting with appropriate tree species; re-establishment of these and other species based on known vegetation history; appropriate silvicultural management (Rodwell and Patterson, 1993).
- *Access principle*: encouragement of the local and general public to participate in and enjoy this new forest should be planned from the start.

The benefits would include local landscape improvement, public enjoyment, research and scientific interest, wildlife value, timber production, and land value increase, which would be based upon the restoration of essential biological processes. Two small clearfells close to Santon Downham have been left to regenerate naturally by Forest Enterprise and now provide developing examples of this kind of habitat.

The idea that the establishment of new deciduous woodland (Rodwell and Patterson, 1993) might be of conservation interest and benefit is in opposition to current views of some conservationists (NCC Breckland Advisory Committee, 1990). Provided such woodland is not developed at the expense of grass-heath restoration and re-establishment, it should add to the ecological interest of the area and be unexceptionable. Whether it is of landscape value in a Breckland context is a matter of opinion.

Forests based on alternatives to clear cutting

Small parts of Thetford Forest have been excluded from the clearfell rotation and are managed using the continental selection thinning system which allows the development of a mixed-aged stand with natural regeneration. Some of these stands are now old enough to have developed a complex, non-uniform vegetation structure and an atmosphere akin to mature continental coniferous forests. Not only are these stands beautiful in their own right but they are of considerable interest for the long-term development of their flora, particularly the carpets of bryophytes.

This is not the place to examine the economics of this low input system, but they do merit comparison with the predominant one. If more stands throughout the forest could be taken out of the rotation in the same way there would be considerable conservation benefits. At the very least, the present little-known stands that do exist should be:

- subject to planned and positive management by selection thinning;
- identified and made more widely known to the public;
- surveyed for their flora;
- monitored for floristic change;
- compared with neighbouring 'controls' within the rotation.

Conclusion

In this chapter I have sought to take a broader view than is usual of nature conservation in the context of the Breckland flora. Dolman and Sutherland's (1991) hope for the grass-heaths is that it should be possible to restore them to their former glory. Notwithstanding the importance of these heaths to our history and culture, this represents a particularly positive way of regarding what I have shown here to be a vegetation characteristic of a grossly abused, man-made, degraded area of land. Nevertheless, the grass-heaths are arguably the most important nature conservation feature of Breckland and must be maintained as the first priority. It would, however, be a narrow vision to regard these alone or together with a number of very rare herbs and grasses as the only important features of Breckland's floristic interest. It is precisely, and rightly, this kind of narrow interest which marginalises nature conservation in society. I have shown that there are additional aims to pursue, both aims specific to nature conservation and others consistent with environmental restoration, and which take account of the major land-use changes in Breckland during the current century. There is undoubtedly a large constituency of people ready to appreciate the results of managing for an attractive flora in a wide variety of Breckland habitats.

Acknowledgements

I am most grateful to Paul Dolman for permission to use his unpublished data (Figure 5.2 in this text), and to the following for their helpful comments on an earlier draft of this paper: Paul Dolman, Dr Mark Hassall, Lynne Farrell, Bill Nickson, Stephen Rothera, Alistair Scott and Bill Sutherland.

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Chapter 6

The ecology of the military orchid

Michael Harding

Summary

The ecology of the military orchid (*Orchis militaris* L.) was compared at its two remaining strongholds in Buckinghamshire and Suffolk. The latter has a much larger population and individuals are more vigorous.

Management was shown to have a strong influence on population size at the two sites. Scrub growth appeared to be suppressing numbers at the Buckinghamshire site, causing extinction of one subcolony. Clearance at the Suffolk site prevented extinction. A moss carpet was thought to be reducing numbers in Suffolk through changing the soil microclimate and harbouring small mammals which ate the orchid tubers. Clearance of moss and further tree removal resulted in dramatic increases in orchid numbers.

Bees are the only likely pollinators. Natural rates of pollination are low. Large numbers of seeds are produced but viability, germination and establishment appear to be low.

At the Suffolk site levels of organic matter and available magnesium were significantly lower in quadrats containing orchids than in quadrats where they were absent. No variables appeared to be significantly related to orchid density. There was a positive relationship between available magnesium and potassium and spike height, and a negative relationship with soil temperature. There was a positive relationship between flower number per spike and depth of moss, but a negative relationship with soil temperature.

The two populations showed different reactions to the same environmental variables. The most likely reason for this is different genetic origins. The Suffolk orchids are likely to be from the same stock as European orchids, which are similarly large and vigorous plants.

Introduction

The military orchid, *Orchis militaris* L., is one of the rarest orchids in the UK and is protected under the Wildlife and Countryside Act, 1981. It is extant in two nature reserves owned by Forest Enterprise and managed by Wildlife Trusts, both of which are protected as Sites of Special Scientific Interest (SSSI). One site, 'Bucks 1', is in the Buckinghamshire Chilterns, an area of former chalk grassland planted for forestry, and the second is 'Rex Graham', a disused chalk pit within Thetford Forest, Suffolk. There are two other recent colonies in the Oxfordshire Chilterns but they are small and the appearance of the orchid is sporadic. This chapter is concerned with the two major sites. The orchids at Bucks 1 were discovered by J.E. Lousely in 1947 and in Suffolk they were discovered by M. Southwell in 1954 (Anon. 1956), although locals claim to have always known of them. The pit is thought to date from 1812, and there are unsubstantiated newspaper references to it from 1844 (Patmore, 1988). In the UK, the orchid grows on freely drained and impoverished chalk soils with low organic contents (Farrell, 1985; Hawke, 1989). Bucks 1 has been wooded for over 150 years (Havers, personal communication), while scrub encroached on the Suffolk site in the last few decades. Phytosociologically, both sites are referable to *Crataegus monogyna-Hedera helix* scrub communities (W21, Rodwell, 1991).

The only rigorous study of the ecology of the orchid so far is Farrell (1985), the remaining references being anecdotal (Summerhayes, 1951; Trist, 1979, 1982; Anon., 1956). Following Farrell's paper uncertainty remained in three key areas:

1. The response of the orchid population to habitat management.

2. Aspects of pollination ecology.

3. The relationship between parameters of orchid population fitness and environmental variables.

This study aims to address these uncertainties by assembling a variety of previously unpublished data collected at the two nature reserves (Church 1987; Patmore, 1988; Baskerville, 1989; Baker, 1990; Appleton, 1990; and Hawke, 1989).

Orchid populations and habitat management

Population graphs with significant management events for Bucks 1 are shown in Figures 6.1(a) and (b) (two subcolonies), and for Rex Graham in Figure 6.2. Early counts are derived from botanists' notes where a variety of counting techniques were used. The accuracy is therefore questionable until Farrell began

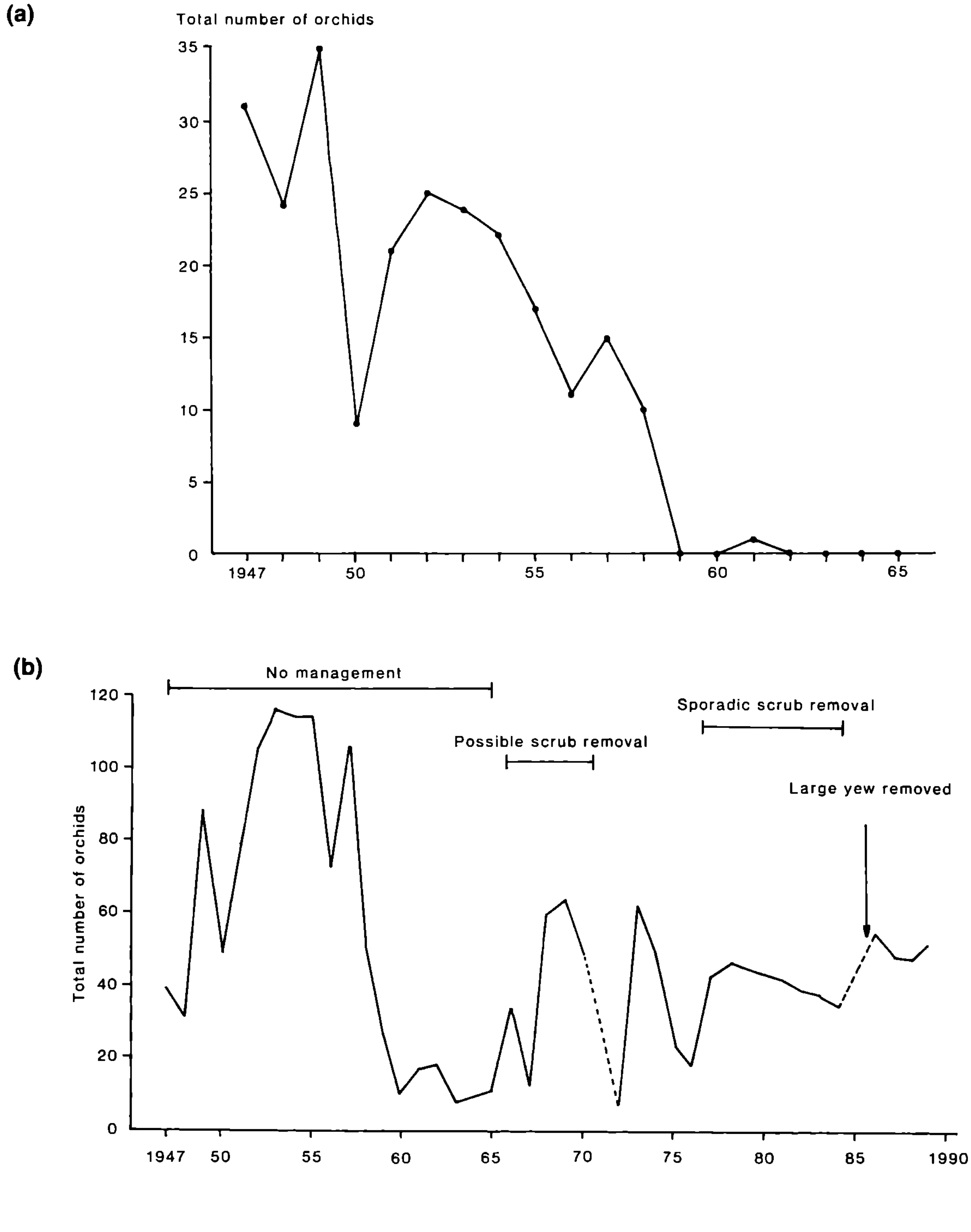


Figure 6.1 (a) Colony A, Buckinghamshire: no management took place over this period (data collected by Lousley, in Farrell, 1985); (b) colony B, Buckinghamshire (data from Havers, personal communication)

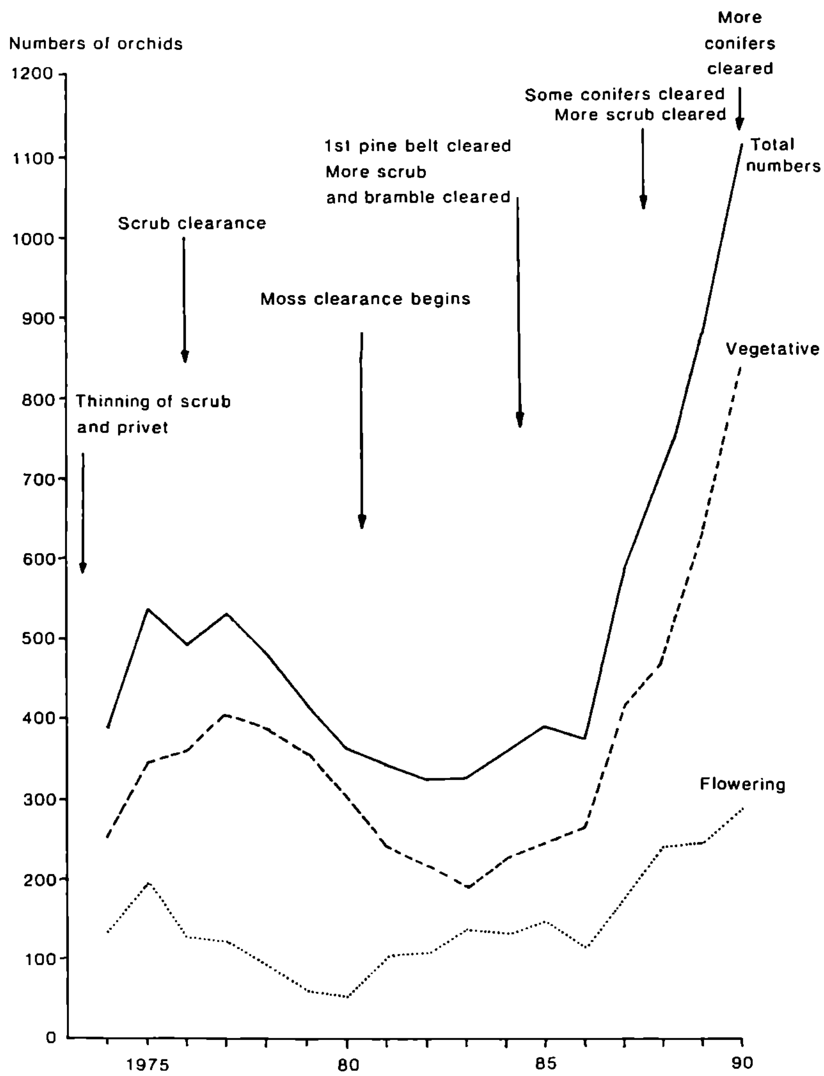


Figure 6.2 Trends in orchid population at Rex Graham, Suffolk

to use the coordinate technique (Wells, 1967) and has derived accurate counts since 1974 at Rex Graham and 1976 at Bucks 1. Vegetative and flowering plants were not separated at Bucks 1.

Trends at Bucks 1

Colony A (Figure 6.1(a)) became increasingly shaded over the period until a canopy of *Rubus, Chamnerion angustifolium* and scrub developed, leading to extinction in 1962. The trees were removed in 1986 but no orchids have reappeared.

Colony B (Figure 6.1(b)) shows a more equivocal response to shade. Beech (*Fagus sylvatica*) was planted in the late 1940s adjacent to the site, so the steep increase between 1947 and 1952 may be due to the general clearance of the site associated with planting. The decline that followed, until 1965, may be a response to shading as the plantation grew. Subsequently, there were episodic periods of scrub removal on a small scale. Between 1977 and 1984, management consisted of lifting the canopy in and around the colony. This clearly was not sufficient to halt the decline. The surrounding beech trees were now over 40 years old, with additional very mature yew trees (*Taxus baccata*) in the middle of the colony. In winter 1985-86 a large yew was removed, with a small increase in orchid population. However, the cleared orchid groups still remained within 5-7 m of the surrounding beech canopy. It is likely that this plantation casts sufficient shade to suppress the orchids and overrides the effect of individual yew clearance within the colony.

Trends at Rex Graham, Suffolk

Data before 1974 are omitted from Figure 6.2, but there was a peak of around 2000 orchids in 1958-60. The decline between then and the early

1970s is dramatic due to birch and sycamore growth within the pit, such growth being up to 13 m high by 1972 (Trist, 1982), with a dense understorey of privet. Recovery was swift after clearance began in 1973. The next significant event was the removal of moss from the pit floor, which had greatly increased in response to more light. Farrell was concerned that the moss was smothering seedling orchids, and also harbouring small mammals which ate and damaged the orchid tubers. Mammal run-ways through the moss were obvious at the pit. The effects of the moss can be seen in the decline of vegetative plants, particularly since 1977. Hand clearance of moss began in 1980, with vegetative orchids apparently taking 4 years to respond. There was no further scrub clearance in this time. A 4-year time lag is in accordance with expectations: Summerhayes (1951) recorded that it took 4 years to form stems from seed, with flowering at 7 years. Farrell (1985) notes seed-to-flower lag times of 3 to 7 years.

Moss may affect orchid germination by affecting the microclimate of the soil surface. Compared with exposed bare soil which the orchid prefers (Farrell, 1985), a moss carpet will produce a cooler, moister and darker microclimate in summer, and a warmer, damper microclimate in winter. This would effectively change the microclimate from a Continental one to a more Oceanic type. The European distribution of the orchid is markedly Continental (Farrell, 1985). There is direct evidence that suggests this would inhibit germination. Farrell (1985) reports that in experiments, temperatures required for germination in the dark (as under a moss carpet) were far higher than in the open. Experiments at Kew (J. Stewart, personal communication) suggest a very cold period of up to 2 months may be required to allow seedlings to establish after germination. These cold temperatures would be ameliorated by the protective cover of a moss carpet.

By the early 1980s Corsican pine which had been planted up to the edge of the pit in 1952 was casting deep shade. The dramatic increase in population coincides with progressive removal of 10 m belts of the trees and also with sporadic tree removal within the pit. Bramble and grass clearance has continued annually throughout the period with occasional removal of moss.

Pollination and seed production

Pollinators

Table 6.1 summarises the insect species observed visiting the flowers of *O. militaris* at Rex Graham. Bees were the most frequent visitors of all, with butterflies, syrphids and hoverflies also frequent. Until 1985, the only animal ever observed carrying pollinia was a bee, *Andrena curvungulata*, and that was in France (Farrell 1985). Subsequently, Church (1987) caught a bee (probably *Apis mellifera*) carrying 15 pollinia and both Patmore (1988) and Appleton (1990) caught *Bombus terrestris* with pollinia.

It is unlikely that syrphids are significant pollinators as they do not go deep enough into the flowers to collect pollinia (Appleton 1990). Similarly, Hawke (1989) noted that butterflies with their very long proboscises could exploit the nectar without contacting the pollinia. Bees have short proboscises and must go deep into the flower to feed. They also have larger bodies which are more likely to brush against pollinia (Hawke, 1989) and are therefore the most likely pollinators.

Rates of pollination

The natural pollination rate is very low (Table 6.2). As hand pollination produces rates of 80-100%, clearly the problem lies with the pollinators. All observers agree that visits over the pollination period are very few, although potential pollinators are highly active in the pit all summer. Other plant species are adequately pollinated, and Appleton (1990) observed honey bees frequently visiting *Listera ovata*. This suggests a preference for other flowers, with perhaps those of *O. militaris* being deficient in nectar or fragrance, or both. The low rate of pollination has been implicated in the decline of the species (Trist, 1982; Farrell, 1985), but the vast number of seeds produced in each successfully fertilised flower should be enough to maintain the population. Of critical importance is the viability of the seed and the germination and establishment rates. These may be particularly low in the UK which is very much on the fringe of the species' range (Farrell, 1985).

Table 6.1 Possible pollinators of *Orchis militaris*. Native species recorded visiting florets

Pollinator	Source	Comments
Hymenoptera		
Bombus terrestris	Hawke, 1989; Patmore, 1988; Appleton, 1990	Pollinia attached (Patmore, 1988; Appleton, 1990)
B. lucorum	Hawke, 1989; Church, 1987; Appleton, 1990; Farrell 1985	
B. pratorum	Hawke, 1989; Church, 1987; Appleton, 1990	
B. lapidarius	Hawke, 1989; Appleton, 1990; Farrell, 1985	
B. agrorum	Hawke, 1989	
Apis mellifera	Hawke, 1989; Church, 1987; Appleton, 1990	Honey bees active on spikes (Patmore, 1988). Carrying pollinia (Church, 1987)
Vespula vulgaris	Hawke, 1989; Church, 1987; Appleton, 1990	
Formicidae spp.	Hawke, 1989; Church 1989; Farrell, 1985	
Sphex rufocinctus	Church, 1987	Carrying twayblade pollen
Ammophilia savalosa	Church, 1987	(Church, 1987)
Diptera		
Syrphidae - many spp.	Hawke, 1989; Appleton, 1990; Farrell, 1985	Frequent visitors but never with pollinia
Erisyrphus baltaetus	Church, 1987	
Melanastoma scalare	Church, 1987	
M. mellinum	Farrell, 1985	
Chrysotoxum cautum	Church, 1987	
Eristalis pertinex	Church, 1987	
Leucozona lucorum	Farrell, 1985	
Empis tessellata	Hawke, 1989	Predatory
Bibio marci	Church, 1987	
Onesia spp.	Farrell, 1985	
Opomyza germinationis	Farrell, 1985	
Platycheirus scutatus	Farrell, 1985	
Rhingia campestris	Farrell, 1985	
Scathophago stercoraria	Farrell, 1985	
Thricops semicinereus	Farrell, 1985	
Coleoptera		
Cantharis rustica	Hawke, 1989	Predatory
Cassida viridis	Hawke, 1989	
Strangalia maculata	Hawke, 1989	
Hemiptera		
Eurygaster spp	Hawke, 1989	
Cercopsis vulnerata	Church, 1987	
Lepidoptera		
Pieris brassicae	Hawke, 1989; Farrell, 1985	
P. rapae	Hawke, 1989	Butterflies frequent visitors,
P. napi	Hawke, 1989; Appleton 1990; Farrell, 1985	but not suitable pollinators
Inactis io	Hawke, 1989; Appleton, 1990	

Table 6.2 Rates of natural and artificial pollination at Rex Graham, Suffolk

Reference	Natural pollination rate	Artificial pollination rate
Appleton (1990)	8.45%	100%
Hawke (1989)	7.3%	100%
Patmore (1988)	19.45%	80%

Orchid population fitness and environment

Background

Rex Graham has a much larger population than Bucks 1. The population is also more vigorous, with taller plants bearing larger leaves and having more flowers per spike. The plants are 'fitter', but it was not known whether this was because the environment of the pit was more suitable or whether the orchids were intrinsically more vigorous, perhaps being derived from different genetic stock. The Rex Graham orchids were, for instance, more akin to European orchids in their measurements (Farrell, 1985). Comparative data on environmental variables were collected for the two sites (Hawke, 1989).

Methods

Thirty 1 m^2 quadrats were laid out at Rex Graham and 15 at Bucks 1 in June 1989. Quadrats with and without orchids were sampled. To compare the environmental variables at the two sites, soil samples were taken from each and the following parameters measured:

Light intensity (kJ m^{-2})
Soil temperature (°C)
Soil moisture content (%)
Organic content (%)
pH
Available potassium (mg l^{-1})
Available magnesium (mg l^{-1})
Available phosphorus (mg l^{-1})

At Rex Graham (but not Bucks 1) the following biotic factors were also measured:

Bare ground cover (Domin scale)
Moss layer cover (Domin scale)
Grass cover (Domin scale)
Herb cover (Domin scale)
Mean depth of moss (cm)
Median vegetation height (cm)

Orchid density, spike height and flower number per spike were measured as parameters of vigour in each quadrat at Rex Graham where orchids occurred. This was to examine the relationship between orchid vigour and environmental variables within a population. The details of the methods are contained in Hawke (1989).

Results

Environmental differences between sites

Figure 6.3 presents the mean, standard deviation and range of values recorded for each of the environmental variables at Bucks 1 and Rex Graham. Table 6.3 shows the significance of the differences between means using *t*-tests. Overall, the data show Rex Graham to have a more impoverished soil, with significantly less organic content and exchangeable cations. The soil is also drier, warmer and has a higher pH. These data confirm the findings of Farrell (1985).

The lack of significant difference between light values may perhaps be due to the wrong technique being used (Hawke, 1989). Light intensity was measured for 5 minutes for each quadrat at one point in one day in June. The variation is not surprisingly large. A more ecologically meaningful parameter would be total daily or seasonal insolation received by each quadrat, but it was not feasible to collect these data.

Environmental variables and plant fitness

Three analyses to assess the influence of environmental parameters on orchid vigour at Rex Graham were undertaken by Hawke (1989). Additional analysis of these data are presented here. Table 6.4 summarises these analyses.

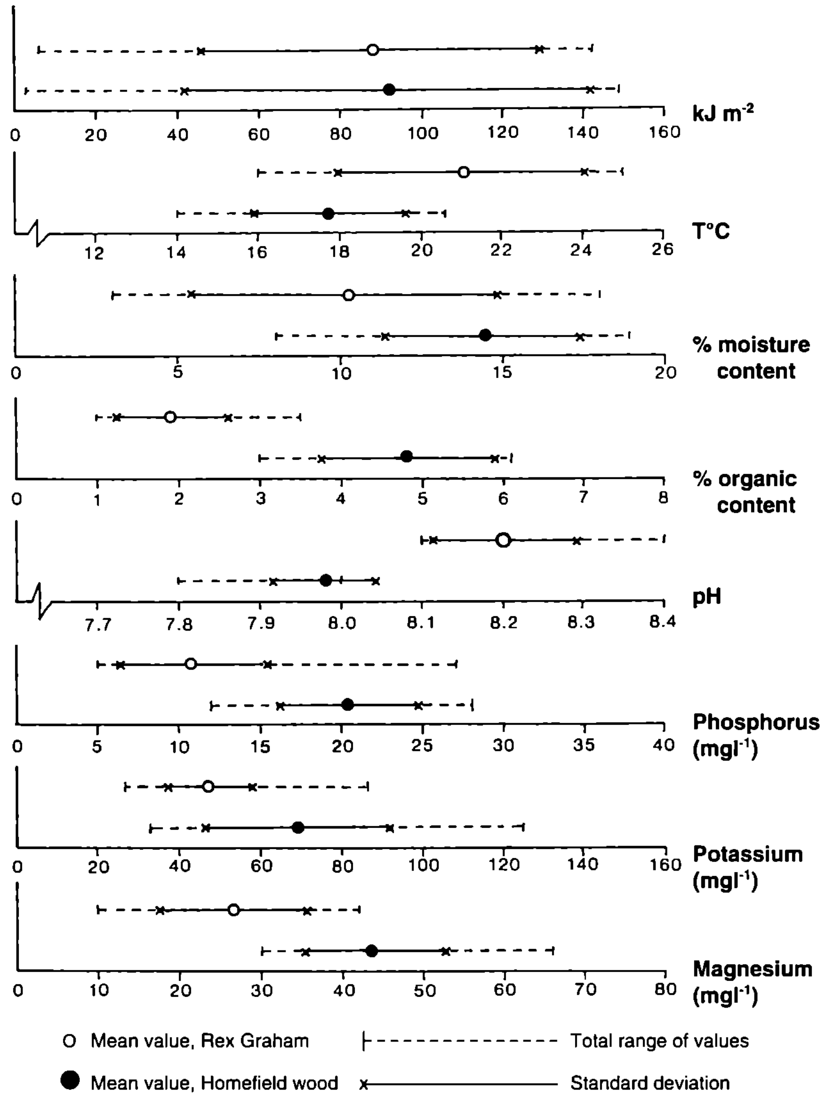


Figure 6.3 The differences between means of environmental parameters at Rex Graham, Suffolk and Bucks 1, Buckinghamshire.

Table 6.3 Range of values of environmental parameters at Rex Graham + Bucks 1 (from Hawke, 1989)

Parameter	Mean value, Rex Graham	Mean value, Bucks 1	Significance of difference
Light intensity (kJ m^{-2})	88.1	91.9	NS
Soil moisture content (%)	10.2	14.5	$p<0.002$
Soil organic content (%)	1.9	4.8	$p<0.001$
Soil temperature (°C)	21.27	17.7	$p<0.001$
Phosphorus (mg l^{-1})	10.6	20.3	$p<0.001$
Potassium (mg l^{-1})	47	69	$p<0.001$
Magnesium (mg l^{-1})	26.7	43.5	$p<0.001$
pH	8.2	8.0	$p<0.001$
Sample size (n)	30	15	–

1. *Effect of variables on presence/absence of orchids.* Using linear discriminant analysis, Hawke (1989) compared quadrats with and without orchids to attempt to identify which environmental variables controlled orchid presence. Establishment appeared to be favoured by high potassium, grass cover and vegetation height and by low soil magnesium. However, these results are questionable; the equation wrongly predicted orchid presence in 26% of quadrats, and many of the results are counter-intuitive and contradict observations of other workers for *O. militaris* (Farrell, 1985) and orchids in general (Summerhayes, 1951).

   Comparisons of the mean levels of the parameters in quadrats with and without orchids using *t*-tests (Table 6.5) showed that magnesium and organic content were significantly lower in quadrats supporting orchids, but other factors identified by Hawke's (1989) analysis were not significantly different. The pH was also significantly lower, but with a difference of only 0.08 of a pH unit, it is unlikely to be ecologically meaningful.

2. *Environmental parameters and orchid density.* Hawke (1989) used a multiple regression analysis for quadrats containing orchids but found no relationship between any of the measured parameters and orchid density. Individual linear regressions with each factor similarly found no relationships (Table 6.4).

3. *Effect of environmental parameters on spike height and flower number per spike.* A strong correlation between spike height and flower number was found (r=0.88, p<0.001). Hawke (1989) used stepwise multiple linear regression analysis (r^2 of 80%) to identify a number of relationships. Again many of the relationships were counter-intuitive, and single linear regressions carried out here did not always agree (Table 6.4). The new analyses obtained a significant positive relationship between spike height and available magnesium (p<0.05) and phosphorus (p<0.001) (Figure 6.4(a)). There was a negative relationship with soil temperature (p<0.01; Figure 6.4(b)), this time agreeing with Hawke's (1989) findings.

Table 6.4 Differences between means of environmental parameters for quadrats with orchids and those without at Rex Graham, Suffolk

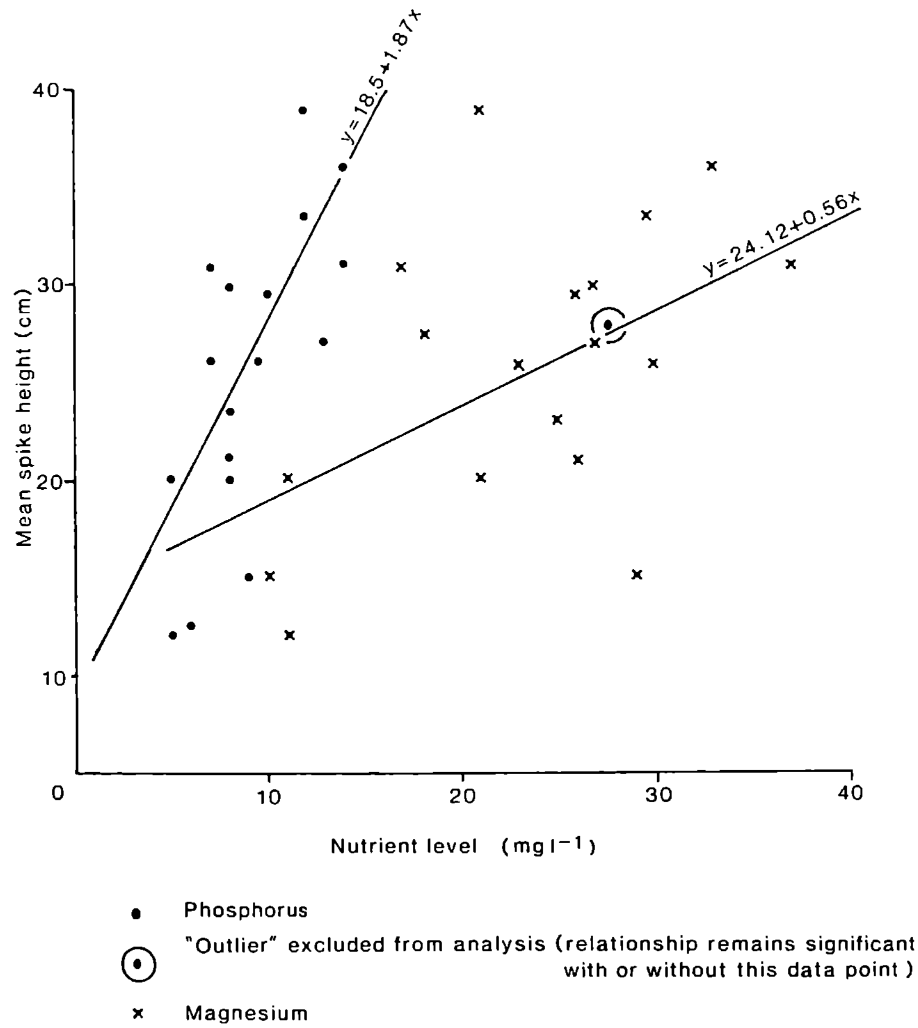
Parameter	Mean value, quadrats with orchids	Mean value, quadrats without orchids	Significance of difference
Light intensity (kJ m^{-2})	93.2	79.36	NS
Soil temperature (°C)	21.32	21.13	NS
Soil moisture content (%)	10.79	9.09	NS
Soil organic content (%)	1.7	2.26	p<0.5
pH	8.24	8.16	p<0.05
Soil phosphorus (mg l^{-1})	9.95	11.82	NS
Soil potassium (mg l^{-1})	45.74	49.09	NS
Soil magnessium (mg l^{-1})	23.58	32.1	p<0.001
Bare ground (Domin)	2.6	1.54	NS
Moss cover (Domin)	5.63	5.45	NS
Grass cover (Domin)	4.95	3.36	NS
Herb cover (Domin)	5.37	5.55	NS
Moss depth (cm)	3.83	4.46	NS
Vegetation height (cm)	40.6	36.8	NS
Sample size (n)	19	11	–

Table 6.5 Summary of the analyses on population vigour and environmental parameter data at Rex Graham, Suffolk

Parameter	Technique	Result
1. Presence/absence of orchids	Linear discriminant analysis (Hawke, 1989)	Orchid establishment favoured by high soil potassium, grass cover and vegetation height; and by low soil magnesium levels
	t-tests between quadrats with and without orchids (this study)	Quadrats with orchids had significantly higher pH but lower levels of magnesium and lower organic content (see Table 6.4)
2. Environmental parameters and orchid density	Multiple linear regression (Hawke, 1989)	No significant relationship
	Single linear regression (this study)	No significant relationship found
3.(a) Effect of parameters on spike height	Stepwise multiple linear regression (Hawke, 1989)	Positive relationship with grass cover. Negative relationship with light intensity, soil moisture and soil temperature
	Linear regression of individual parameters (this study)	Positive relationship with magnesium and phosphorus. Negative relationship with soil temperature
3.(b) Effect of parameters on flower number	Stepwise multiple linear regression (Hawke, 1989)	Positive relationship with grass cover and moss depth. Negative relationship with light intensity, soil temperature and soil moisture
	Linear regression of individual parameters (this study)	Positive relationship with moss depth. Negative relationship with soil temperature and light intensity

Flower number per spike in individual regressions by this author was positively related to moss depth ($p<0.02$) and negatively related here to soil temperature ($p<0.01$) and light levels ($p<0.02$; Figures 6.5(a)-(c)), agreeing well with Hawke's findings (Table 6.4). However, considering the relationship with light intensity (Figure 6.5(c)), if the data point at 57 on the y-axis had not been recorded, the relationship could be positive, and this relationship must be considered somewhat unreliable. Considering the problems with the method of recording light levels, this result should probably be ignored.

(a)



(b)

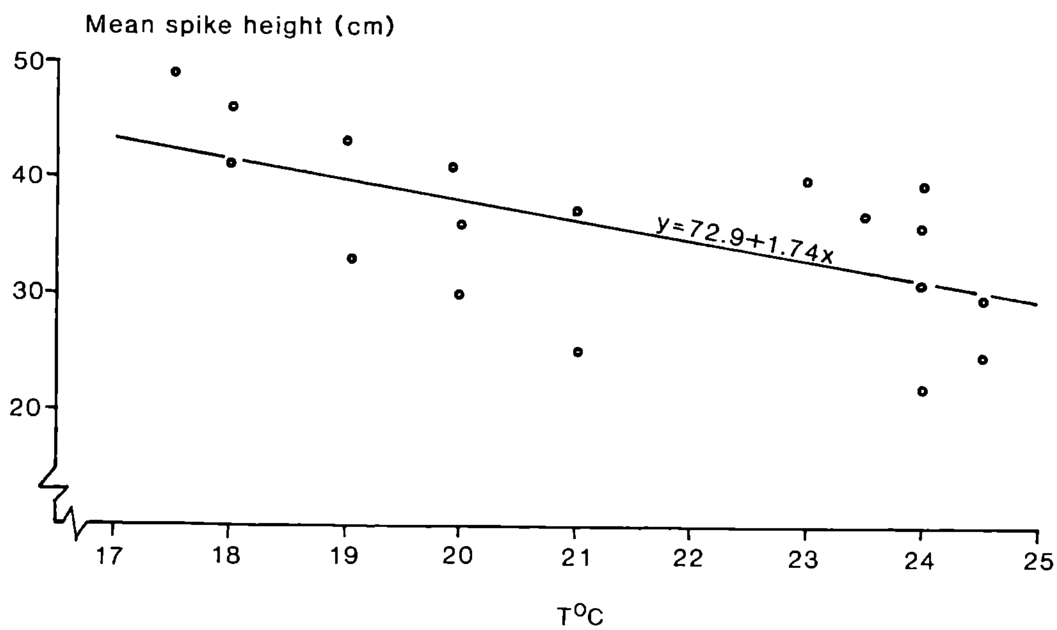


Figure 6.4 Relationship between (a) orchid spike height and levels of magnesium and phosphorus, and (b) spike height and soil temperature at Rex Graham, Suffolk

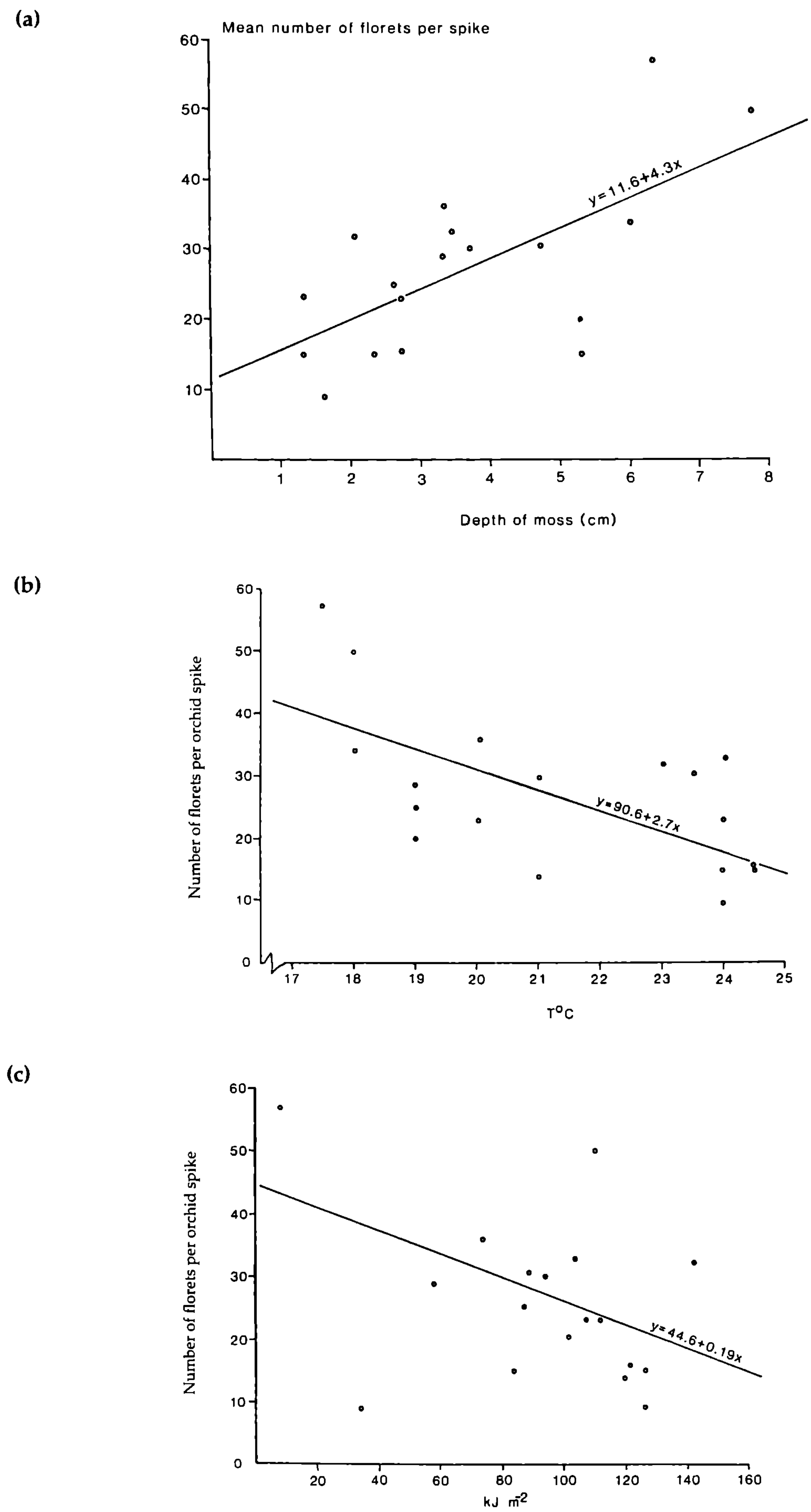


Figure 6.5 Relationship between (a) depth of moss and number of florets per spike, (b) number of florets per spike and soil temperature, (c) number of florets per spike and light levels at Rex Graham, Suffolk

Problems with the analyses

Other factors identified in Hawkes (1989) analysis as influencing establishment or parameters of orchid vigour are counter-intuitive and some of his analyses appear unreliable. They were often not supported by the analyses done here. This is difficult to assess statistically as Hawke (1989) did not provide significance levels or r^2 values for his linear discriminant or regression models. All new analyses have had significances calculated. Part of the disagreement in results may be derived from the small data sets used.

Discussion

From the comparison of environmental variables between Bucks 1 and Rex Graham it would appear that the latter experiences a more Continental microclimate and has a more impoverished soil. These conditions are similar to those described by Farrell (1985) for sites she visited in Europe, where the orchid colonies are larger and individuals similarly robust. Intuitively, soil and microclimate differences between the sites might explain the difference in population size and vigour. However, results from the analysis of the influence of environmental variables on plant vigour conducted at Rex Graham may support an alternative explanation.

Orchid establishment is favoured by low levels of soil organic content and available magnesium. However, the mean value for organic content for the Bucks 1 site where orchids are established at 4.8% is more than twice the level of quadrats at Rex Graham where orchids have not established (2.26%). Clearly, the Rex Graham population requires lower organic contents for establishment. Similarly, the mean level of magnesium for quadrats without orchids at Rex Graham (32 mg l^{-1}) is still less than the site mean for Bucks 1 of 43.5 mg l^{-1}. The data suggest that, overall, the Rex Graham population requires a far more impoverished soil and has a far narrower range of tolerance for germination and establishment conditions than the orchids at Bucks 1. This appears to be true despite the heavy shading and unfavourable management at Bucks 1, such that inherent soil characteristics appears to be a more critical factor than shading.

The density of orchids in a quadrat could not be correlated with any environmental factors, not even magnesium or soil organic content. It is possible that such factors determine the probability of establishment, but that other biotic factors such as competition with surrounding vegetation and the depredations of invertebrate grazers and predators may control the success rate of individual species. The data on competition may not be precise enough to reveal relationships and no data on the other factors were collected.

There was a negative relationship between soil temperature and vigour (both spike height and flower number). However, at Bucks 1, soil temperature is significantly lower than Rex Graham (Table 6.3) with a great deal of overlap in the range of values recorded (Figure 6.3). Intuitively, one would expect the orchids to be more vigorous than at Rex Graham, but they are less vigorous. Similarly, individual regression analysis reveals a positive relationship between spike height and levels of available magnesium and especially, phosphorus. This is understandable as both are essential nutrients for plant growth. However, levels of both are significantly higher at the Bucks 1 site (Table 6.3), although there is a great deal of overlap in the range of values (Figure 6.3). Nevertheless, the orchids are much smaller than those of Rex Graham. Thus the two populations are showing contradictory growth responses to the same environmental variables. The greater robustness of the Rex Graham orchids is not due to clearance of trees and more light because even when they were densely shaded they were tall and many-flowered (Anon., 1956; Trist, 1982), while conversely, even orchids growing in the open at Bucks 1 are typically small (Havers, personal communication).

When two populations show different responses to the same environmental variables it suggests one of three explanations:

1. *The measured relationships are erroneous, arising from either an inadequate data set or through statistical chance.* It is true that the data sets are relatively small and that larger samples from both sites would boost reliability of the data, but at least for the new analyses presented here, statistical significances were calculated. The generalisations above are drawn from a range of significant relationships and analyses, not from one or two. While the response of the orchid to individual factors may be susceptible to problems of small data sets or measurement methods, the overall argument is unlikely to be.

2. *There are other interrelated variables at work that were not measured.* It is possible that other unmeasured variables have a stronger influence on the orchids than those measured in this study; if so, they are likely to be biotic factors such as the level of invertebrate grazing or competitive effects of surrounding vegetation. Comments in Farrell (1985) suggest that grazing at Bucks 1 is likely to be less than at Rex Graham due to habitat changes at Bucks 1 reducing the abundance of slugs, the main grazers. This would favour increased plant fitness at Bucks 1. Predation caused by small mammals is a recorded factor at Rex Graham, but not Bucks 1, again favouring plant fitness at Bucks 1. Plant parasites and viruses have not been recorded on *O. militaris* (Farrell, 1985). Competitive interaction with other vegetation types were not recorded at both sites so that no statistical comparison could be undertaken, but the problem with the moss carpet detailed at Rex Graham has already been described.

3. *The two populations have separate genetic origins.* It is possible that the Rex Graham population is a recent derivation from Continental stock. It is well outside the historical range of the species (Farrell, 1985), and it is the most proximal location to Continental stock of all the historical sites in the UK. Similarity to the Continental physiognomy suggests common genetic origin. It is concluded that of the three alternatives, genetic differences are the most likely explanation.

The possibility of the Rex Graham population being derived from European stock begs the question of how it arrived in the UK. Military orchid seeds are numerous, tiny and extremely light (7×10^{-7}g, Farrell, 1985), and could have blown here. However, this would have been against prevailing winds. If seed scattering were random, one might expect colonisation in other parts of Breckland where chalk rises to the surface and the climate is Continental, but none have been known to occur (Trist, 1979).

Conclusion

This study has elucidated the response of *Orchis militaris* to management. It appears to be suppressed by scrub growth and at the Suffolk site also by the growth of a dense moss carpet. Population numbers have responded well to remedial management. Observations regarding pollinators have been collected. It appears that the plant is most likely to be pollinated by bees, with the low success rate perhaps due to poor fragrance and nectar production. The orchid appears to be favoured by a Continental microclimate and by impoverished and infertile chalky soils. However, the response of the two populations studied to variations in key environmental variables appears to be different. The soil conditions at Bucks 1 suggest it should be a more numerous colony with more vigorous individuals, whereas there are fewer and smaller plants. It has been suggested that the reason for this is that the Rex Graham orchids are genetically distinct, being derived from more robust European genetic stock. However, these conclusions should be treated with some caution; the data were derived from small samples and the differing analyses did not always produce complementary results. The study should be seen as a basis for further study rather than a definitive statement.

Acknowledgements

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Chapter 7

The lichens of Breckland and the effects of afforestation

Christopher Hitch and Peter Lambley

Summary

The impact of afforestation in Breckland on the lichen communities on trees and on heathlands is discussed. There is a moderately interesting lichen flora on some of the deciduous trees within the forest and the plantations appear to provide some shelter from air pollution and damage from agricultural chemicals. However, the conifers have a very poor lichen flora as in other parts of lowland England and possible explanations for this are discussed. The main interest in the lichen flora is centred on the lichen communities on acid sandy heaths and calcareous grassland. This flora has a continental element comparable to the flowering plants and includes a number of species which are rare or absent from elsewhere in the British Isles. In recent years there has been a marked decline in the quality of the communities and several species are now becoming very rare with those on calcareous soils worst affected. Many of the grasslands are no longer grazed and have become rank. The lack of grazing has also encouraged the spread of pine from the adjacent plantations and this appears to have had a significant effect on the vegetation, probably by altering the microclimate. However, there have also been declines on sites where pine invasion is not a problem and pollution perhaps from nitrates is considered a possible factor. The implications for conserving these lichens are briefly discussed.

Introduction

The lichen flora of East Anglia is not particularly rich, with 352 species recorded from Norfolk (Lambley, 1988) and 428 species recorded from Suffolk. The Breckland lichen flora for the most part does not differ greatly from that in the rest of East Anglia, with lichen communities developed on stone, principally in churchyards and on old walls, trees in woodland and parkland and on the ground on heaths. However, Breckland is noteworthy for having a number of lichen communities on heaths and on calcareous grasslands which are either better developed or which are more often coastal elsewhere in the British Isles. Another feature of the flora is a continental influence comparable to that found in the flowering plants, and several species are restricted within the British Isles to this area. The afforestation of Breckland has been one factor in the reduction in the size and quality of these communities, though it does appear that other factors are also involved.

Lichen habitats

Saxicolous communities

In the absence of natural stone outcrops, the lichens on stone are mostly confined to walls and churchyards. The flora of these habitats differs little from those in other parts of East Anglia and has been described by Lambley (1988). This habitat has presumably been little affected by the afforestation of the Breckland and is therefore not discussed further. The lichen nomenclature follows Purvis *et al.* (1992).

Corticolous communities

The lichen flora of deciduous trees has been influenced by the apparent absence of ancient woodland (Goodfellow and Peterken, 1981) and moderate levels of air pollution which are known to occur. Using the pollution scale developed by Hawksworth and Rose (1970) Breckland appears to fall into zone 7, that is the lichen flora indicate that winter sulphur dioxide (SO_2) levels are equivalent to about

40 µg m^{-3}. This, however, may reflect previous levels as recent measurements indicate lower levels of around 11 µg m^{-3} (Williams *et al.*, 1989). In a few sites ancient trees survive, as at Merton Park on the edge of Breckland, where one oak had a flora which included two species considered by Rose to be ancient woodland indicators – *Lecanactis lyncea* and *L. premnea*. However, such survivals are rare. The forest does appear to have some beneficial effect in that deciduous trees growing along the forest roads generally appear to have a richer flora than those in other parts of the area. This is also apparent in the Stanford Army Training Area. The reason appears to be due to the lack of exposure to agricultural chemicals, particularly artificial fertilisers which are thought to be damaging to lichens (James, 1973). It is also possible that the forest provides some shelter from long distance air pollution, in particular sulphur dioxide derived from power stations along the Trent and elsewhere. The avenue of hybrid limes at Santon Downham for instance has a flora of about 20 species including several which in East Anglia are rarely found outside parkland, including *Chrysothrix candelaris* and *Calicium viride*. *Parmelia caperata*, a species which is moderately sensitive to air pollution is relatively common on deciduous trees in the forest. Perhaps the most interesting species within the forest boundary is *Fellhanera bouteillei* which grows on the leaves and twigs of box (*Buxus sempervirens*). It is known only in East Anglia from plantations near Great Hockham where it probably benefits from the high humidity within the forest and which is accentuated by the numerous small pools in the area.

Compared with the deciduous trees, the conifers have an extremely poor lichen flora with only the pollution tolerant *Lecanora conizaeoides* and *Hypogymnia physodes* recorded on them. Rose (personal communication) states that this is also true for plantations in Sussex and Hampshire with the addition of *Platismatia glauca*. However, old subspontaneous pine on New Forest heaths has a slightly richer flora which also includes *Parmelia saxatalis*, *P. caperata*, *Parmeliopsis aleurites*, *Foraminella hyperopta*, *Usnea subfloridana*, and very rarely *Bryoria fuscescens*, *Hypocenomyce scalaris* and *Trapeliopsis granulosa*. In contrast, Coppins (personal communication) has recorded 139 taxa from the old plantations of Culbin Forest in Morayshire, of which 67 were corticolous, 17 of these were restricted to pine and the total flora on the pine was about 40. However, these plantations are within the natural geographic range of *Pinus sylvestris*. Native Scottish pinewoods are in contrast much richer and Coppins (personal communication) has recorded 354 taxa from these woodlands though this includes some terricolous species. The reasons for the poverty of plantation pines in lowland Britain are probably due to a number of factors, including:

- The recent age of the forests.
- The low light levels in most plantations.
- Air pollution increasing the already acid nature of the bark.
- The absence of old dead wood, an important habitat in native forests.
- Climate, in particular the low rainfall.
- The long distance from a source of propagules.

The terricolous communities

On the Breckland heaths plant communities rich in lichens have developed on two very different soils: one shallow and extremely calcareous and the other deep acid sands. Watt (1940) in his classic study on the importance of soil in determining vegetation patterns in Breckland called the extreme calcareous community 'grassland A' and the acid grasslands E, F and G. They are both habitats where there is less competition for lichens from flowering plants. The lichen communities that develop on the deep acid sands are often referred to as lichen heath and when well developed are considered to represent examples of the *Coelocaulon aculeatum* – *Cladonia arbuscula* sub-community of the *Festuca ovina* – *Agrostis capillaris* – *Rumex acetosella* grassland (U1a) in the National Vegetation Classification (NVC) system. In Breckland this community is now best developed at Wangford Glebe, Foxhole Heath, part of Deadman's Grave, Icklingham, and Thetford Heath (especially the military area), usually where there are still active rabbit warrens. These communities notable for the extensive areas which are dominated by lichens particularly *Cladonia* species include *Cladonia arbuscula*, *C. ciliata* var. *tenuis*, *C. portentosa*, *C. gracilis*, *C. squamosa*, *C. cervicornis* subsp. *verticillata*, *C. foliacea*, *C. furcata* and *Coelocaulon aculeatum*. The stands in Table 7.1 from Foxhole Heath, Suffolk, give an indication of the composition of this community.

Table 7.1 Four stands from Foxhole Heath, Suffolk. Domin scale; 1991 data, 1.0 m x 1.0 m quadrats

	1	2	3	4
Bare ground %	2	20	2	0
Lichens				
Cladonia arbuscula	–	–	8	8
C. ciliata var. *tenuis*	5	8	4	–
C. coccifera agg.		1	–	–
C. furcata	4	4	–	–
C. gracilis	4	–	4	1
C. portentosa	1	–	2	–
C. squamosa	1	–	–	–
C. uncialis ssp. *biuncialis*	2	1	1	–
Coelocaulon aculeatum	2	–	–	–
Bryophytes				
Dicranum scoparium	–	–	–	4
Polytrichum piliferum	5	2	1	–
Ptilidium ciliare	–	2	–	1
Herbaceous vegetation				
Agrostis capillaris	4	2	1	1
Erodium cicutarium	–	–	–	1
Festuca ovina	7	5	5	5
Ornithopus perpusillus	–	–	–	1
Rumex acetosella	2	1	–	1
Senecio sylvaticus	3	2	1	–
Teesdalia nudicaulis	4	3	1	2

Within the British Isles *Verrucaria xyloxena* (Orange, 1991) is known only from Thetford Heath where it was recorded by James in 1959 from this community, but has not been seen recently. There is a 19th century record for *Usnea articulata* from Wangford Warren (Bloomfield, 1905). This spectacular lichen is now largely confined to trees and shrubs in south-west England; however, it still occurs on dunes on the north Norfolk coast in a community with *Bryoria fuscescens* also known from Breckland heaths in the 19th and early 20th centuries. It may be that similar communities to those on the north Norfolk coast once occurred on the mobile dunes in Breckland.

The lichen communities on the calcareous soils are of the greatest interest. The sites are situated in the south-western part of Breckland centred on Lakenheath Warren. Their significance was recognised in a survey of lowland heath habitats when Lakenheath Warren was considered to be of Grade 2 status, that is, of national importance (Fletcher *et al.*, 1984). Other known sites are at Deadman's Grave, Icklingham, Thetford Heath, Weeting Heath and Barnham Heath, all recently surveyed by Moore (1993) using the NVC. These communities have developed on very shallow chalk soils which are either natural or the result of human activity. They are characterised by a broken sward with sufficient bare ground for lichens to grow between the small tussocks of *Festuca ovina*, *Hieracium pilosella* and *Thymus* species with low frequencies of other perennials. This grassland was termed 'grassland A' by Watt (1940). Under the nomenclature used in the NVC grassland A is considered to equate to the *Ditrichum flexicaule – Diploschistes muscorum* sub-community of the *Festuca ovina – Hieracium pilosella – Thymus praecox/pulegioides* grassland (CG7a) (Rodwell, 1992). These communities include an interesting assemblage of lichens, some of which occur nowhere else in Britain.

Lichen communities of this type have been studied widely in central Europe where they are referred to as the *Fulgensietum fulgentis*. Follmann (1974) examined this association in central Europe and found that it extended from southern Algeria over the Mediterranean basin to southern Sweden and from the Aral Sea to the Atlantic coast of France. In the British Isles similar communities are known from a number of coastal sites in the south and south-west and inland in Breckland and have been described by James *et al.* (1977), and Gilbert (1978, 1993). The Breckland variant of the community along with those now extinct on the Sussex coast appears closest to the facies found in central Europe (James *et al.*, 1977). There are several species which are now confined to Breckland notably *Buellia asterella* and *Squamarina lentigera*. These communities are dominated by large patches of placodioid or squamulose species such as *Buellia asterella, Catapyrenium pilosellum, C. squamulosum, Cladonia pocillum, Collema tenax, Diploschistes muscorum, Fulgensia fulgens, Psora decipiens, Squamarina lentigera* and *Toninia caeruleonigricans* which together with *Coelocaulon aculeatum, Cladonia rangiformis, C. furcata* and *Peltigera didactyla* give a striking appearance to the community. Linked with this community is an association called the *Lecideetum watsoniae* (James *et al.*, 1977) which is developed on the small chalk pebbles and flints which are scattered over the ground. James *et al.* (1977) list a stand from Thetford Heath which included *Lecidea lichenicola, Clauzdea metzleri, C. monticola, Lecidella stigmatea, Petractis clausa, Physcia adscendens, Protoblastenia rupestris, Staurothele hymenogonia, Verrucaria hochstetteri, V. muralis, V. nigrescens* and *V. viridula*.

These communities are developed at Lakenheath Warren on a gentle south facing slope where there are a series of chalky hummocks which were possibly exposed during the great sand blows of the 17th century. The site at Deadman's Grave was formerly mined for flint until about 1880, while the chalk at Thetford was exposed in about 1945 as a result of road working. In suitable conditions these communities can start to establish quite quickly as can be demonstrated by the colonisation of the chalk rubble exposed during the construction of a pipeline across Lakenheath about 1975. However, some species appear to colonise these new sites less readily than others. *Fulgensia fulgens* and *Psora decipiens* being confined to Lakenheath Warren whereas *Toninia caeruleonigricans* is known from all the suitable sites. This colonisation of secondary habitats has been noted elsewhere in central Europe by Follmann (1974).

Recent changes in the extent and quality of the terricolous communities

These communities have certainly declined both in extent and quality since the beginning of the century. Early losses included Thetford Warren which probably had both the acid and calcareous communities and was developed as a golf course around 1900. Nearly 50% of Lakenheath Warren was lost in the construction of Lakenheath airfield in the war, in particular that part of the Warren with extensive areas of blowing sand. Extensive areas of heathland were lost in agricultural reclamation schemes, particularly in the 1950s (Lambley, 1990; Dolman and Sutherland, 1991). More recently the rabbit population has been significantly reduced by outbreaks of myxomatosis, starting with the first in the spring of 1954. This has had a major impact on heaths by reducing the grazing pressure. This was exacerbated by a reduction or cessation of grazing on many heaths, for instance sheep grazing ceased at Lakenheath Warren in 1956, perhaps for the first time in 2000 years.

Direct losses due to afforestation are not known because of the scarcity of historic data, though Mildenhall Warren and Wangford Warren are recorded as having several interesting species (Bloomfield, 1905). However, the plantations are a vast source of seed and this, coupled with the reduction of grazing, has resulted in a large scale invasion of pine onto many heaths. This was predicted by Farrow (1925) who stated 'it is thus seen that the rabbits prevent the dry upper areas of Breckland from being colonised by young pines and from being converted ultimately into fairly useful pinewoods'. In 1945 there were no trees on Lakenheath Warren except for a few around the Warren Lodge; now pines cover an estimated 50% of the Warren. This change has been well documented by Marrs *et al.* (1986), while Watt (1981) has described some of the changes to the vegetation in the vicinity of the pines.

Although Lakenheath Warren remains the most important site for the grassland A or CG7a communities, it is also the site which has exhibited the greatest deterioration in the last 10 years. In 1984 the lichen communities were still extensive despite the invading pine and the plants appeared to be in a healthy state. One species, *Fulgensia fulgens*, has been restricted to two mounds towards the eastern end of the area since the mid 1960s and probably since at least the 1940s when Watt (1940) referred to it occurring at two sites. There is an early record from Wangford by F.K. Eagle (1769-1856) (Bloomfield, 1905) which may have been from this site. The associated community was recorded by Gilbert and Lambley in 1973 (Gilbert, 1978) and subsequently visited at intervals by one of us (PWL) until 1984. Evidence from photographs and notes suggests that during this time the community remained apparently stable though pines were growing taller in the vicinity and pine seedlings were more dense than previously. During this time the thalli were dense on the ground and produced the effect of a yellow carpet.

However, by 1986 concern over the deterioration of the colony suggested that intervention was needed. A soil core of approximately 10 cm diameter containing 20 minute *Fulgensia* thalli were transplanted into an adjacent area where species such as *Toninia caeruleonigricans*, *Squamarina lentigera* and *Buellia asterella* were still abundant (Hitch, 1988). By the summer of 1988 the transplanted colony was still healthy and had made spectacular growth (Hitch, 1988), though since then it has declined markedly. A number of the Breck specialities have since been transplanted and these are being monitored at present (Gilbert, 1992). The main colony of *Fulgensia* continued to deteriorate and by January 1991 only one tiny fragment of *Fulgensia* thallus remained on the original mounds. This has persisted until the present and with some judicious management has grown slightly. A comparison of the 1973 data with quadrats (non-permanent) placed on the same mounds in 1991 (Table 7.2) illustrates these changes, even allowing for some differences in time of year and methodology.

The striking differences include the loss of bare ground and the growth of mosses particularly *Pleurocarpus* species at the expense of the lichens and some of the small bryophytes like *Encalypta*. The chalk and flint pebbles with their characteristic lichen flora have also been smothered in the moss carpets. Perhaps linked with these changes there may also have been a lowering of pH values. Watt (1940) gives a range of 7.9-8.2 for grassland A in the top 1.5 inches (4 cm) of soil, whereas 1991 data using the method described in Page *et al.* (1982) gives a range of 7.48-7.78 including areas where the characteristic grassland A communities persist. The *Fulgensia* mounds had values of 7.48-7.63. These changes in vegetation have been paralleled on many of the other mounds where the other characteristic species occur. Perhaps this is a result of increased acidity from pine leaf litter.

Observations at Lakenheath Warren suggest that the greatest growth of moss cover has been in areas where there has been the most shelter from pines. This is particularly marked where dense growths of 1 to 4-year-old pines occur on some of the mounds, in places these densities reaching numbers of 9 m^{-2} (1991 data). Under these conditions the ground is covered in moss and the grassland A community is apparently changed irreversibly. These observations agree with those of Watt (1981), who had previously noted that by 1975 the self-sown pinewood, then about 17 years old, was encroaching on grassland A and influencing the vegetation. He suggested that the growth of trees was sheltering the area from northerly winds and possibly reducing the intensity of ground frost. The ground cover was more continuous and under the individual trees the change is even more marked with the short vegetation being replaced by a ranker growth of grasses and herbs, doubtless, he concluded, the effect of shelter and of added water plus leachates from the crowns. The period between 1985 and 1988 included a number of unusually wet years in Breckland. This appears to have encouraged an increased number of seedling pines which combined with the continued growth of the mature trees may have been sufficient to cause the widespread changes seen in grassland A in the absence of grazing.

However, although the growth of pines has almost certainly had a major impact on the lichen communities at Lakenheath Warren, the situation is almost certainly more complicated. A trend towards ranker heathland vegetation throughout Breckland has been noted by others (Lambley, 1990; Dolman and Sutherland, 1991). There are also indications that grasslands and heathlands elsewhere in north-west Europe have exhibited similar trends (During and Willems, 1983).

Even in areas not badly affected by the pine invasion where the sward still remains broken, some of the rarer lichens appear to have declined both in quantity and vigour, those most affected being *Buellia asterella*, *Squamarina lentigera* and *Psora decipiens*. A similar situation has been observed at the other two main

Table 7.2 Six stands from the *Fulgensia* mounds at Lakenheath Warren showing changes between 1973 and 1991. Cover using Domin scale. 1973 data 0.5 m x 0.5 m (+ = adjacent to quadrat): July 1973, O.L. Gilbert and P.W. Lambley; 1991 data using 1.0 m x 1.0 m: March 1991, P.W. Lambley

	1973			1991		
	1	2	3	4	5	6
Bare ground % cover	40	10	35	4	2	>5
Lichens						
Bacidia sabuletorum	+	2	1	–	–	–
Buellia asterella	1	–	2	–	–	–
Catapyrenium sp.	2	2		–	–	
Cladonia foliacea	2	3	2	4	2	2
C. furcata	3	3	1	–	–	–
C. pocillum	–	+	–	–	–	–
C. rangiformis	–	–	–	7	5	6
Coelocaulon aculeatum	2	1	1	1	–	2
Collema tenax	1	–	–	–	1	–
Diploschistes muscorum	+	1	3	1	1	–
Fulgensia fulgens	3	3	3	–	–	1
Lecanora muralis	–	+	2	–	–	–
Peltigera rufescens	+	–	–	2	4	2
Protoblastenia rupestris	3	1	2	–	–	–
Psora decipiens	1	+	–	–	–	–
Sarcogyne regularis	1	1	+	–	–	–
Squamarina lentigera	1	1	+	–	–	–
Toninia caeruleonigricans	3	3	3	–	–	–
Verrucaria hochstetteri	1	1	–	–	–	–
Bryophytes						
Camptothecium lutescens	–	3	+	–	–	–
Ditrichum flexicaule	2	–	+	4	2	2
Encalypta streptocarpa	1	4	4	–	–	1
Hypnum cupressiforme	–	1	–	6	5	6
Herbaceous vegetation						
Astragalus danicus	–	3	–	–	–	–
Botrychium lunaria	1	2	+	–	–	–
Carex arenaria	+	+	2	3	–	4
C.ericetorum	+	–	+	–	–	–
Carex sp.	–	–	–	–	2	–
Carlina vulgaris	1	1	1	1	1	1
Centaurium erythraea	1	2	+	–	–	–
Euphrasia officinalis	–	1	2	–	–	–
Festuca ovina	4	4	3	4	4	5
Galium verum	2	–	–	–	–	–
Hieracium poisella	4	4	2	4	4	5
Koelaria macrantha	2	2	2	–	2	–
Leontodon taraxacoides	–	2	1	–	–	–
Linum catharticum	1	1	2	–	–	–
Lotus corniculatus	4	1	–	–	–	–
Ornithopus perspusillus	–	–	–	–	–	–
Pinus sylvestris	–	+	–			
Prunella vulgaris	–	1	1			
Senecio jacobaea	1	–	+			
Silene otites	+	–	–			
Taraxacum laevigatum	1	2	+			
Thymus sp.	6	5	7			

grassland A sites at Thetford Heath and Deadman's Grave where the swards still remain quite open and pine invasion is not a problem. Some indication of these changes are illustrated by the difference in abundance of *Squamarina lentigera* at Thetford Heath where, in 1977, 91 thalli were counted in 11 one-metre quadrats in an area of calcareous grassland of approximately 320 m^2; a search of this whole area in 1991 revealed 15 thalli. Table 7.3 shows some evidence of other changes which have taken place at Thetford.

Table 7.3 A comparison of stands within one area of Thetford Heath between 1977 and 1991. Quadrats 1.0 m x 1.0 m. Domin scale 1 and 2: P.W. Lambley, July 1977; 3 and 4: C.J.B. Hitch and P.W. Lambley, April 1991

	1977		**1991**	
	1	2	3	4
Bare ground % cover	15	n.a.	10	>5
Lichens				
Bacidia sabuletorum	–	–	1	–
Buellia asterella	–	1	–	–
Cladonia chlorophaea	–	–	–	1
C. foliacea	–	–	–	5
C. rangiformis	–	2	1	4
Peltigera rufescens	–	–	2	–
Squamarina lentigera	3	3	–	1
Toninia caeruleonigricans	2	2	2	2
Bryophytes				
Encalypta streptocarpa	–	1	–	–
Hypnum cupressiforme	–	1	5	5
Herbaceous vegetation				
Achillea millefolium	2	–	1	–
Campanula rotandifolium	2	–	1	1
Carlina vulgaris	–	1	1	4
Erigeron acer	–	1	–	–
Festuca ovina	7	8	8	8
Galium verum	2	–	–	–
Koeleria cristata	2	2	2	2
Lotus corniculatus	2	2	–	–
Medicago lupulina	–	–	1	–
Pilosella officinarum	2	4	4	4
Senecio jacobaea	–	–	–	1
Taraxacum laevigatum	–	2	2	2
Thymus sp.	4	4	4	4
Vicia lathyroides	–	2	–	–

A feature of remaining thalli at all sites, except in one small area of Thetford Heath and Little Heath, Barnham (1993 observation), has been the unhealthy appearance of the plants. The thalli at Thetford in 1991 were fragmented and often infertile, whereas the plant is normally abundantly fertile with thalli 1-2 cm across. In Smith and Sowerby (1790-1814), the thallus of *Squamarina lentigera* is described as having 'a porcelain-like brilliancy and being snow-white though frequently with a pale green hue when moist'. The thalli of *Squamarina lentigera* generally do not have this brilliancy now though they did in the early 1980s. It is difficult to suggest reasons for this though Sochting (1990) has reported widespread injuries to reindeer lichens (*Cladonia* species) in coastal lichen heathland in Denmark in the early 1980s. The lichen matts were black at the edges and in some places large coherent areas of dead thalli were seen. This was believed to be a possible result of air pollution, nitrogen deposition in particular. In Britain there has been at least a twofold increase in nitrates in rain since the mid-19th century (Brimblecombe and Pitman, 1980). The rainfall in the East Midlands and East Anglia (including Breckland) contains the highest average concentration of both ammonium and nitrate in Britain (UK RGAR, 1990). Despite the relatively low rainfall in East Anglia, this results in a greater annual deposition of nitrogen than for other major heathland areas in southern England and is exceeded in Britain only in the western uplands (UK RGAR, 1990). The levels of dry deposited N are also known to be at a high level (Williams *et al.*, 1989). These high concentrations are reflected in the amount of nitrogen in *Calluna* tissue from the Breckland which was found to be greater than anywhere else in Britain (Pitcairn *et al.*, 1991). So far damage has not been observed in *Cladonias* in the Breckland but it is possible that some of the squamulose and placoid species such as *Buellia asterella* and *Squamarina lentigera* might be more sensitive. However, if high levels of nitrogen were having an impact on the lichen flora one might expect an increase in nitrophilous species such as *Xanthoria* and *Physcia*; this does not seem to have happened.

During and Willems (1986) have also documented the impoverishment of the Bryophyte and lichen flora of the Dutch Chalk grasslands in the 30 years 1953-1983, which appear to broadly parallel those in Breckland with the loss of species such as *Catapyrenium lachneum*, *Toninia caeruleonigricans* and *Squamarina cartilaginea* (a species closely related to *S. lentigera*). They hypothesised that this change was mainly the result of the combined effects of the abandonment of the old grazing regime (which was only replaced in a few places by mowing) and also of air pollution. They suggest that despite the large buffering capacity of the chalk soil, air pollution might act either indirectly through the extra input of nutrients (mainly nitrogen) leading to a higher productivity and a denser herb layer or directly on some species of bryophyte and lichen.

The best indications at present are that the decline in the terricolous lichen floras, especially of those on calcareous soils, appears to be due to a combination of factors of which lack of grazing is probably the most important. Positive conservation measures now under way, such as the removal of pines from sites like Lakenheath Warren and the reinstatement of grazing, may restore these habitats but the evidence from Deadman's Grave and Thetford Heath suggest that these measures may not be enough to prevent the gradual loss of the rarer lichens from the Breckland flora.

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Chapter 8

The effect of pine afforestation on the Lepidoptera of Breckland

Gerry Haggett and Michael Hall

Summary

Breckland is of international importance for its calcareous heath which supports specialised Lepidoptera. Until 18th century planting of shelter belts and coverts Breckland was described as 'an almost treeless waste'. Pine afforestation by the Forestry Commission began in 1922. The majority of land planted was grassland, heatherland and the true brecks, which was the preferred habitat of several species of Lepidoptera unique in Britain. The Lepidoptera of the area were well known by the end of the last century. Comparison with the present day fauna reveals the extinction of some species, with others much declined or endangered.

The secondary habitat provided by the forest has encouraged a multitude of common Lepidoptera, which were already present in Norfolk and Suffolk, to exploit ruderal ground plants, broadleaved shrubs and trees that have become established within the Scots pine forest. But the importance of Thetford Forest Park for common Lepidoptera must be seen in the context of past understocking within its plantations and, above all, in the choice of the light-crowned Scots pine as the principal conifer. The change to Corsican pine and the increased demand for more complete establishment of the crop are likely to offer fewer opportunities for the present wide range of common Lepidoptera in the forest.

Consideration should be given to the conservation of Lepidoptera by the restoration of calcareous heath sites, *Calluna* sites, ride improvement, and to sensitive weeding and cleaning. Scots pine and large areas of over-mature conifers should be maintained as far as is practicable.

Introduction

Lepidoptera, along with birds and flowering plants, are among the few major wildlife groups of the Breckland that have been extensively studied since the last century. They offer an oppor-tunity to trace population changes as the character of habitat has altered from open heath to coniferous forest.

Four moths, unique in Britain to the Breck ecosystem, are accepted as critical indicator or 'key' species (Appendix 8.1). Other species described in this study as 'key' are also from lists based on national scarcity made in 1984 and 1987 by the Nature Conservancy Council; these are Red Data Book categories 1, 2 and 3, Notable a and Notable b. To these are added non-listed species of calcareous heath and acid heath that have declined in the Forest Park since 1984 (see also Welch and Hammond, Chapter 9).

In this study the availability of the specialised habitats required by the macro-Lepidoptera of the Breckland is compared with what is to be found after the establishment of pine forest over a large part of the area. The structure of the forest is reviewed as a habitat for resident Lepidoptera and an assessment is given of their response to the sequence of forest operations.

Breckland before afforestation

For most of historical time Breckland was devoid of trees. Clarke (1925) summarised the impressions of bleakness, openness and near-desert conditions recorded by travellers of the 17th and 18th centuries. Planting of Scots pine hedges and belts and small copses began just before the time of the enclosures, which date from 1801. Further planting was done by larger estates in the 19th century. By the time of the

First World War the Breck landscape still offered open spaces, heathland and some shifting sands, with woodlands mainly clustered around estate centres.

The land acquired for afforestation by the Forestry Commission was largely calcareous grass heath, heather heath and the true brecks, that is, land intermittently put under temporary cultivation and then left fallow. Much had been intensively warrened for rabbits since the 15th century (see Sheail and Bailey, Chapter 2). Within this area were several wetlands concentrated along the valleys of the rivers Wissey, Little Ouse and Lark. There was little acquisition of woodland, and none of ancient woodland sites. By 1950, about one-fifth of the overall area of Breckland had been acquired by the Forestry Commission.

There is recorded history, between 1909 and 1990, of the change of the Breck habitat at one important site that may be indicative of much of the area. In 1909 Clarke recorded 'a few hundred yards east of Cranwich Heath, on both sides of the road between there and Mundford, Spanish catchfly (*Silene otites*) was growing almost as thickly as a hay crop' (Clarke, 1910). In 1950 three of the key Breck Lepidoptera, *Hadena irregularis, Emmelia trabealis* and *Scopula rubiginata* were present along these road verges and on the adjacent Forestry Commission fallow site, now leased to the Ministry of Defence (Haggett, 1951b, 1952a). By 1990 these three moths were absent. The ground on the south side of the road to Mundford was high forest and to the north agricultural. The *Silene otites* that was so dense in 1909 for some 2 kilometres, and which still occupied about half a hectare in 1950, was by 1990 reduced to a few scattered plants within a few square metres.

The Lepidoptera before afforestation

Three habitats dominated before afforestation – calcareous heath, acid heath and wetlands – although the latter occupied only a fraction of the total Breck area. Each had their own specialised moths in addition to a much greater number of species tolerant of a wider range of site types. There were also species associated with broadleaved trees and shrubs that occupied the secondary woodlands and spinneys, and the hedgerows.

The Breck had long been known for an assemblage of moths, not recorded elsewhere in Britain which, although colony insects, were well distributed through the area. It was also renowned for a number of moths that occur elsewhere on coastal sand-dunes, while a further group was associated with chalk downland in other parts of the country. Moths of the calcareous heath appeared to be dependent upon open conditions and sparse ground cover. Most thrive on abandoned agricultural land where they fed from a variety of plants and their presence on roadside verges was commonplace. The fauna was well known and described by county recorders. The following are the principal species (in declining order of Nature Conservancy Council ranking (Hadley, 1984; Shirt, 1987).

- **From acid heath**: *Noctua orbona, Plebejus argus, Hipparchus semele, Eupithecia absinthiata* f. *goossensiata, Chesias rufata, Arctia villica, Diachrisia sannio, Xestia agathina, Stilbia anomala.*
- **From calcareous heath**: *Hadena irregularis, Emmelia trabealis, Tyta luctuosa, Scopula rubiginata, Lithostege griseata, Heliothis viriplaca, Phibalapteryx virgata, Adscita statices, Eupithecia subumbrata, Sideridis albicolon, Heliophobus reticulata, Apamea sublustris, Erynnis tages.*
- **From wetlands**: *Perizoma sagitatta, Senta flammea, Archanara algae, Sesia apiformis, Idaea muricata, Eupithecia trisignaria, Anticollix sparsata, Simyra albovenosa, Macrochilo cribrumalis, Clostera pigra, Archanara geminipuncta, Archanara dissoluta, Chilodes maritimus, Deltote uncula, Earias clorana.*
- **From more than one habitat type**: *Sesia bembeciformis, Eupithecia insigniata, Hemaris fuciformis, Photedes fluxa, Rheumaptera cervinalis, Philereme vetulata, Eupithecia dodoneata, Xestia rhomboidea.*

A key moth associated with conifers was *Eupithecia indigata*, and there were two broadleaved woodland species, *Apoda limacodes* and *Drepana cultraria.*

Thetford Forest structure today

A policy of intensive land use for cropping has left little of the total forest area under other forms of land use. Tables 8.1 and 8.2(a), (b), (c) are from Forestry Commission data.

Table 8.1 The land statement, as at 19 March 1987. (More recent data is not presented in a way that allows the ready identification of the categories shown, which are meaningful in wildlife habitat terms.)

	ha
High forest	19 753
Felled	744
Low grade broadleaved	385
Plantation scrub	50
Retained scrub	140
Blank	319
Plantable land in hand	10
Agriculture and holdings	611
Recreation sites	92
	22 104

Table 8.2 Statement of plantations, as at 31 March 1990. (a) Forest type distribution, (b) tree species distribution, (c) tree age class distribution

(a)

Forest type	%
Conifer	85
Conifer/broadleaved mixtures	9
Broadleaves	6

(b)

Conifers	%	**Broadleaves**	%
Scots pine	31	Oak	3
Corsican pine	54	Beech	4
Larches	1	Birch	1
Douglas fir	2	Poplar	1
Other conifers	2	Other broadleaves	1
	90		10

(c)

Age (years)	**Conifer (%)**	**Broadleaved (%)**
1–5	10	1
6–10	11	1
11–20	13	1
21–55	41	64
56–85	25	26
85+ (pre-1900)		7

Forest roads and rides

The significance to wildlife of roads and rides in Thetford Forest Park cannot be overstated. They constitute the largest part of the total open space (about 5%) within the forest and provide a permanent reservoir of plant communities. Within plantations identical communities disappear as the trees close canopy. There is no forest area larger than 20 ha that is not bounded by a permanent ride on one side, or more usually on all sides. The rides also provide permanent linkages of open areas.

Few of the roads and rides occupy a width greater than tree height at maturity, so as each restocked crop ages, the roads and rides become side-shaded, with a great many totally under canopy.

Table 8.3 Forest crop growth phases

Age (years)	%	Habitat description
Clear felled	3	Bare to early establishment
1–5	8	
6–10	9	Late establishment to canopy closure
11–20	12	Thicket
21–55	42	Plantations in thinning
56–85	25	Past normal felling age
85+ (pre 1900)	1	

The forest as a habitat for Lepidoptera

Different age-classes of forest (Table 8.3) provide specific conditions for Lepidoptera. Clear felled and newly stocked land offers the most open conditions for flowering plants with good powers of dispersal and their associated butterflies and moths for up to 5 years. Increasing canopy closure can still allow inter-row regrowth to present a variety of shrub and low woody growth foodplants. The thicket stage, from 11 to 20 years, presents a higher, uniform canopy which is limited to conifer feeders unless it contains broadleaved species such as gorse and broom. Thereafter, heavy selective and line thinning permits increasing light penetration and an increase in the ground and shrub flora. Significant cover is often established by 40 years after planting. The longer the period before felling the greater its potential for woodland and generalist Lepidoptera.

The presence in the Forest Park of such a wide diversity of Lepidoptera is largely a consequence of the widespread distribution of their common foodplants. This is due to two principal factors: firstly, previous use of Scots pine as the main crop; and secondly, past establishment methods. Both are closely inter-related. At Thetford, Scots pine is a thin- and small-crowned conifer casting little shade and thereby permitting much broadleaved invasion. Gaps occurring in the plantations have been occupied by woody growth that supports a far greater variety of Lepidoptera than the pine itself. Further scope for intrusive species arises from *Fomes annosum* attack (see Gibbs and Greig, Chapter 4) and windthrow gaps. Oak, birch, sallow and hawthorn occur commonly and these are the top four larval foodplants (Appendix 8.3). Among ground flora often associated with broadleaves, and gaps in pine crops, are *Lamium* spp., *Plantago* spp., *Rumex* spp., *Stellaria* spp., *Taraxacum officinale* and Gramineae, which are those plants next most frequently used by the Lepidoptera for larval food. However, although a great number of generalised Lepidoptera species are present, specialised Breckland Lepidoptera only occur outside the forest or, in some cases, on broad, permanent rides and open spaces. Only the wetland species have survived intact because very little conifer planting, and only limited poplar planting, was done on that habitat type.

Present day Lepidoptera of Thetford Forest

A total of 492 species of macro-Lepidoptera are known today to be resident within the Thetford Forest Park area, a figure that compares well with any similar sized territory in Great Britain. The habitats within the Forest Park each support a specific assemblage of species with a further group of generalists found in a number of habitats (Table 8.4, Appendix 8.2).

Lepidoptera associated with broadleaved trees are common to a range of woodland types from emergent and immature to long established secondary woodlands. They exclude species that are associated with ancient woodlands of the Midlands and south-east England. The heath and wetland species include moths that have a very restricted British distribution.

The species of calcareous and acid heaths are greatly restricted in numbers probably due to the scarcity of their foodplants and breeding sites. This in turn is linked to a requirement for open space and plant communities free from coarse and woody plant invasion.

Table 8.5 does not include species lost locally which have also suffered larger scale withdrawal from East Anglia, such as fritillary butterflies, or those newcomers that have spread across Britain.

Table 8.4 Preferred habitat of Forest Park Lepidoptera

Habitat	Number of species	% of total species
More than one habitat	249	50
Broadleaved forest	109	22
Calcareous heath	49	10
Acid heath	25	5
Wetland	47	10
Conifer forest	13	3

Table 8.5 Summary of Red Data Book and NCC Notable Lepidoptera of Breckland

Status	Resident before afforestation	(of which wetland)	New arrivals	(of which wetland)
RDB 1 (now extinct)	2			
RDB 2 (now endangered)	2	(1)		
RDB 3	5	(2)	1	
Na	12	(8)	4	(1)
Nb	26	(6)	4	
Total	47	(17)	9	(1)

RDB 1: endangered; RDB 2: vulnerable; RDB 3: rare.Na (Notable a): recorded nationally from 30 or less 10 km squares. Nb (Notable b): recorded nationally from 100 or less 10 km squares.
See Appendix 8.1 for full species list.

The fate of the following six species is of national significance.

- *Plebejus argus* silver-studded blue butterfly (Nb) — This species requires young growth of *Calluna vulgaris* and *Ulex* spp. flowers as larval food. Last sighted in the Brecks at Mildenhall in 1965, just before canopy closure of the pine plantations. Formerly widespread in the southern Breck acid heaths.

- *Hadena irregularis* viper's bugloss moth (RDB 1) — A colony insect dependent upon viper's bugloss (*Silene otites*) on calcareous heath sites, which survived at Cranwich until the 1960s. Unique to the Breck and now believed to be extinct in Britain.

- *Emmelia trabealis* spotted sulphur moth (RDB 1) — Another calcareous heath colony insect which used the common *Convolvulus arvensis* for food. Last seen in the forest at Cranwich and Mundford in 1951. Unique to the Brecks and so now believed to be extinct in Britain.

- *Scopula rubiginata* tawny wave moth (RDB 3) — Formerly widespread throughout Breckland and persisting until 1987 in forest clearings from King's Forest to Mundford. Another calcareous heath moth and one that survives on heaths surrounding the Forest Park.

- *Lithostege griseata* grey carpet moth (RDB 3) — A Breckland speciality frequenting weedy arable land and, in modern times, only recorded in the Forest Park area on arable game crops land at King's and near Brandon. Present throughout Breckland, the larval foodplant is flixweed, *Descurainia sophia*, which requires recently turned soil on calcareous heath.

- *Tyta luctuosa* four-spotted moth (RDB 2) — Known from Lynford and Cranwich as well as from a former wide distribution on calcareous sites. Not recorded from forest areas now although still reported from Breckland.

A number of moths were commonly encountered throughout Breckland until recent years but are now localised, with very low and fragmented populations dependent on flowering Breck plants and, within the Forest Park, upon rideside and clearings. These are: *Arctia villica britannica*, cream-spot tiger, *Heliothis viriplaca*, marbled clover, *Heliophobus reticulata marginosa*, bordered gothic, *Phibalapteryx virgata*, oblique striped, *Apamea sublustris*, reddish light arches, *Catarhoe cuculata*, royal mantle, and *Sideridis albicolon*, white colon.

Some acid heath moths have disappeared from the forest due to diminished availability of heather, but survive on the principal heaths of the surrounding brecks. They include *Eupithecia absinthiata* f. *goossensiata*, ling pug, *Eupithecia nanata angusta*, narrow-winged pug, *Diacrisia sannio*, clouded buff, *Anarta myrtilli*, beautiful yellow underwing, and *Stilbia anomala*, anomalous.

Arrivals since afforestation include *Polygonia c-album*, comma, and *Ladoga camilla*, white admiral, with the latter still only in the eastern broadleaved forest area. Two newcomers are remarkable in having Thetford Forest Park as one of only two centres in Britain: *Spargania luctuata*, the white-banded carpet, a willow-herb feeder found across most of the central blocks of the forest and otherwise only in Kent and East Sussex, since 1950 (Haggett, 1952b), and *Epithecia egenaria*, pauper pug, which feeds in flowers of the avenue limes and which is found elsewhere only in the Wye valley, and dates from 1953 (J. Fenn, personal communication). *Xanthia ocellaris*, pale-lemon sallow, has occupied stands of poplar, as it has elsewhere in eastern England. Two moths not previously recorded from Norfolk are *Deileptenia ribeata*, the satin beauty, which is a birch and conifer feeder, and *Trichopteryx polycommata*, barred tooth-striped that here feeds only on privet. *Hyloicus pinastri*, the pine hawk-moth, has spread throughout southern and eastern England since 1920, being primarily a pine feeder. The larva of the curious little moth, *Parascotia fuliginaria*, waved black, lives on fungi of dead wood and was unknown in this area until 1979.

Exclusively coniferous feeders comprise but 13 species, and they are all moths. Twelve have largely pine-eating larvae but some of these will also feed on larch and Douglas fir. Two eat cypress, another spruce and Douglas fir, and one mainly larch. One is a yew/Douglas fir feeder that will take to pine and birch and there are an additional eight generalised broadleaved feeders which will feed on the common conifers (Hatcher and Winter, 1990). No conifer feeder has caused defoliation problems at Thetford.

Afforestation is only one of the reasons for the decline of heathland Lepidoptera, another being changes in agricultural practice. But whereas small fragmented sites for key species persist elsewhere in the Breck, within the forest area there are few comparable refuges.

Future prospects for Lepidoptera of Thetford Forest Park

The current success of Thetford Forest as a secondary habitat for common Lepidoptera is attributed to the diversity of ground flora, woody shrubs and broadleaved trees present in Scots pine plantations. It follows that modern techniques, that give better success in restocking with Corsican pine, are likely to reduce this diversity and thus the Lepidoptera that live there. Exclusive use of Corsican pine is in itself highly detrimental to ground flora and invertebrates because of its heavy needle litter which grows deeper, and lies unchanged from the time of canopy closure, while the canopy shade is itself much heavier than from Scots pine. Short-rotation clear felling provides open bare-site conditions which support generalist Lepidoptera.

Recommendations to assist survival of key and generalised Lepidoptera in Thetford Forest Park

These are the main recommendations.

1. *Restoration of calcareous heath: creation of reserves.* As the most appropriate and economic time for the removal of land from cropping would be following clear fell, the options for this are fast reducing in areas such as Mundford, where there is the most need. Urgent consideration is therefore paramount. Each reserve should be at least 10 ha in area.

2. *Ride widening.* Widening of rides on the calcareous and *Calluna* sites and their expansion on selected sites.

3. *Open spaces.* Retention and enlargement of open spaces.

4. *Calluna reserves.* The creation of further large *Calluna* reserves, such as that already made at King's Forest.

5. *Scots pine.* Maintain Scots pine and naturally regenerated tree crops on as many sites as possible.

6. *Mature crops.* Maintain as large a total area of well-distributed and overmature conifer crops as can be compatible with other land use requirements, such as amenity and recreation.

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Appendix 8.1
Red Data Book (RDB 1, 2, 3) and NCC Notable a and b (Na, Nb) Lepidoptera of Thetford Forest Park

[a]	*Hadena irregularis* Hufn.	Viper's bugloss	RDB 1	now extinct
[a]	*Emmelia trabealis* Scop.	Spotted sulphur	RDB 1	now extinct
[a]	*Perizoma sagittata* Fabr.	Marsh carpet	RDB 2	
[a]	*Tyta luctuosa* D. & S.	The four-spotted	RDB 2	now endangered
[a]	*Scopula rubiginata* Hufn.	Tawny wave	RDB 3	now endangered
	Eupithecia egenaria H.-S.	Pauper pug	RDB 3	(first British record 1953)
[a]	*Lithostege griseata* D. & S.	Grey carpet	RDB 3	
[a]	*Senta flammea* Curt.	Flame wainscot	RDB 3	
[a]	*Archanara algae* Esp.	Rush wainscot	RDB 3	
[a]	*Heliothis viriplaca*	Marbled clover	RDB 3	now endangered
[a]	*Sesia apiformis* Cl.	Hornet moth	Na	
[a]	*Sesia bembeciformis* Hb.	Lunar hornet moth	Na	
[a]	*Idaea muricata* Hufn.	Purple-bordered gold	Na	
[a]	*Phibalapteryx virgata* Hufn.	Oblique striped	Na	
	Spargania luctuata D. & S.	White-banded carpet	Na	(first British record 1924)
[a]	*Eupithecia insigniata* Hb.	Pinion-spotted pug	Na	
[a]	*Eupithecia trisignaria* H.-S.	Triple-spotted pug	Na	
	Chloroclystis chloerata Mab.	Sloe pug	Na	(first British record 1971)
[a]	*Anticollix sparsata* Treit.	Dentated pug	Na	
	Trichopteryx polycommata D. & S.	Barred tooth-striped	Na	(first Norfolk record 1980)
[a]	*Hemaris fuciformis* Linn.	Broad-bordered bee hawk	Na	
	Xanthia ocellaris Borkh.	Pale-lemon sallow	Na	
[a]	*Simyra albovenosa* Goeze	Reed dagger	Na	
[a]	*Photedes fluxa* Hb.	Mere wainscot	Na	
[a]	*Elaphria venustula* Hb.	Rosy marbled	Na	
[a]	*Macrochilo cribrumalis* Hb.	Dotted fan-foot	Na	
[a]	*Adscita statices* Linn.	The forester	Nb	
[a]	*Apoda limacodes* Hufn.	The festoon	Nb	
[a]	*Plebejus argus argus* Linn.	Silver-studded blue	Nb	now extinct in Breck
[a]	*Drepana cultraria* Fabr.	Barred hook-tip	Nb	
[a]	*Rheumaptera cervinalis* Scop.	Scarce tissue	Nb	
[a]	*Philereme vetulata* D. & S.	Brown scallop	Nb	
[a]	*Eupithecia inturbata* Hb.	Maple pug	Nb	
[a]	*Eupithecia valerianata* Hb.	Valerian pug	Nb	
[a]	*Eupithecia subumbrata* D. & S.	Shaded pug	Nb	
[a]	*Eupithecia indigata* Hb.	Ochreous pug	Nb	[b]
[a]	*Eupithecia pimpinellata* Hb.	Pimpinel pig	Nb	
[a]	*Eupithecia dodoneata* Guen.	Oak-tree pug	Nb	
	Ennomos autumnaria Werneb.	Large thorn	Nb	
	Deileptenia ribeata Cl.	Satin beauty	Nb	[b]
[a]	*Paradarisa extersaria* Hb.	Brindled white-spot	Nb	
[a]	*Ptilodontella cucullina* D. & S.	Maple prominent	Nb	
[a]	*Clostera pigra* Hufn.	Small chocolate-tip	Nb	
	Rhyacia simulans Hufn.	Dotted rustic	Nb	
[a]	*Noctua orbona* Hufn.	Lunar yellow underwing	Nb	
[a]	*Xestia rhomboidea* Esp.	Square-spotted clay	Nb	
[a]	*Sideridis albicolon* Hb.	White colon	Nb	
[a]	*Heliophobus reticulata marginosa* Haw.	Bordered gothic	Nb	now endangered in Breck
[a]	*Orthosia populeti* Fabr.	Lead-coloured drab	Nb	

[a]	*Apamea sublustris* Esp.	Reddish light arches	Nb
[a]	*Archanara geminipuncta* Haw.	Twin-spotted wainscot	Nb
[a]	*Archanara dissoluta* Treit.	Brown-veined wainscot	Nb
[a]	*Chilodes maritimus* Tausch.	Silky wainscot	Nb
[a]	*Deltote uncula* Cl.	Silver hook	Nb
[a]	*Earias clorana* Linn.	Cream-bordered green pea	Nb
	Parascotia fuliginaria Linn.	Waved black	Nb

[a] Indicates species resident before afforestation.
[b] Indicates species with conifer feeding larvae.

Appendix 8.2
Lepidoptera species found in each of the habitat types listed in Table 8.4. Records of vagrants and those of undetermined status have been omitted.

(a) Generalised species from more than one habitat

Hepialus humuli humuli Linn.	Ghost moth
Hepialus sylvina Linn.	Orange swift
Hepialus hecta Linn.	Gold swift
Hepialus lupulinus Linn.	Common swift
Zeuzera pyrina Linn.	Leopard moth
Sesia bembiciformis Hb.	Lunar hornet moth
Thymelicus sylvestris Poda	Small skipper
Ochlodes venata faunus Turati	Large skipper
Gonepteryx rhamni rhawni Linn.	The brimstone
Pieris brassicae Linn.	Large white
Pieris rapae Linn.	Small white
Pieris napi sabellicae Steph.	Green-veined white
Anthocharis cardamines britannica Ver.	Orange-tip
Aglais urticae Linn.	Small tortoiseshell
Inachis io Linn.	The peacock
Pyronia tithonus britanniae Ver.	The gatekeeper
Maniola jurtina insularis Thompson	Meadow brown
Poecilocampa populi Linn.	December moth
Lasiocampa quercus quercus Linn.	Oak eggar
Philudoria potatoria Linn.	The drinker
Gastropacha quercifolia Linn.	The lappet
Cilix glaucata Scop.	Chinese character
Thyatira batis Linn.	Peach blossom
Habrosyne pyritoides Hufn.	Buff arches
Alsophila aescularia D. & S.	March moth
Jodis lactearia Linn.	Little emerald
Timandra griseata Peters.	Blood-vein
Scopula imitaria Hb.	Small blood-vein
Scopula floslactata floslactata Haw.	Cream wave
Idaea biselata Hufn.	Small fan-footed wave
Idaea seriata Schr.	Small dusty wave
Idaea dimidiata Hufn.	Single-dotted wave
Idaea aversata Linn	Riband wave
Xanthorhoe spadicearia D. & S.	Red twin-spot carpet
Xanthorhoe ferrugata Cl.	Dark-barred twin-spot carpet
Xanthorhoe quadrifasciata Cl.	Large twin-spot carpet
Xanthorhoe montanata montanata D. & S.	Silver-ground carpet
Xanthorhoe fluctuata fluctuata Linn.	Garden carpet
Scotopteryx chenopodiata Linn.	Shaded broad-bar
Epirrhoe alternata alternata Mull.	Common carpet
[a] *Epirrhoe rivata* Hb.	Wood carpet
Camptogramma bilineata bilineata Linn.	Yellow shell
Larentia clavaria Haw.	The mallow
Anticlea badiata D. & S.	Shoulder stripe
Anticlea derivata D. & S.	The streamer
Pelurga comitata Linn.	Dark spinach
Eulithis testata Linn.	The chevron
Eulithis pyraliata D. & S.	Barred straw
Ecliptopera silaceata D. & S.	Small phoenix

a	*Chloroclysta miata* Linn.	Autumn green carpet
	Chloroclysta citrata citrata Linn.	Dark marbled carpet
	Chloroclysta truncata Hufn.	Common marbled carpet
	Cidaria fulvata Forst.	Barred yellow
	Plemyria rubiginata rubiginata D. & S.	Blue-bordered carpet
	Colostygia pectinataria Knoch	Green carpet
	Hydriomena furcata Thunb.	July highflyer
	Horisme vitalbata D. & S.	Small waved umber
	Horisme tersata D. & S.	The fern
	Melanthia procellata D. & S.	Pretty chalk carpet
	Rheumaptera cervinalis Scop.	Scarce tissue
a	*Triphosa dubitata* Linn.	The tissue
	Philereme vetulata D. & S.	Brown scallop
	Philereme transversata britannica Lempke	Dark umber
	Euphyia unangulata Haw.	Sharp-angled carpet
	Euphyia unangulata Haw.	Sharp-angled carpet
	Epirrita christyi Allen	Pale November moth
	Epirrita autumnata Borkh.	Autumnal moth
	Operophtera brumata Linn.	Winter moth
	Perizoma alchemillata Linn.	Small rivulet
	Perizoma bifaciata Haw.	Barred rivulet
	Perizoma flavofasciata Thunb.	Sandy carpet
	Perizoma didymata didymata Linn.	Twin-spot carpet
	Eupithecia exiguata exiguata Hb.	Mottled pug
	Eupithecia insigniata Hb.	Pinion-spotted pug
	Eupithecia pygmaeata Hb.	Marsh pug
	Eupithecia centaureata D. & S.	Lime-speck pug
	Eupithecia absinthiata Cl.	Wormwood pug
	Eupithecia assimilata Doubl.	Currant pug
	Eupithecia vulgata vulgata Haw.	Common pug
	Eupithecia tripunctaria H.-S.	White-spotted pug
	Eupithecia subfuscata Haw.	Grey pug
	Eupithecia succenturiata Linn.	Bordered pug
a	*Eupithecia fraxinata* Crewe	Ash pug
	Chloroclystis v-ata Haw.	The V-pug
a	*Chloroclystis chloerata* Mab.	Sloe pug
	Chloroclystis rectangulata Linn.	Green pug
	Gymnoscelis rufifasciata Haw.	Double-striped pug
a	*Trichopteryx polycommata* D. & S.	Barred tooth-striped
	Acasis viretata Hb.	Yellow-barred brindle
	Abraxas grossulariata Linn.	The magpie
	Lomaspilis marginata Linn.	Clouded border
	Ligdia adustata D. & S.	Scorched carpet
	Petrophora chlorosata Scop.	Brown silver-line
	Opisthograptis luteolata Linn.	Brimstone moth
	Ennomos autumnaria Werneb.	Large thorn
	Ourapteryx sambucaria Linn.	Swallow-tailed moth
	Apocheima pilosaria D. & S.	Pale brindled beauty
	Biston betularia Hufn.	Peppered moth
	Agriopis marginaria Fabr.	Dotted border
	Erannis defoliaria Cl.	Mottled umber
	Menophra abruptaria Thunb.	Waved umber
	Peribatodes rhomboidaria D. & S.	Willow beauty
	Alcis repandata repandata Linn.	Mottled beauty
	Ectropis bistortata Goeze	The engrailed
	Ectropis crepuscularia D. & S.	Small engrailed
	Aethalura punctulata D. & S.	Grey birch

	Cabera pusaria Linn.	Common white wave
	Cabera exanthemata Scop.	Common wave
	Lomographa bimaculata Fabr.	White-pinion spotted
	Lomographa temerata D. & S.	Clouded silver
	Theria primaria Haw.	Early moth
	Campaea margaritata Linn.	Light emerald
	Sphinx ligustri Linn.	Privet hawk-moth
	Mimas tiliae Linn.	Lime hawk-moth
	Smerinthus ocellata Linn.	Eyed hawk-moth
	Laothoe populi Linn.	Poplar hawk-moth
a	*Hemaris fuciformis* Linn.	Broad-bordered bee hawk-moth
	Deilephila elpenor Linn.	Elephant hawk-moth
	Phalera bucephala Linn.	Buff-tip
	Cerura vinula Linn.	Puss moth
	Furcula furcula Cl.	Sallow kitten
	Notodonta dromedarius Linn.	Iron prominent
	Eligomodonta ziczac Linn.	Pebble prominent
	Pheosia gnoma Fabr.	Lesser swallow prominent
	Pheosia tremula Cl.	Swallow prominent
	Ptilodon capucina Linn.	Coxcomb prominent
	Pterostoma palpina Cl.	Pale prominent
	Clostera curtula Linn.	Chocolate-tip
	Diloba caerulocephala Linn.	Figure of eight
	Orgyia antiqua Linn.	The vapourer
	Euproctis similis Fuess.	Yellow-tail
	Leucoma salicis Linn.	White satin moth
	Thumatha senex Hb.	Round-winged muslin
	Eilema griseola Hb.	Dingy footman
	Eilema complana Linn.	Scarce footman
	Eilema lurideola Zinck.	Common footman
	Arctia caja Linn.	Garden tiger
	Spilosoma lubricipeda Linn.	White ermine
	Spilosoma luteum Huffn.	Buff ermine
	Diaphora mendica Cl.	Muslin moth
	Phragmatobia fuliginosa fuliginosa Linn.	Ruby tiger
	Nola cucullatella Linn.	Short-cloaked moth
	Euxoa nigricans Linn.	Garden dart
	Agrotis segetum D. & S.	Turnip moth
	Agrotis exclamationis Linn.	Heart and dart
	Agrotis puta puta Hb.	Shuttle-shaped dart
	Axylia putris Linn.	The flame
	Ochropleura plecta Linn.	Flame shoulder
	Rhyacia simulans Hufn.	Dotted rustic
	Notua pronuba Linn.	Large yellow underwing
	Noctua comes Hb.	Lesser yellow underwing
	Noctua fimbriata Schreb.	Broad-bordered yellow underwing
	Noctua janthina D. & S.	Lesser broad-bordered yellow underwing
	Noctua interjecta caliginosa Schaw.	Least yellow underwing
	Diarsia rubi View.	Small square-spot
	Xestia c-nigrum Linn.	Setaceous Hebrew character
	Xestia ditrapezium D. & S.	Triple-spotted clay
	Xestia triangulum Hufn.	Double square-spot
	Xestia baja D. & S.	Dotted clay
	Xestia rhomboidea Esp.	Square-spotted clay
	Xestia sexstrigata Haw.	Six-striped rustic
	Xestia xanthographa D. & S.	Square-spot rustic

	Naenia typica Linn.	The gothic
	Anaplectoides prasina D. & S.	Green arches
	Cerastis rubricosa D. & S.	Red chestnut
	Dicestra trifolii Hufn.	The nutmeg
	Polia nebulosa Hufn.	Grey arches
	Mamestra brassicae Linn.	Cabbage moth
	Melanchra persicariae Linn.	Dot moth
	Lacanobria w-latinum Hufn.	Light brocade
	Lacanobia thalassina Hufn.	Pale-shouldered brocade
	Lacanobia oleracea Linn.	Bright-line brown-eye
	Ceramica pisi Linn.	Broom moth
a	*Hadena compta* D. & S.	Varied coronet
	Hadena bicruris Hufn.	The lychnis
	Cerapteryx graminis Linn.	Antler moth
	Tholera cespitis D. & S.	Hedge rustic
	Tholera decimalis Poda	Feathered gothic
	Orthosia cruda D. & S.	Small quaker
	Orthosia opima Hb.	Northern drab
	Orthosia gracilis D. & S.	Powdered quaker
	Orthosia cerasi Fabr.	Common quaker
	Orthosia incerta Hufn.	Clouded drab
	Orthosia gothica Linn.	Hebrew character
	Mythimna ferrago Fabr.	The clay
	Mythimna impura impura Hb.	Smoky wainscot
	Mythimna pallens Linn.	Common wainscot
	Mythimna comma Hb.	Shoulder-striped wainscot
	Brachylomia viminalis Fabr.	Minor shoulder-knot
a	*Aporophyla nigra* Haw.	Black rustic
	Allophyes oxyacanthae Linn.	Green-brindled crescent
	Mniotype adusta Esp.	Dark brocade
	Polymixis flavicincta D. & S.	Large ranunculus
	Agrochola lota Cl.	Red-line quaker
	Agrochola litura Linn.	Brown-spot pinion
	Agrochola lychnidis D. & S.	Beaded chestnut
	Atethmia centrago Haw.	Centre-barred sallow
	Xanthia togata Esp.	Pink-barred sallow
	Xanthia icteritia Hufn.	The sallow
	Acronicta leporina Linn.	The miller
	Acronicta tridens D. & S.	Dark dagger
	Acronicta psi Linn.	Grey dagger
	Cryphia domestica Hufn.	Marbled beauty
	Amphipyra tragopogonis Cl.	Mouse moth
	Mormo maura Linn.	Old lady
	Rusina ferruginea Esp.	Brown rustic
	Euplexia lucipara Linn.	Small angle shades
	Phlogophora meticulosa Linn.	Angle shades
	Parastichtis suspecta Hb.	The suspected
	Cosmia trapezina Linn.	The dun-bar
	Cosmia pyralina D. & S.	Lunar-spotted pinion
	Apamea monoglypha Hufn.	Dark arches
	Apamea lithoxylaea D. & S.	Light arches
	Apamea crenata Hufn.	Clouded-bordered brindle
	Apamea epomidion Haw.	Clouded brindle
	Apamea remissa Hb.	Dusky brocade
	Apamea anceps D. & S.	Large nutmeg
	Apamea sordens Hufn.	Rustic shoulder-knot
	Oligia strigilis Linn.	Marbled minor
a	*Oligia versicolor* Borkh.	Rufous minor

	Oligia latruncula D. & S.	Tawny marbled minor
	Oligia fasciuncula Haw.	Middle-barred minor
	Mesoligia furuncula D. & S.	Cloaked minor
	Mesoligia literosa Haw.	Rosy minor
	Mesapamea secalis Linn.	Common rustic
	Photedes fluxa Hb.	Mere wainscot
	Luperina testacea D. & S.	Flounced rustic
	Amphipoea oculea Linn.	Ear moth
	Hydraecia micacea Esp.	Rosy rustic
	Gortyna flavago D. & S.	Frosted orange
	Charanyca trigrammica Hufn.	Treble lines
	Hoplodrina alsines Brahm	The uncertain
	Hoplodrina blanda D. & S.	The rustic
	Caradrina morpheus Hufn.	Mottled rustic
	Caradrina clavipalpis Scop.	Pale mottled willow
a	*Elaphria venustula* Hb.	Rosy marbled
	Panemeria tenebrata Scop.	Small yellow underwing
	Protodeltote pygarga Hufn.	Marbled white spot
	Diachrysia chrysitis Linn.	Burnished brass
	Autographa gamma Linn.	Silver Y
	Autographa pulchrina Haw.	Beautiful golden Y
	Autographa jota Linn.	Plain golden Y
a	*Abrostola trigemina* Werneb.	Dark spectacle
	Abrostola triplasia Linn.	The spectacle
	Lygephila pastinum Treit.	The blackneck
	Scoliopteryx libatrix Linn.	The herald
	Rivula sericealis Scop.	Straw dot
	Hypena probiscidalis Linn.	The snout
	Herminia tarsipennalis Treit.	The fan-foot
	Herminia grisealis D. & S.	Small fan-foot
a	*Parascotia fuliginaria* Linn.	Waved black

[a] Indicates species that are scarce in Thetford Forest Park.

Appendix 8.2 (continued)

(b) Species from broadleaved forest

	Apoda limacodes Hufn.	The festoon
	Pyrgus malvae Linn.	Grizzled skipper
	Quercusia quercus Linn.	Purple hairstreak
	Stymonidia w-album Knoch	White letter hairstreak
	Celastrina argiolus britanna Ver.	Holly blue
[a]	*Ladoga camilla* Linn.	White admiral
[a]	*Polygonia c-album* Linn.	The comma
	Pararge aegeria tircis Butl.	Speckled wood
	Aphantopus hyperantus Linn.	Ringlet
	Falcaria lacertinaria Linn.	Scalloped hook-tip
	Drepana binaria Hufn.	Oak hook-tip
	Drepana cultraria Fabr.	Barred hook-tip
	Drepana falcataria falcataria Linn.	Pebble hook-tip
	Tethea ocularis octogesimea Hb.	Figure of eighty
	Ochropacha duplaris Linn.	Common lutestring
	Cymatophorima diluta hartwiegi Reisser	Oak lutestring
	Achyla flavicornis galbanus Tutt	Yellow horned
	Polyploca ridens Fabr.	Frosted green
	Archiearis parthenias Linn.	Orange underwing
	Geometra papilionaria Linn.	Large emerald
	Comibaena bajularia D. & S.	Blotched emerald
	Hemithea aestivaria Hb.	Common emerald
	Cyclophora albipunctata Hufn.	Birch mocha
	Cyclophora porata Linn.	False mocha
	Cyclophora punctaria Linn.	Maiden's blush
	Cyclophora linearia Hb.	Clay triple-lines
	Idaea trigeminata Haw.	Treble brown spot
	Idaea straminata Borkh.	Plain wave
	Mesoleuca albicillata Hb.	Beautiful carpet
	Chloroclysta siterata Hufn.	Red-green carpet
	Electrophaes corylata Thunb.	Broken-barred carpet
[a]	*Spargania luctuata* D. & S.	White-banded carpet
	Epirrita dilutata D. & S.	November moth
	Operophtera fagata Scharf.	Northern winter moth
	Perizoma affinitata Steph.	The rivulet
	Eupithecia inturbata Hb.	Maple pug
	Eupithecia pulchellata pulchellata Steph.	Foxglove pug
[a]	*Eupithecia egenaria* H.-S.	Pauper pug
	Eupithecia abbreviata Steph.	Brindled pug
	Eupithecia dodoneata Guen.	Oak-tree pug
	Asthena albulata Hufn.	Small white wave
	Hydrelia flammeolaria Hufn.	Small yellow wave
	Lobophora halterata Hufn.	The seraphim
	Trichopteryx carpinata Borkh.	Early tooth-striped
	Abraxas sylvata Scop.	Clouded magpie
	Plagodis pulveraria Linn.	Barred umber
	Plagodis dolabraria Linn.	Scorched wing
	Apeira syringaria Linn.	Lilac beauty
	Ennomos quercinaria Hufn.	August thorn
	Ennomos alniaria Linn.	Canary-shouldered thorn
	Ennomos fuscantaria Haw.	Dusky thorn
	Ennomos erosaria D. & S.	September thorn

Selenia dentaria Fabr.	Early thorn
Selenia lunularia Hb.	Lunar thorn
Selenia tetralunaria Hufn.	Purple thorn
Odontopera bidentata Cl.	Scalloped hazel
Crocallis elinguaria Linn.	Scalloped oak
Colotois pennaria Hb.	Feathered thorn
Apocheima hispidaria D. & S.	Small brindled beauty
Lycia hirtaria Cl.	Brindled beauty
Biston strataria Hufn.	Oak beauty
Agriopis leucophaearia D. & S.	Spring usher
Agriopis aurantiaria Hb.	Scarce umber
Serraca punctinalis Scop.	Pale oak beauty
Cleorodes lichenaria Hufn.	Brussels lace
Paradarisa extersaria Hb.	Brindled white-spot
Furcula bifida Brahm	Poplar kitten
Stauropus fagi Linn.	Lobster moth
Peridea anceps Goeze	Great prominent
Ptilodontella cucullina D. & S.	Maple prominent
Drymonia dodonaea D. & S.	Marbled brown
Drymonia ruficornis Hufn.	Lunar marbled brown
Calliteara pudibunda Linn.	Pale tussock
Lymantria monacha Linn.	Black arches
Miltochrista miniata Forst.	Rosy footman
Eilema deplana Esp.	Buff footman
Nola confusalis H.-S.	Least black arches
Graphiphora augur Fabr.	Double dart
Diarsia mendica mendica Fabr.	Ingrailed clay
Diarsia brunnea D. & S.	Purple clay
Orthosia populeti Fabr.	Lead-coloured drab
Orthosia munda D. & S.	Twin-spotted quaker
Brachionycha sphinx Hufn.	The sprawler
Lithophane semibrunnea Haw.	Tawny pinion
Lithophane ornitopus lactipennis Dadd.	Grey shoulder-knot
Xylocampa areola Esp.	Early grey
Dichonia aprilina Linn.	Merveille du jour
Dryobotedes eremita Fabr.	Brindled green
Eupsilia transversa Hufn.	The satellite
Conistra vacinii Linn.	The chestnut
Agrochola circellaris Hufn.	The brick
Agrochola macilenta Hb.	Yellow-line quaker
Agrochola helvola Linn.	Flounced chestnut
Xanthia citrago Linn.	Orange sallow
Xanthia aurago D. & S.	Barred sallow
Acronicta megacephala D. & S.	Poplar grey
Acronicta aceris Linn.	The sycamore
Acronicta alni Linn.	Alder moth
Craniophora ligustri D. & S.	The coronet
Amphipyra pyramidea Linn.	Copper underwing
Dypterygia scabriuscula Linn.	Bird's wing
Ipimorpha subtusa D. & S.	The olive
Apamea scolopacina Esp.	Slender brindle
Bena prasinana Linn.	Scarce silver-lines
Pseudoips fagana britannica Warr.	Green silver-lines
Nycteola revayana Scop.	Oak nycteoline
Colocasia coryli Linn.	Nut-tree tussock
Laspeyria flexula D. & S.	Beautiful hook-tip

[a] Indicates species not recorded by Barrett (1901) or Morley (1937) from the Breck.

Appendix 8.2 (continued)

(c) Species from calcareous heath

[a]	*Adscita statices* Linn.	The forester
	Zygaena filipendulae stephensi Dupont	Six-spot burnet
	Zygaena trifolii palustrella Ver.	Five-spot burnet
	Zygaena lonicerae latomarginata Tutt.	Narrow-bordered five-spot burnet
	Thymelicus lineola Ochs.	Essex skipper
[a]	*Erynnis tages tages* Linn.	Dingy skipper
	Aricia agestis D. & S.	Brown argus
	Polyommatus icarus icarus Rott.	Common blue
	Lasiommata megera Linn.	The wall
	Coenonympha pamphilus pamphilus Linn.	Small heath
[a]	*Scopula rubiginata* Hufn.	Tawny wave
[a]	*Phibalapteryx virgata* Hufn.	Oblique striped
	Catarhoe cuculata Hufn.	Royal mantle
	Cosmorhoe ocellata Linn.	Purple bar
[a]	*Colostygia multistrigaria* Haw.	Mottled grey
	Eupithecia haworthiata Doubl.	Haworth's pug
	Eupithecia linariata D. & S.	Toadflax pug
	Eupithecia venosata venosata Fabr.	Netted pug
	Eupithecia satyrata satyrata Hb.	Satyr pug
	Eupithecia icterata subfulvata Haw.	Tawny speckled pug
	Eupithecia subumbrata D. & S.	Shaded pug
[a]	*Eupithecia pimpinellata* Hb.	Pimpinel pug
[a]	*Aplocera plagiata plagiata* Linn.	Treble-bar
[a]	*Aplocera efformata* Guen.	Lesser treble-bar
[a]	*Lithostege griseata* D. & S.	Grey carpet
	Semiothisa clathrata clathrata Linn.	Latticed heath
	Pseudopanthera macularia Linn.	Speckled yellow
	Aspitates ochrearia Rossi	Yellow belle
	Deilephila porcellus Linn.	Small elephant hawk-moth
	Tyria jacobaeae Linn.	The cinnabar
	Hada nana Hufn.	The shears
[a]	*Sideridis albicolon* Hb.	White colon
[a]	*Heliophobus reticulata marginosa* Haw.	Bordered gothic
	Hecatera bicolorata Hufn.	Broad-barred white
	Hadena rivularis Fabr.	The campion
	Hadena perplexa perplexa D. & S.	Tawny shears
	Hadena confusa Hufn.	Marbled coronet
	Mythimna conigera D. & S.	Brown-line bright-eye
[a]	*Cucullia chamomillae* D. & S.	Chamomile shark
	Cucullia umbratica Linn.	The shark
	Cucullia verbasci Linn.	The mullein
	Omphaloscelis lunosa Haw.	Lunar underwing
	Thalpophila matura Hufn.	Straw underwing
[a]	*Apamea sublustris* Esp.	Reddish light arches
	Eremobia ochroleuca D. & S.	Dusky sallow
[a]	*Pyrrhia umbra* Hufn.	Bordered sallow
[a]	*Heliothis viriplaca* Hufn.	Marbled clover
	Callistege mi Cl.	Mother shipton
	Euclidia glyphica Linn.	Burnet companion

Present in 1950

Hadena irregularis Hufn.	Viper's bugloss
Emmelia trabealis Scop.	Spotted sulphur
Tyta luctuosa D. & S.	The four-spotted

[a] Indicates species that are scarce and/or declining in Thetford Forest Park.

Appendix 8.2 (continued)

(d) Species from acid heath

	Callophrys rubi Linn.	Green hairstreak
	Lycaena phlaeas eleus Fabr.	Small copper
	Hipparchia semele semele Linn.	The grayling
	Macrothylacia rubi Linn.	Fox moth
	Pavonia pavonia Linn.	Emperor moth
	Pseudoterpna pruinata atropunctaria Walk.	Grass emerald
	Idaea subsericeata Haw.	Satin wave
[a]	*Scotopteryx luridata plumbaria* Fabr.	July belle
[a]	*Eupithecia absinthiata* f. *goossensiata* Mab.	Ling pug
[a]	*Eupithecia nanata angusta* Prout	Narrow-winged pug
	Chesias legatella D. & S.	The streak
	Chesias rufata rufata Fabr.	Broom-tip
	Ematurga atomaria atomaria Linn.	Common heath
	Cybosia mesomella Linn.	Four-dotted footman
[a]	*Arctia villica britannica* Ob.	Cream-spot tiger
[a]	*Diacrisia sannio* Linn.	Clouded buff
	Euxoa tritici Linn.	White-line dart
	Agrotis vestigialis Hufn.	Archer's dart
	Agrotis clavis Hufn.	Heart and club
[a]	*Noctua orbona* Hufn.	Lunar yellow underwing
	Paradiarsia glareosa glareosa Esp.	Autumnal rustic
	Lycophotia porphyrea D. & S.	True lover's knot
[a]	*Anarta myrtilli* Linn.	Beautiful yellow underwing
	Aporophyla lutulenta lutulenta D. & S.	Deep-brown dart
[a]	*Stilbia anomala* Haw.	The anomalous
	Present in 1950	
	Plebejus argus argus Linn.	Silver-studded blue

[a] Indicates species that are scarce and/or declining in Thetford Forest Park.

Appendix 8.2 (continued)

(e) Species from wetlands

	Sesia apiformis Cl.	Hornet moth
	Scopula immutata Linn.	Lesser cream wave
	Idaea muricata Hufn.	Purple-bordered gold
	Idaea emarginata Linn.	Small scallop
	Orthonama vittata Borkh.	Oblique carpet
	Xanthorhoe designata Hufn.	Flame carpet
	Lampropteryx suffumata D. & S.	Water carpet
	Eulithis prunata Linn.	The phoenix
	Eulithis mellinata Fabr.	The spinach
	Hydriomena impluviata D. & S.	May highflyer
	Rheumaptera undulata Linn.	Scallop shell
	Perizoma albulata albulata D. & S.	Grass rivulet
	Perizoma sagittata Fabr.	Marsh carpet
	Eupithecia tenuiata Hb.	Slender pug
	Eupithecia valerianata Hb.	Valerian pug
	Eupithecia trisignaria H.-S.	Triple-spotted pug
	Anticollix sparsata Treit.	Dentated pug
	Euchoeca nebulata Scop.	Dingy shell
	Pterapherapteryx sexalata Reitz.	Small seraphim
	Semiothisa wauaria Linn.	The V-moth
	Epione repandaria Hufn.	Bordered beauty
	Clostera pigra Hufn.	Small chocolate tip
	Nudaria mundana Linn.	Muslin footman
	Lacanobia suasa D. & S.	Dog's tooth
	Mythimna pudorina D. & S.	Striped wainscot
	Senta flammea Curt.	Flame wainscot
[a]	*Xanthia ocellaris* Borkh.	Pale-lemon sallow
	Simyra albovenosa Goeze	Reed dagger
	Parastichtis ypsillon D. & S.	Dingy shears
	Apamea unanimis Hb.	Small clouded brindle
	Apamea ophiogramma Esp.	Double lobed
	Photedes minima Haw.	Small dotted buff
	Photedes pygmina Haw.	Small wainscot
	Calaena leucostigma leucostigma Hb.	The crescent
	Nonagria typhae Thunb.	Bulrush wainscot
	Archanara geminipuncta Haw.	Twin-spotted wainscot
	Archanara dissoluta Treit.	Brown-veined wainscot
	Archanara algae Esp.	Rush wainscot
	Rhizedra lutosa Hb.	Large wainscot
	Arenostola phragmitidis Hb.	Fen wainscot
	Coenobia rufa Haw.	Small rufous
	Chilodes maritimus H.-S.	Silky wainscot
	Deltote uncula Cl.	Silver hook
	Earias clorana Linn.	Cream-bordered green pea
	Catocala nupta Linn.	Red underwing
	Schrankia costaestrigalis Steph.	Pinion-streaked snout
	Macrochilo cribrumalis Hb.	Dotted fan-foot

[a] Indicates species not recorded from the Breck by Barrett (1901) but well established by 1937 (Morley).

Appendix 8.2 (continued)

(f) Species from conifer forest

	Thera firmata Hb.	Pine carpet
	Thera obeliscata Hb.	Grey pine carpet
[a]	*Eupithecia intricata arceuthata* Freyer	Freyer's pug
	Eupithecia indigata Hb.	Ochreous pug
	Eupithecia pusillata pusillata D. & S.	Juniper pug
	Eupithecia lariciata Freyer	Larch pug
[a]	*Eupithecia tantillaria* Boisd.	Dwarf pug
	Semiothisa liturata Cl.	Tawny-barred angle
[a]	*Deileptenia ribeata* Cl.	Satin beauty
	Bupalus piniaria Linn.	Bordered white
	Hylaea fasciaria Linn.	Barred red
[a]	*Hyloicus pinastri* Linn.	Pine hawk-moth
	Panolis flammea D. & S.	Pine beauty

[a] Indicates species not recorded from the Breck by Barrett (1901) or Morley (1937).

Appendix 8.3

Number of species of macro-Lepidoptera larvae listed by foodplant within each of the six habitat groups discussed for Thetford Forest Park

Larval foodplant	Number of macro-Lepidoptera larvae by habitat						
	Two or more	Broad-leaf	Chalk heath	Acid heath	Wet-lands	Coni-fers	Total
Abies spp.						4	4
Acer campestre	25	19					44
Acer pseudoplatanus	23	11					34
Achillea millefolium	2		1				3
Algae	2	3			1		6
Alnus glutinosa	36	13			2		51
Arctium spp.	11						11
Artemisia spp.	4	1					5
Berberis vulgaris and *Mahonia aquifolium*		1					1
Betula spp.	56	43	1	1			101
Calluna vulgaris	7			8			15
Castanea sativa	15	7					22
Carex spp. and *Juncus* spp.					5		5
Centaurea spp.			1				1
Chenopodium spp.	14						14
Cirsium spp.	2		2				4
Clematis vitalba	1		1				2
Cornus sanguinea	34	3		1			38
Corylus avellana	27	16		1			44
Crataegus spp.	61	21	1	1			84
Crepis spp. (and other Compositae)			6				6
Cruciferae	20				1		21
Cytisus scoparius	15			4			19
Decaying vegetation	1			1	1		3
Descurainia sophia			3				3
Digitalis purpurea	23	2					25
Echium vulgare	1						1
Epilobium spp.	2	1					3
Euonymus europaeus	15	1					16
Eupatorium cannabinum	8						8
Fagus sylvatica	17	22					39
Filipendula ulmaria	14		1	1	1		17
Fragaria vesca	16	1	1				18
Fraxinus excelsior	18	16					34
Fungi						1	1
Galeopsis spp.	1						1
Galium verum	35		6	4			45
Galium spp. (other than *G. verum*)	39	1	1	3	3		46
Geraniaceae			9				1
Gramineae	38	2		4	4		57

Larval foodplant	Number of macro-Lepidoptera larvae by habitat						
	Two or more	Broad-leaf	Chalk heath	Acid heath	Wet-lands	Coni-fers	Total
Hedera helix	4	2					6
Helianthemum nummularium	1		2				3
Humulus lupulus	5	2					7
Hypericum spp.			3				3
Ilex aquifolium	4	1					5
Iris spp.	3				1		4
Lamium spp.	35	2		2			39
Larix spp.	2					9	11
Lichens	4	1					5
Ligustrum vulgare	26	8	2				36
Linaria vulgaris	2		2				4
Lonicera periclymenum	26	1					37
Lotus spp. and *Trifolium* spp.	12		8				20
Lysimachia spp.	1	1			1		3
Malus sylvestris	33	13					46
Malva spp.	2						2
Matricaria spp.			2				2
Minor conifers	1				7		8
Odontites verna	1						1
Ononis spp.	17	1	5				23
Phalaris arundinacea					1		1
Phragmites australis	2				7		9
Picea spp.		1				6	7
Pinus spp.	1	1			1	10	12
Plantago spp.	39	2	1	3			46
Populus tremula	27	17			1		44
Populus spp. (other than *P. tremula*)	32	11			1		44
Potentilla spp.	1	1					3
Primula spp.	35	2					37
Prunus padus	10						10
Prunus spinosa	50	17	1	1			69
Prunus spp. (not *P. padus* or *P. spinosa*)	11	9					20
Pseudotsuga menziesii						8	8
Pteris spp.	4						4
Quercus petraea and *Quercus robur*	36	55					91
Reseda spp.	3		3				6
Rhamnus catharticus	24	6		1			31
Rhinanthus spp.			1		1		2
Ribes spp.	14	1			3		18
Rosa spp.	27	11					38
Rubus fruticosus aggregate	30	3	1	2			36
Rubus idaeus	31	3		1			35
Rumex spp. (docks)	55	5	1	3	1		65
Rumex spp. (sorrels)	10	2		4			16

Appendix 8.3 (continued)

Larval foodplant	**Number of macro-Lepidoptera larvae by habitat**						
	Two or more	**Broad-leaf**	**Chalk heath**	**Acid heath**	**Wet-lands**	**Coni-fers**	**Total**
Salix spp.	75	24			7		106
Sambucus nigra	19						19
Senecio spp.	8		1	1			10
Silene dioica	6	1					7
Silene latifolia alba	7						7
Silene otites			3				3
Silene vulgaris	17		7				24
Sorbus aucuparia	22	5					27
Stellaria spp.	53	3	2				58
Syringa vulgaris	17	8					25
Taraxacum spp.	45	2	1	4			52
Taxus baccata						1	1
Teucrium spp.	2		1				3
Thalictrum flavum					1		1
Tilia spp.	22	20					42
Typha spp.					1		1
Ulex spp.	1	1		4			6
Ulmus spp.	35	25		1			61
Umbelliferae (flowers)	6		3		1		10
Urtica spp.	24	1					25
Valeriana spp.			1		2		3
Verbascum spp.	1		1				2
Vicia	14		1				15
Viola spp.	2			1			3
	1580	463	87	57	55	39	2281
percentages	69	20	4	3	2	2	

Foodplant usage by larvae is grouped into preferred habitats. Plants that are commonly eaten by a species in more than one habitat (column one) and are also eaten by a different species exclusively in another habitat will occur in both (or more) columns.

The low values for conifers reflect the small number of conifer feeding macro-Lepidoptera that are indigenous to Britain although they may share a substantial part of the limited range of both native and introduced tree species.

Chapter 9

Breckland Coleoptera

R. Colin Welch and Peter Hammond

Summary

The conservation significance of the 1700 or so Coleoptera known from the Norfolk/Suffolk Brecklands is reviewed. Of these 459 have Red Data Book or other special conservation status, but only 25.3% are associated with woodlands, and very few depend on conifers. Most are either characteristic of open country (38.6%) or wetlands (27%). The continuing importance of conserving characteristic open Breck habitats within the Forest is stressed, as several species occur nowhere else in Britain.

Introduction

The Norfolk and Suffolk Brecklands cover a variously defined area within which the elements of the Thetford Forest Park are distributed. For the purposes of this study the boundaries employed by the Breck Committee, illustrated in Twist (1979), have been used as a general guide-line. For many years one of us (PMH) has maintained an inventory of Breckland Coleoptera. This includes all known published records, together with more extensive personal and unpublished data sets, and to date contains approximately 1700 species. It can be fairly confidently predicted that a detailed study of the more 'difficult' genera of families such as the Staphylinidae and Cryptophagidae would be likely to extend this number of species by up to 10%.

Clearly any such list of species will comprise a high proportion of common, widespread and ubiquitous species. It is, therefore, necessary to identify those rarer elements of the fauna in order to place some assessment of the conservation value on the site. In the Insect Red Data Book (RDB) (Shirt, 1987) Britain's rarest Coleoptera are listed, with 142 species classified as Endangered (RDB1), 84 as Vulnerable (RDB2), and 266 as Rare (RDB3). Together these comprise 14% of our known beetle fauna. At about the same time the Nature Conservancy Council, through its Invertebrate Site Register project, was also preparing a series of National Species Reviews which sought to identify and document uncommon species (Ball, 1986). Two categories of Nationally Notable species were used: 'Notable a' (Na) for species recorded from 30 or less 10 km national grid squares since 1970, and 'Notable b' (Nb) for those known from 100 or less squares for the same period. Ball also incorporated two other subsidiary classifications adopted for rare Coleoptera. Hyman (1986a), in his first attempt at a National Review of Coleoptera, included four miscellaneous categories, only three of which are relevant here: list 1: naturalised species of rare occurrence; list 2: non-established immigrant species, and species of doubtful status; list 3: rare synanthropic species. Harding (1977) produced a list of 195 species of Coleoptera associated with over-mature deciduous trees in woodland in lowland Britain. These were graded 1-3 as a measure of their presumed value as indicators of a continuity of over-mature timber. A modified list was later produced by Harding and Rose (1986) containing 196 species of saproxylic Coleoptera characteristic of ancient woodland with dead-wood habitats, and we have used this in our analysis of the Breckland fauna.

Since this Symposium was held, Hyman and Parsons (1992, 1994) have published a two-part definitive review of the scarce and threatened terrestrial Coleoptera of Great Britain. These incorporate a wealth of information on the occurrences and distributions of the rarer British beetles which, in turn, has necessitated a reassessment of their status. As these reviews are more widely available than the earlier NCC CSD Reports by Ball (1986) and Hyman (1986a), they have become the standard reference works for determining the Red Data Book or Notable status of British Coleoptera, and our original tables have been modified accordingly (see Tables 9.1, 9.2, 9.3). Two new Red Data Book categories have been added, RDBI (Indeterminate) and RDBK (Insufficiently Known) for a range of species for which there is currently not enough information to decide as to which category they should be assigned. In addition to the inevitable up- or down-grading of individual species, the Na and Nb categories have sometimes been amalgamated into a single Nationally Notable category, particularly within the Staphylinoidea. The aquatic Coleoptera have been assessed separately (see Appendix 1 in Hyman and Parsons, 1992) using slightly different criteria which may increase their representation in any list of rare species.

Breckland's rare beetles

Approximately 27% of the beetle species recorded from the Breckland are included in the Red Data Book and Nationally Scarce categories used by Hyman and Parsons (1992, 1994). Although the categorisations of species statuses will be continuously under review as new data become available, they nevertheless provide a useful general focus for any discussion of the Breckland fauna. A recent resurgence of interest by entomologists in this unique area of East Anglia has resulted in records for over three-quarters of the 459 RDB and Notable species of beetles being made within the past 20 years (Table 9.1). However, approximately 12.0% of the species lack post-1920 records. Four of these species, *Leiodes pallens* (Leiodidae), *Orthoperus atomarius* (Corylophidae), *Chromoderus affinis* and *Bagous petro* (Curculionidae), are now believed to be extinct in Britain; they have been included in the 'Other' category in Table 9.1 which consists predominantly of dead-wood species in Harding's grade 3.

In Table 9.2 the 459 'rare' species have been classified into three broad habitat preference types: woodland, open country and wetland, with an additional fourth 'other' category of unclassifiable or generalist species. The woodland category includes all species associated with the wood of woodland trees, woodland floor litter, fungi and slime moulds, and also includes 4 largely synanthropic species (Hyman, List 3). The wetland category includes aquatic, semi-aquatic, riparian, fen and marsh-dwelling species. The 'other' category includes generalists associated with various types of decaying matter, e.g. dung, but without preference for open or wooded habitats, and various miscellaneous species. By using this simple classification it can be seen that, when only Red Data Book and Nationally Notable (Na) categories are considered, 33.8% of these rare species are associated with open country, and wetland habitats contain 28.3%, while the woodland fauna comprises only 22.1%. When the species in all Nationally Scarce/Notable categories are included in the analysis the preponderance of the open country Coleoptera increases by 4.8% to 38.6%, mainly at the expense of the miscellaneous 'others' category (9.1%). The representation of woodland species also shows a small increase of 3.2% to 25.3% while wetland species decrease by 1.3% to 27%.

Table 9.1 Records of Breckland Coleoptera: Insect Red Data Book category x date of records

	RDB1	RDB2	RDB3	RDBK and RDBI	Notable	Other	Total
Post-1970	4	9	22	19	281	17	352
1920-1970	1	-	1	8	39	4	53
Pre-1920	4	2	4	7	33	4	54
Total	9	11	27	34	353	25	459

Table 9.2 Records of Breckland Coleoptera: habitat x Insect Red Data Book category

	Woodland	Open country	Wetland	Other	Total
RDB1	1	5	3	-	9
RDB2	3	4	4	–	11
RDB3	4	9	14	–	27
RDBK	9	6	5	6	26
RDBI	2	4	1	1	8
Na	13	21	14	16	64
Total RDB + Na	32	49	41	23	145
Total (all categories)	116	177	124	42	459
% RDB + Na	22.1	33.8	28.3	15.9	
% all categories	25.3	38.6	27.0	9.1	

The 81 Red Data Book species which have been recorded from the Breckland are listed in Table 9.3, with an indication of their status and habitat preference. Ten of these are known from the Breck only by pre-1920 records, and a further 16 species have not been recorded from the area since 1970. Others are known only from this region, or occasionally from a few other localities. Details provided for some of these species (Shirt, 1987) soon became out of date. At that time there were only two modern records for the water beetle *Bidessus unistriatus* from the Norfolk Broads, but Hyman (1986b) recorded it from Home Mere and West Mere, within the Stanford Battle Area, in 1985. The anobiid *Caenocara affinis* is known only from the eight specimens bred from a puff-ball fungus collected at Barton Mills in 1917 (Shirt, 1987). Another puff-ball frequenting species, the endomychid *Lycoperdina succincta*, is also restricted to the Breckland. Since the account prepared for Shirt (1987) this species has been recorded from near Barton Mills in 1981 (J. A. Owen), and in 1985 from Icklingham Plain and Wangford Warren Woods (H. Mendel), and Lakenheath Warren (P. Hyman).

The 19th century record for the horned dung beetle, *Copris lunaris*, from Deadman's Grave near Icklingham, appears to have been overlooked by Shirt (1987). The only recent records for this species are from Box Hill, Surrey, the last being in 1955 (Jessop, 1986). Another scarabaeid, *Diastictus vulneratus*, is known in Britain only from the open heaths of the Suffolk Breckland. The chrysomelid *Cryptocephalus exiguus* has always been restricted to the fen areas of eastern England. It had not been recorded since 1908 prior to Mendel (1987) finding it at Pashford Poors Fen in 1980. *Cryptophagus labilis* is a rare cryptophagid associated with dead deciduous trees. It is known from seven scattered English localities, the most recent of which was in 1988 from Stanford (Johnson, 1988), and also from South Wales (Hammond and Hine, 1994). The click beetle *Elater ferrugineus* was known this century only from Windsor Forest until Mendel (1989) found larvae in the red-rot of a hollow grey poplar at Icklingham Plain in 1986, thus confirming Breckland records for the last century. *E. ferrugineus* has also been rediscovered at a third British locality, Richmond Park, Surrey, where it was found in a fallen oak branch in 1988 (Hammond and Owen, in press). Mendel (1990) has recently recommended that Morley's (1915) record for another elaterid, *Ampedus cinnabarinus*, be disregarded following the discovery of *A. quercicola* in a rotten birch log on Tuddenham Heath.

Hyman found the minute ptiliid *Microptilium pulchellum* by a dried-up pond at Red Lodge Warren in 1985. This species was found in a gravel pit at Earith, Cambridgeshire in 1980, being previously known only from Berkshire in 1906 (Johnson, 1987). The spider beetle *Ptinus dubius*, although only recently recognised (Hodge and Parry, 1982), has been known from pine in the Mildenhall area since 1936 and was found in the Stanford Battle Area in 1990 by M. Collier. Elsewhere it has been found only in Kent. The anobiid *Hemicoelus nitidus* was first recorded from an over-mature grey poplar on Icklingham Plains in 1980 (Mendel, 1983) and has since been reared from a maple log collected in Windsor Great Park by J. A. Owen in 1984 (Owen, 1990).

The weevil *Cionus longicollis* feeds on *Verbascum* and is known only from populations in the Breck and Hampshire. The ground beetle *Cymindis macularis* was first identified as British from fragments in stone curlew's pellets from Icklingham (Hammond, 1982) and its presence in the Breck confirmed by specimens collected near Barton Mills in 1966 (Williams, 1984). Several more were found by J. A. Owen and H. Mendel on Thetford Common in 1989, but the species has not been found in Britain beyond the borders of the Breck.

Table 9.3 Red Data Book Coleoptera recorded from the Breckland

Species	Category	Status	Habitat
Aphodius quadrimaculatus	1	a	O
Aphodius subterraneus	1	a	O
Apion brunnipes	1	b	O
Bidessus unistriatus	1		W
Copris lunaris	1	a	O
Cryptocephalus exiguus	1		W
Cymindis macularis	1		O
Elater ferrugineus	1		D
Longitarsus ferrugineus	1	a	W
Ceutorhynchus querceti	2		W
Diastictus vulneratus	2		O
Gracilia minuta	2	a	F
Harpalus froelichi	2		O
Hydraena palustris	2		W
Hydroporus rufifrons	2	a	W
Hydroporus scalesianus	2		W
Lycoperdina succincta	2		O
Rhynchaenus testaceus	2		F
Tychius quinquepunctatus	2		O
Trachys minuta	2		F
Agabus undulatus	3		W
Apion rubiginosum	3		O
Aulonothroscus brevicollis	3		F
Caenocara bovistae	3	a	O
Ceutorhynchus parvulus	3	b	O
Ceutorhynchus unguicularis	3		O
Dryophilus anobioides	3		O
Dryops anglicanus	3		W
Dryops griseus	3		W
Dryops similaris	3		W
Enochrus isotae	3		W
Gyrinus suffriani	3		W
Haliplus variegatus	3		W
Harpalus puncticollis	3	a	O
Helochares obscurus	3		W
Hydrochus brevis	3		W

Table 9.3 continued

Species	Category	Status	Habitat
Hydrochus carinatus	3		W
Hydrochus ignicollis	3		W
Hydroporus elongatulus	3		W
Hydroporus glabriusculus	3		W
Hypera diversipunctata	3		O
Laccornis oblongus	3		W
Leptura fulva	3		F
Lycoperdina bovistae	3		O
Procraerus tibialis	3		F
Psylliodes sophiae	3	b	O
Ptinus lichenum	3	a	F
Caenocara affinis	I	a	O
Hemicoelus nitidus	I		F
Hypocoprus latridioides	I	a	O
Leiodes flavescens	I	b	?
Limnebius aluta	I		W
Meligethes nanus	I	b	O
Rhynchaenus decoratus	I	a	F
Rugilus geniculatus	I		O
Acrotrichis arnoldi	K	a	F
Agathidium arcticum	K		F
Anthonomus piri	K		F
Astenus procerus	K		O
Atomaria clavigera	K		?
Atomaria lohsei	K		F
Colon appendiculatum	K		?
Cryptophagus micaceus	K	a	F
Cypha seminulum	K		F
Gyrophaena munsteri	K		F
Heterothops dissimilis	K	b	O
Hypera ononidis	K		O
Leiodes triepkii	K		?
Microptilium pulchellum	K	b	W
Neobisnius procerulus	K		W
Neohilara subterranea	K	b	?
Onthophilus punctatus	K		?
Oxytelus piceus	K		O
Philonthus lepidus	K		O
Ptiliolum marginatum	K		F
Schistoglossa aubei	K		W
Schistoglossa viduata	K	b	W
Stenichnus poweri	K	a	?
Stenus morio	K	a	W
Stilbus atomarius	K	b	W
Tachyporus scitulus	K		O

Categories: Red Data Book 1 (endangered), 2 (vulnerable), 3 (rare), I (Indeterminate), K (Insufficiently Known).
Status: [a] No post-1920 records from Breckland; [b] no post-1970 records.
Habitat: F: forest/woodland; O: open country; W: wetland; ?: other habitats.
Nomenclature and RDB categories follow Hyman and Parsons (1992, 1994).

Conifer-associated species

Approximately 40 species of Coleoptera that are intimately and exclusively associated with coniferous trees are known from the Breckland. Clearly these owe their presence to the 'recent' plantings carried out over the past 100 years. The majority of these species, especially those of the families Scolytidae and Anobiidae, are associated with the wood or bark of the trees.

Several of the conifer-associated species now found in Thetford Forest were not known to occur in Britain outside of Scotland until this century (Hammond, 1974). It has been generally assumed that most such species have spread south from Scotland, either by a natural expansion of their range, or by man's agency, although southern English populations of some, like those species discussed below, may be of Continental origin. Good examples include the staphylinids *Phloeostiba lapponica* (Hammond, 1974) and *Nudobius lentus*; the melandriid *Abdera triguttata* (Buck, 1957); the cerambycid *Asemum striatum*; the 'weevils' *Cimberis attelaboides*, *Brachonyx pineti* (Morley, 1941) and *Pissodes pini* (Bevan, 1971); and the scolytids *Pityogenes trepanatus* (Allen, 1976) and *Orthotomicus suturalis* (Donisthorpe, 1943). The Breck remains the only area for which there are southern records of *P. lapponica* and *A. triguttata*. Others such as *Cimberis* are very locally distributed in southern England, whereas *Nudobius* is now widespread in the south under the bark of a wide range of both conifer and deciduous tree species.

A handful of conifer-frequenting Coleoptera, not known to occur in Britain at all 100 years ago, have since become established in Thetford Forest. Such species appear to owe their presence in the Breckland to the establishment there and elsewhere in southern Britain of suitable habitats, i.e. conifer plantations, within their normal climatic range, enabling colonisation from Continental Europe (see Hammond, 1974). Examples include: the histerid *Plegaderus vulneratus* (Welch, 1973), now known from more than one Breckland site; the derodontid *Laricobius erichsoni* (Hammond and Barham, 1982) which appears to have arrived in Suffolk naturally prior to its experimental release in Kent as a biological control agent; and the coccinellid *Harmonia quadripunctata* whose spread since its first detection in Suffolk in 1937 has already been discussed elsewhere (Hammond, 1974).

Other more or less exclusively conifer-associated Coleoptera known from the Breck area are as follows: Staphylinidae, *Phloeonomus pusillus*; Anobiidae, *Dryophilus pusillus*, *Ernobius mollis*, *E. nigrinus*, *E. pini* and *E. angusticollis*; Ptinidae, *Ptinus dubius*; Coccinellidae, *Scymnus nigrinus*, *S. suturalis*, *Myrrha 18-guttata*, *Myzia oblongoguttata*; Tenebrionidae, *Corticeus linearis*; Cerambycidae, *Tetropium gabrieli*; Curculionidae, *Hylobius abietis* and *Pissodes castaneus*; Scolytidae, *Hylurgops palliatus*, *Hylastes ater*, *H. attenuatus*, *H. opacus*, *Tomicus piniperda*, *Cryphalus abietis*, *Pityophthorus pubescens*, *Pityogenes bidentatus* and *P. chalcographus*. Of course, the majority of beetle species to be found in the Breckland conifer plantations are not exclusively associated with conifer trees. This is true of a number of species, notably various Staphylinidae, such as *Atrecus affinis*, and Rhizophagidae that feed in decaying wood; various phyllophage weevils, such as *Otiorhynchus singularis*, that feed on shoots and needles; and various ladybirds, such as the common *Coccinella septempunctata*, that are predators of Homoptera. The litter-dwelling and fungus-feeding Coleoptera found in the Breckland conifer plantations are very largely generalist species that are equally abundant in deciduous woodlands. In fact, the conifer-associated species in these latter categories are, generally speaking, a sub-set of those to be found in mixed broadleaved woodland.

Open-ground species

The Breckland remains an area of national importance for beetle species requiring a range of open-ground habitats. Changing patterns of agriculture and land management have seen a contraction of the distributions of many such species. However, it is remarkable how common some can be at a number of sites throughout Breckland, and how many of the more interesting species may be found in one place together. The significance of these assemblages lies in the fact that, as a whole, psammophilous, heathland and other open, sandy ground species have declined in Britain over the past 200 years (Hammond, 1974) and many are now very localised indeed. Among the phytophagous beetles that have a close association with a particular hostplant, or a narrow range of plants, many notable species are of common occurrence in the open Breck. Curiously, by no means all of them have host-plants that are especially restricted in their occurrence. Virtually all the notable British species of

Ceutorhynchus and *Gymnetron* weevils are known to occur in the Breckland, along with other notable weevils such as *Hypera dauci*, *Cionus longicollis*, *Miarus* spp., and leaf beetles such a *Psylliodes sophiae*, *Longitarsus quadriguttatus* and other members of this genus, and also some notable pollen beetles, *Meligethes* spp.

Those species which are more or less directly psammophilous in habit are perhaps the most notable element among the open-ground beetle fauna of the Breckland. This element has been discussed previously (Morley, 1908; Donisthorpe, 1943; Hammond, 1974; Morris, 1975). Included among the notable psammophilous species, found only where blown sand occurs, are the carabid *Broscus cephalotes* (Morris, 1975); the scarabaeid *Psammodius asper*; the tenebrionids *Crypticus quisquilius* and *Melanimon tibiale* (Brendell, 1975); and the weevil *Cleonus piger*; all of which are discussed by Morley (1908). To these may be added the carabid *Calathus mollis*; the tenebrionid *Ctenopius sulphureus*; and the weevils *Chromoderus affinis* and *Tychius tibialis*. All of these species are otherwise very rarely found away from the coast.

A number of other notable species that are less closely associated with blown sand, but are generally associated with areas of bare sandy soil, include several polyphagous weevils, e.g. six species of *Trachyphloeus*, *Otiorhynchus ovatus*, *Cneorhinus plumbeus*, *Philopedon plagiatus* (Morris, 1987), *Gronops lunatus* and *Orthochaetes setiger*; various ground beetles, for example, *Harpalus anxius*, *H. serripes* and *H. vernalis*; *Amara consularis*, *A. fulva* and *A. tibialis*; *Calathus ambiguus* and *C. erratus*; *Cymindis axillaris* and *C. macularis*; *Licinus depressus* and *Notiophilus quadripunctatus*; and some rare rove beetles such as *Philonthus lepidus*, *Staphylinus ophthalmicus* and *S. fortunatarum*; some nine species of Byrrhidae (mostly moss-feeders), notably *Byrrhus pustulatus* and *Porcinolus murinus*; various Scarabaeidae (dung-feeders and scavengers) such as *Diastictus vulneratus*, *Aphodius villosus*, *A. coenosus* and *A. quadrimaculatus*, and members of various other families such as *Cardiophorus asellus* (Elateridae), *Orthocerus clavicornis* (Colydiidae), *Trox sabulosus* (Trogidae), *Silpha tristis* (Silphidae) and *Hypocoprus latridioides* (Hypocopridae).

There are a few additional species of note, recorded from the Breckland, that are not especially associated with open heathland or sandy ground, but are nevertheless very scarce in Britain because of their requirements for a Continental type of climatic regime. Some examples from the Staphylinidae include *Oxytelus piceus*: the only post-1951 record for this dung-feeding species is from Tuddenham Heath; two of the only four known British localities for *Heterothops dissimilis* are from Worlington and Shadwell Park on the outskirts of the Breck; and *Tachyporus scitulus* is known from only four British sites, one of which is Barton Mills.

Wetland species

It is perhaps surprising in an area of Britain renowned for its sandy, well-drained soils that the wetland element of the Breckland beetle fauna should feature so prominently. Indeed this broad habitat supports 27 species of Red Data Book Coleoptera, only one fewer than the number recorded from open-country but considerably more than from woodland habitats. In addition nearly 100 Nationally Notable species from the Breck can also be classified as 'wetland species' (see Table 9.2). These include the truly aquatic beetles together with those of marsh and fen.

Following the requisitioning of some 6500 ha in 1942 to establish the Stanford Practical Training Area (PTA), access remained limited until 1976 when the Institute of Terrestrial Ecology undertook an ecological survey for the Nature Conservancy Council (Hooper, 1978). Mrs M. A. Palmer surveyed the aquatic systems and found several rare water beetles which had not been recorded in the region since the turn of the century. Since then members of the Balfour-Browne Club have discovered many more notable species, both within the PTA, and from adjacent sites such as Wreatham Heath Meres, the Thompson Common pingoes, and Foulden Common to the north-west (Palmer, 1981; Foster, 1985, 1986; Hyman, 1986b).

In addition to the fluctuating meres, pingoes and bomb craters, a few small relict patches of fen still remain within the confines of the Breck in the vicinity of the River Lark, e.g. Tuddenham Fen, near Worlington, and near West Stow; in the vicinity of the Little Ouse and, to a lesser extent, by the Thet and Wissey. Hammond (1974) has already discussed the effect that fragmentation of fen habitats has had on their associated beetle communities during the present century. Although the Breckland fens have some links, via the rivers, with the fens of Cambridgeshire and the Norfolk/Suffolk Broads, many fenland beetles have very disjunct distributions, occurring elsewhere in such sites as the Somerset Levels, Kent marshes and Border mires. Two examples among the water beetles are *Hydroporus glabriusculus*, known from four Norfolk localities and five in Berwickshire (Sinclair, 1976), and *H. elongatulus* from two Breckland sites and five on the Scottish border (Foster, 1984). A good example of a fenland species is the staphylinid *Stenus palustris*, found abundantly at Tuddenham and West Stow. There are otherwise reliable post-1945 records only from some 11 scattered localities west to South Wales, and north to Yorkshire, and several in Norfolk: Old Buckenham Fen, Lopham Little Fen, Catfield Fen and Hickling Broad (Hammond, unpublished).

Other Breckland species which are at present largely confined to remnant fen habitats in Britain include: the carabids *Badister unipustulatus*, *Oodes helopioides*, and *Dromius longiceps*; the dytiscids *Hydroporus rufifrons*, *H. scalesianus*, *Laccornis oblongus*, *Agabus undulatus*, and *Rhantus grapii*; the hydrophilids *Hydrochus carinatus* and *Helophorus nanus*; the ptiliid *Microptilium pulchellum*; the staphylinids *Carpelimus lindrothi*, *Stenus carbonarius*, *S. europaeus* and *Schistoglossa viduata*; the pselaphid *Pselaphus dresdensis*, and the cantharid *Silis ruficollis*. There are recent Breckland records for all these species, with the exception of *Hydroporus rufifrons* which was recorded from Brandon in 1889 but since 'appears to have died out in the easternpart of its range' (Shirt, 1987). A few wetland species such as the staphylinids *Olophrum fuscum* and *Platystethus nodifrons* have a very limited distribution in the south where they are mainly confined to fen situations, but are relatively widely distributed in northern Britain.

Discussion and recommendations

The establishment of Thetford Forest on the Brecklands of Norfolk and Suffolk has had a profound effect upon the beetle fauna of the region. The presence of such an extensive area of predominantly coniferous forest has provided the opportunity for many species to colonise a part of the country previously inhospitable to them. Its proximity to the east coast of Britain, and hence to the European mainland, coupled with its continental climate, increases the possibility of natural immigrants establishing populations in Britain. However, despite the array of beetle species which can be found associated with these conifers these are, for the most part, common species widely distributed in such habitats. The rarer woodland Coleoptera known from the Breckland are largely associated with deciduous trees. Of the 18 rare forest species listed in Table 9.3 only the scolytid *Pityogenes trepanatus* is associated with conifers. It is not only important that the overmature broadleaved trees, upon which many of the rarer Coleoptera depend, are retained but that representatives from younger age classes be allowed to grow to maturity to cater for the needs of future generations of Coleoptera and other invertebrates.

There should be no doubts in anyone's mind that the greatest ecological interest in the Brecklands rests with the remaining areas of open country, that is areas most closely resembling the traditional Breck landscape. The concentrations of rare species of Coleoptera which can still be found in the few surviving areas are unique. Many of these locations are already afforded some protection as Nature Reserves, and the Stanford PTA has inadvertently protected an important area, but the small size of many of the remaining sites renders them very vulnerable to destruction by a variety of activities, including afforestation. There is nothing to be gained from decrying the loss of open Breckland by past programmes of tree planting, but Thetford Forest is perhaps now at a point in its history where its future management can be reassessed and, if necessary, modified. Woodlarks and nightjars have exploited areas of forest recently clear felled (Green and Bowden, Chapter 11). It is possible that these areas may also provide suitable habitats for some of the beetles associated with sparsely vegetated open country. As more and more compartments reach the age for felling there is an urgent need for further studies into the colonisation of such areas by beetles and other invertebrates. It is unrealistic to expect such felled areas not to be replanted, but it is perhaps possible for wider rides, and some more open spaces, to be incorporated into the long-term management plans for the forest. Much is now known about the beneficial effects of wider rides (Ferris-Kaan, 1991) and, although invertebrate studies have concentrated on butterflies, Hall and Greatorex-Davies (1989) demonstrated the effects of shade upon Chrysomelidae, Curculionidae and Heteroptera associated with the herbs in plantation rides.

The importance of the remaining areas of fen, marsh and open water has been demonstrated. Their value as reservoirs for whole communities of rare beetles of high conservation value cannot be stressed too highly, although drying out of fen remnants along the Breckland rivers was seen as a threat to their insect populations almost a century ago (Morley, 1908). The Breckland meres are notorious for emptying in times of drought and many of these sites have suffered as a result of the exceptionally low rainfall throughout the region during 1990/91. Early in 1991 all the pools and meres on the Stanford PTA were found to contain no free water and the survival of many of the rare water beetles appeared threatened. However, all these species were found to be present when the pools were re-surveyed in 1993 (M. Collier, personal communication). With such naturally occurring climatic hazards to contend with, every effort should be made to maintain any wetland sites within Thetford Forest, and management should be such that it ensures their continued existence. It is encouraging to learn that the Ministry of Defence intend to institute a programme of estate management to recreate heathland/Breckland habitat from Forestry Commission clear fell areas within the Stanford PTA (Long, 1991). We trust that this imaginative experiment will be fully monitored, and the results used as a guideline for future initiatives elsewhere in Thetford Forest.

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Chapter 10

Woodland as an amphibian and reptile habitat with special reference to Thetford Forest

Rob Oldham, Mary Swan and Nick Gibbons

Summary

Amphibian surveys were conducted in 320 km^2 of Thetford Forest and associated woodland as part of a national survey covering approximately 3000 km^2 of a series of habitats throughout Britain. Common toads were found in a significantly higher proportion of water-bodies in woodland, both nationally and at Thetford, than in other habitats (p<0.005). This evidence of success in woodland was supplemented by toad length and mass measurements, which showed Thetford specimens to be particularly large and fecund. Nationally, common frogs were also found in a significantly higher proportion of woodland pools than non-woodland (p<0.001), but they occurred less frequently at Thetford than in other woodlands (p<0.001), perhaps as a result of dry conditions. Smooth newts and crested newts did not show significant differences in their occurrence in woodland (Thetford and national) and non-woodland water-bodies. Reptiles were recorded in the Thetford area during the same period as the amphibians but as 79 incidental observations. There were only three sightings of slow worms but grass snakes, adders and common lizards were recorded more frequently. Suggestions for habitat management are provided for both amphibians and reptiles.

Introduction

The aims of this chapter are:

1. To examine the current status of amphibians and reptiles in Thetford Forest and associated woodland and to place it in a national context.

2. To review amphibian ecology in terms of woodland and non-woodland habitats.

3. To consider how woodland might be managed to enhance its conservation value for amphibians and reptiles.

The work was initiated as part of the Nature Conservancy Council's (now English Nature) Common Amphibian and Reptile Survey. This national survey, based at De MontFort University (formerly Leicester Polytechnic), has been collecting data on amphibian and reptile sites for 8 years and 2 years, respectively, through a national network of volunteer recorders. A systematic survey of water-bodies, potential amphibian breeding sites, in the Thetford area was undertaken by volunteers from the Thetford Natural History Society, beginning in 1989. Records were also kept of incidental sightings of reptiles during the same period.

In Buckley's (1975) account of Norfolk amphibians and reptiles, there are post-1960 records of four species of amphibian in the Thetford area, namely: common toad (*Bufo bufo*), common frog (*Rana temporaria*), smooth newt (*Triturus vulgaris*), crested newt (*T. cristatus*). Buckley (1975) lists three species in his post-1960 records of reptiles from the Thetford area, namely: common lizard (*Lacerta vivipara*), grass snake (*Natrix natrix*) and adder (*Vipera berus*).

Methods

Amphibian data were collected using the national survey 'blanket survey' strategy (Swan and Oldham, 1989), in which every water-body in a given area of land is examined. To check for every species, a variety of methods was used: spawn clump counts for common frogs; nocturnal torchlight searches for adult toads and newts; and vegetation egg searches, bottle trapping and dipnetting for newts. The data on the species and numbers of individuals present were entered on to national survey 'pond questionnaires' which also contained sections for the description of aquatic structure and vegetation cover, and the predominant terrestrial land-uses at different distances from the water-body. For the present study, *a woodland pond* is defined as one in which woodland was identified as the predominant habitat between 10 and 500 m away. The first 10 m was excluded because ponds are frequently surrounded by trees, even in predominantly agricultural land, and 500 m was chosen as the outer limit since this probably allows for most of the dispersion of all four of the amphibian species being considered (Oldham and Nicholson, 1986; Moore, 1954). Water-bodies were only classified as amphibian sites if there was evidence of breeding animals.

Unlike the amphibia, the reptiles do not congregate in large breeding aggregations in easily recognised habitats. This, coupled with the low density of reptile occurrence in most parts of Britain, means that it is difficult to undertake systematic surveys of the group. Reptiles were recorded by members of the Thetford Natural History Society whenever they were encountered. The results are likely, therefore, to be strongly influenced by the behaviour of the recorders.

Survey areas

The study area of 320 km^2, straddling the Norfolk/Suffolk border (Figure 10.1), includes 125 km^2 of Forestry Commission plantation forest (mainly Scots and Corsican pines with only 10% broadleaved trees), together with dry

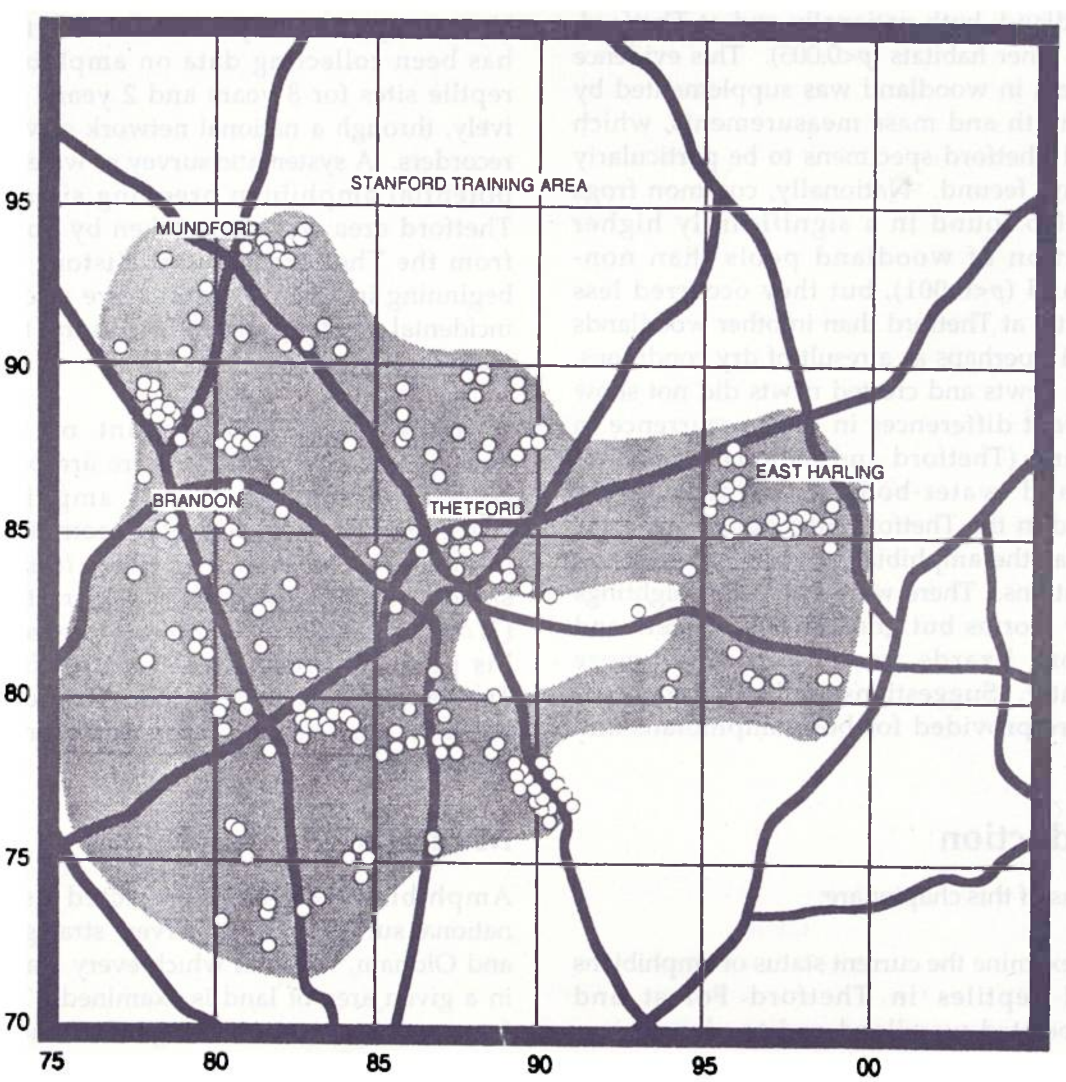

Figure 10.1 Distribution of ponds within the blanket survey area

heaths, arable farms, river valleys, carr woodlands and fens. A total of 240 water-bodies was found in this area, 93% of which were woodland ponds, as defined above. These were surveyed during the springs of 1989 and 1990. In the analysis which follows, the small sample of non-woodland ponds at Thetford is excluded; only the woodland ponds will be considered and no distinction is made between the 71 Forestry Commission ponds and the remainder. Twenty-nine per cent of the ponds were surrounded by mixed woodland, 41% by coniferous woodland and 29% by deciduous woodland.

The national database

Between 1987 and 1990 (Swan and Oldham, 1989, 1993), over 3000 km^2 (approximately 1.3% of mainland Britain) containing over 2000 water-bodies in 52 counties were surveyed in 91 separate 'blanket surveys' for the national survey. Data on the terrestrial habitats in the vicinity of the water-bodies were supplied in 1154 cases and on this basis 45% were identified as 'woodland' (33% mixed, 24% coniferous and 43% deciduous).

The national database contains 4585 records of reptiles, 20% of them from East Anglia. The habitat data provided with the records do not permit a subdivision of material in the manner adopted for the amphibians.

Results: amphibians

As in Buckley's (1975) survey, four amphibian species were found in the Thetford area: common frog, common toad, smooth newt and crested newt. At least one species was found in 60% of 223 woodland ponds. The most frequently occurring was the toad, found in 46% of the water-bodies (Figure 10.2), followed by the frog (20%), smooth newt (12%) and crested newt (8%). The corresponding values from the national database are illustrated in Figure 10.2. Toads and frogs present the most striking differences. Nationally, both species were found in a significantly higher proportion of woodland than non-woodland sites (toads $p<0.005$ and frogs $p<0.001$). In Thetford woodland toads were found in a similar proportion of ponds to the national woodland average (Figure 10.2), unlike frogs which were found in significantly fewer sites ($p<0.001$). No significant differences were detected in the proportions of ponds occupied by either of the two newt species in the three habitats (Figure 10.2).

Frequency of occurrence at potential breeding sites provides one indicator of amphibian status, a second is provided by counts of the numbers of animals at each site. Data on the numbers of toads seen are available from both the Thetford (30 counts) and the national surveys (44 counts

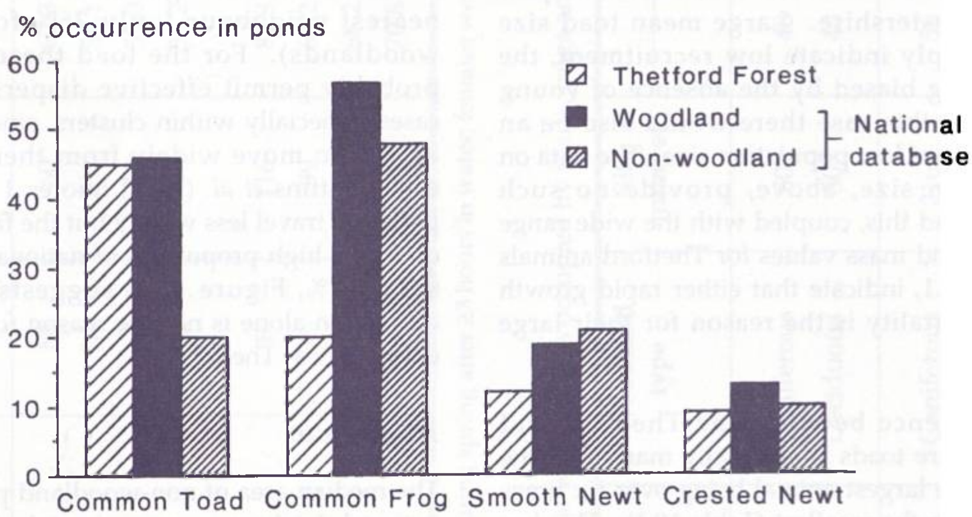

Figure 10.2 Proportions of water-bodies occupied by each of four amphibian species in Thetford Forest and in woodland and non-woodland sites nationally

for woodland pools, 39 for non-woodland). The median counts for Thetford and national woodland pools were similar (15 and 11, respectively) and did not differ significantly. Non-woodland pools tended to have higher counts (median 46), but again there was no significant difference between these and the woodland pool counts. In each of the three habitats there was, however, a positive correlation between toad count and pond area ($p<0.05$ or less in each case).

A third indicator of population status is individual animal size, since this is related to egg production (Swan, 1986; Gittins *et al.*, 1984). Data on amphibian sizes were not obtained as part of the national survey but we made measurements of a large series of toads during a population management exercise associated with a road development in Thetford in 1988 (Oldham, 1989) and, for comparison, we have data on three populations from Leicestershire. All measurements were made under similar conditions at the start of the breeding season.

The Thetford toads were striking for their large size (Table 10.1). The largest animal encountered was a female of length 95.0 mm (snout – urostyle measurement) and mass 120.2 g, of similar size to the largest female of 99.0 mm recorded in Frazer's (1983) review. Both sexes in the Thetford sample were significantly longer and heavier ($p<0.001$) than in the woodland or non-woodland samples from Leicestershire. Large mean toad size might simply indicate low recruitment, the mean being biased by the absence of young adults. In this case there would also be an expectation of low population size. The data on population size, above, provide no such evidence and this, coupled with the wide range of length and mass values for Thetford animals in Table 10.1, indicate that either rapid growth or low mortality is the reason for their large size.

The difference between the Thetford and Leicestershire toads is especially marked in the females, the largest animal being over six times heavier than the smallest (Table 10.1). This has clear implications for egg production. Swan (1986) has shown in Leicestershire toads (measured at the same time of year as above) that there is a positive correlation between female size and egg number (egg number = 53 x female mass (g) + 195; a female of 25 g producing 1520 eggs, one of 50 g producing 2845). The Thetford toads fall outside the size range determined by Swan but measurements of fecundity in two females (58.5 g and 86 g females producing, respectively, 3530 and 4250 eggs) indicate that the relationship is similar.

Although the evidence on size and productivity points to particularly good conditions for toads in Thetford woodland, it does not follow that this is a consequence of the woodland habitat, since the non-woodland sample from Leicestershire (Table 10.1) contained significantly larger toads than either of the Leicestershire woodland samples.

The observed differences in amphibian occurrence (Figure 10.2) may reflect variables other than the simple presence or absence of woodland. In the national survey a wide variety of habitat parameters is recorded for each amphibian breeding site and for the terrestrial habitats in its vicinity (Swan and Oldham, 1989). Those thought to have a particular bearing upon the observed differences are considered below.

Pond dispersion

Pond density in woodlands at Thetford and nationally was recorded as relatively low (0.7 km^2 and 0.6 km^2 respectively: equivalent to an average spacing of one pond every 1200 and 1300 m respectively) by comparison with non-woodland areas (1.6 km^2, ponds on average 800 m apart). Ponds were clustered in Thetford woodlands, 41% being less than 100 m from the nearest neighbour (only 26% for national woodlands). For the toad these distances probably permit effective dispersal in most cases, especially within clusters, since toads are known to move widely from their breeding sites; Gittins *et al.* (1984) quotes 1 km. Frogs probably travel less widely but the fact that they occupy a high proportion of national woodland sites (57%, Figure 10.2) suggests that pond dispersion alone is not the reason for low pond occupancy at Thetford.

Pond size

The median area of non-woodland ponds in the national database is approximately 400 m^2, that of woodland ponds is lower (but not significantly so; $p>0.1$) at 300 m^2, while in Thetford woodland the value is even lower at 200 m^2 (significantly different from the national woodland value, $p<0.001$). Toads are generally found in larger ponds than other amphibians, the national median toad pond area being 639 m^2, by comparison with median

Table 10.1 Measurement of adult common toads from Thetford Forest and from three sites in Leicestershire

	Sex	Snout – urostyle length (mm)				Mass (g)[a]			
		n	mean	SD	range	*n*	mean	SD	range
Thetford Forest	M	60	62.3	3.0	69.5-54.5	89	29.8	4.5	42.4-19.6
Leics. woodland, site 1	M	64	55.1	3.9	62.5-43.5	87	18.4	4.7	35.9-8.7
Leics. woodland, site 2	M	40	55.0	3.5	61.0-48.0	97	19.8	3.5	29.4-11.9
Leics. non-woodland	M	90	56.2	3.4	67.0-49.5	96	22.9	5.1	39.7-13.7
Thetford Forest	F	116	82.3	5.6	95.0-65.5	74	81.0	19.1	120.2-39.2
Leics. woodland, site 1	F	99	66.2	5.2	80.5-53.0	81	37.7	9.2	60.6-19.6
Leics. woodland, site 2	F	83	68.2	4.5	78.0-57.0	63	40.1	9.0	62.8-22.8
Leics. non-woodland	F	46	70.8	4.9	83.0-57.0	41	49.9	9.2	70.1-29.0

[a]All mass determinations during spring after ≥3 hours in water; females weighed before ovulation.

Table 10.2 Proportions of water-bodies occupied by toads, frogs and newts in coniferous and deciduous woodland in Thetford Forest and nationally

	Woodland type	Site number	% occurrence			
			Toad	Frog	Smooth newt	Crested newt
Thetford Forest	Coniferous	60	48	27	12	12
	Deciduous	50	40	18	8	4
National woodland sites	Coniferous	216	56 } [a]$p<0.01$	58 } [a]$p<0.05$	16 } [a]$p<0.001$	
	Deciduous	309	41	54	23	

[a]Significant differences.

values for the other three species lying between 320 m^2 and 400 m^2. However, in Thetford woodland the median area of toad and frog ponds was only 175 m^2 and 125 m^2 respectively, suggesting that pond size is not a critical factor in the selection of a breeding site. The positive correlation between pond area and observed toad numbers does suggest, however, that toad population density may be controlled by the availability of aquatic habitat.

Pond side vegetation

Shading from trees might be anticipated for woodland ponds, and indeed a significantly higher proportion was heavily shaded (24% of ponds with 75% or more of the perimeter shaded) than for non-woodland ponds (16%; $p<0.01$). An even higher proportion of Thetford woodland ponds was heavily shaded (37%). This factor does not seem to be detrimental to the success of the toads, but it could be a contributory cause of the low frequency of frog breeding sites, especially in ponds shaded from the south; Swan and Oldham (1989) showed that a significantly high proportion of frog sites was not south shaded ($p<0.001$).

Aquatic vegetation

There is evidence of similarity of aquatic habitats in woodland and non-woodland breeding sites from the national and Thetford data on emergent and submerged pond vegetation. There are no clear distinctions between ponds in woodland and non-woodland sites in either of these respects. In Thetford Forest an unusual feature of some ponds is the absence of vegetation and turbidity caused by deer wallowing.

Terrestrial vegetation

Significant differences were found in the frequency of occurrence of three of the amphibian species in coniferous and deciduous woodland in the national database (Table 10.2). The toad and frog were found more frequently in coniferous woodland ($p<0.001$ and $p<0.01$ respectively), the reverse was true for the smooth newt ($p<0.05$). No significant differences were found between the occurrence of the crested newt in the two woodland types, either at Thetford or nationally.

Terrestrial moisture

Amphibia require aquatic habitats for annual breeding but they also depend upon a relatively moist habitat throughout the year. Frogs and perhaps smooth newts (Perring, 1973; Blackith and Speight, 1974; Swan, 1986) are commonly associated with wet habitats during the summer months. Thetford woodland is notable for its relatively dry conditions. Ditches were recorded within 100 m of only 11% of sites. The equivalent value for streams was 10%. In contrast, 24% of woodland ponds in the national database had ditches and 18% had streams, within the same distance. These differences are significant ($p<0.05$). We have already seen that the Thetford ponds themselves are small and this, coupled with the absence of wet terrestrial habitat, results in a paucity of moist refugia. This might explain the low occurrence of common frogs. Indeed, in the Thetford survey frogs were found mainly in the river valleys, especially near to West Harling, where there is a large area of damp woodland with a concentration of ponds on the south side of the River Thet.

Results: reptiles

The three reptile species recorded by Buckley (1975) were all found in Thetford Forest in the current survey, together with three sightings of the slow worm. A total of 79 sightings were made, 22% common lizard, 4% slow worm, 44% grass snake and 31% adder (Figure 10.3). For comparison, the proportions of the four species recorded in the national database are shown (Figure 10.3). The East Anglian values closely resemble those from Britain as a whole but for each species the Thetford proportions show marked variation with lower values for the two lizards and higher values for the snakes.

Discussion: amphibians

There is clear evidence of favourable conditions for toads in Thetford woodlands, with a higher than average occurrence of breeding sites, larger individual animals and greater productivity. It is possible that both aquatic and terrestrial habitat conditions contribute to this difference, but the limited evidence we have on the former suggests that these are reasonably consistent in woodland and non-woodland. We have no evidence to suggest which components of the terrestrial habitat might account for the observed toad success but a large food supply and good refugia seem likely. Although the occurrence of toads is high in the woodland habitats, it would probably be higher still given a greater density of breeding sites. There is also evidence that population density would be increased if the breeding sites were larger.

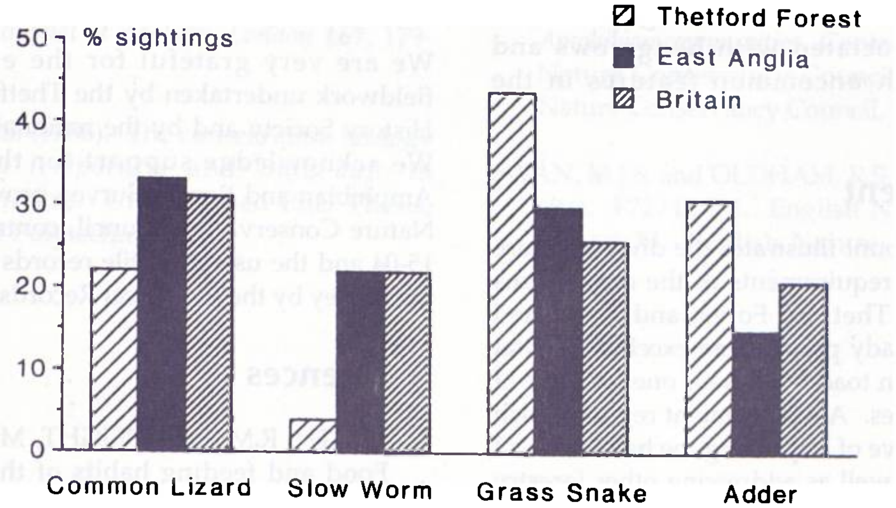

Figure 10.3 Proportions of sightings of four reptile species in Thetford Forest, in East Anglia and nationally

For the common frog there is clear evidence of differences in status in different habitats but this time the difference lies between the national woodland and Thetford woodland. Again, the terrestrial habitat is implicated but in this case probably as a result of dry ground conditions that present a desiccating environment for the animals, the juveniles perhaps being particularly susceptible. Swan (1986) showed that streams and wet ditches are used as breeding migration routes by common frogs. The paucity of water courses at Thetford is therefore likely to reduce the dispersal of the species. This effect might have been exacerbated by the recent dry summers. The higher level of shading of breeding sites at Thetford may present an additional unfavourable factor for frogs.

Both the smooth and crested newts were found in similar frequencies in Thetford woodlands, in other woodlands surveyed for the national database and in non-wooded environments. This raises the question as to why the newts are neither as successful as the toad at Thetford nor as unsuccessful as the frog. On the one hand, like the frog, they may be unable to take advantage of dry terrestrial conditions. Additionally (unlike the frog), they eat largely soft-bodied prey which are also dependent upon moist conditions. On the other hand, the newts, particularly the crested newt, have an extended aquatic phase during the late spring and summer when they feed in water and are not therefore so susceptible to the dry terrestrial conditions as the frog.

In the absence of more detailed habitat analysis, we cannot determine whether the higher frequency of occurrence of both the common toad and common frog in pools in coniferous rather than deciduous woodland is a primary effect caused by differences between the two woodland types or whether it is a secondary consequence of associated habitats. Coniferous woodlands in Thetford are managed commercially, with a sequence of operations involving clear felling and subsequent regeneration over a number of years. Coniferous woodlands are therefore likely to consist of a mosaic of very different habitats. This structural and spatial variety may be the key to the success of the animals in coniferous woodland. The smooth newt shows the expected trend of a higher frequency of occurrence in deciduous rather than coniferous woodland.

Discussion: reptiles

The relatively small data set from the Thetford area and the arbitrary nature of the survey method limits the value of any analysis. It is likely that the high proportion of grass snake sightings was in part a result of their occurrence in one or two wetland areas used for public recreation (e.g. Punch Bowl Mere forestry picnic site). Adders are probably common in the area because of the prevalence of heathland, a favoured habitat. Again, the high frequency of sightings was probably a consequence of their occurrence in areas frequented by the public, in this case golf courses. Common lizards occur in similar habitat but are less easily observed, while slow worms favour the high structural diversity associated with hedgerows and gardens, both uncommon features in the Thetford area.

Management

The above account illustrates the diverse nature of the habitat requirements of the amphibians and reptiles. Thetford Forest and associated woodland already provides an excellent habitat for the common toad but a poor one for most of the other species. A management regime which had the objective of improving the habitat for all the species, as well as addressing other forestry requirements, would clearly need to be based upon careful planning and zonation. In the following two sections, we summarise some of the measures which might be undertaken in the terrestrial and aquatic habitats to ameliorate the environment for the named amphibians and reptiles. Greater detail of management procedures for reptiles are provided by Langton (1989).

Terrestrial habitat

Purposeful neglect of drainage systems would increase the prevalence of standing water and associated wetland habitats and aid frogs and newts. The retention of dead wood as refugia would aid all species. Selective scrub clearance in clear felled areas would provide reptiles with basking sites. Similarly, the widening of woodland rides would benefit reptiles, particularly lizards. The provision of piles of dead vegetation, such as grass mowings, would provide egg-laying sites for grass snakes. A forest management regime which increased the mosaic nature of the woodland would benefit all species.

Aquatic habitat

Pond creation, especially in unshaded locations, would improve the habitat for all the amphibians and for grass snakes. A depth profile is needed which will minimise the impact of deer wallowing. Enlargement of ponds would be likely to increase toad population size. A continuing programme of macrophyte management would ensure that senescence does not overtake existing ponds. The avoidance of fish introduction would benefit frogs and newts.

Acknowledgements

We are very grateful for the enthusiastic fieldwork undertaken by the Thetford Natural History Society and by the national volunteers. We acknowledge support for the National Amphibian and Reptile Survey provided by the Nature Conservancy Council, contract no. F72-15-04 and the use of reptile records released for the survey by the Biological Records Centre.

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Chapter 11

The ecology of woodlarks and nightjars breeding on pine plantations in Thetford Forest

Rhys Green and Chris Bowden

Summary

Restocked pine plantations in Thetford Forest have become an important habitat for two nationally scarce birds, woodlark and nightjar, which formerly occupied Breckland heaths. They now nest on plantations for up to 5 years (woodlark) or 20 years (nightjar) after preparation and planting. Populations of both of these birds in the forest have trebled between the mid 1970s and the late 1980s as the area replanted per year has grown. Both species would be expected to decline after the felling of the first rotation crop, when the area being replanted falls. Studies of the birds' habitat preferences have been made in an attempt to identify ways in which the smaller area of potential habitat available in future could be managed to enhance woodlark and nightjar populations.

In both species there were strong correlations of population density with the type of ground vegetation. In the case of woodlark, this link was confirmed as being caused by a field experiment in which ground vegetation was altered by means of a herbicide. It is suggested that the ground vegetation of plantations should be managed by shallow ploughing to prolong the period for which they are suitable for woodlarks. Nightjars may also benefit from this treatment.

Introduction

Before Thetford Forest was established in the first half of the 20th century, the tracts of heathland were much more extensive than those of today. Much of the heathland was subject to soil disturbance and heavy grazing by rabbits *Oryctolagus cuniculus* which helped to create suitable conditions for three species of heathland birds, stone-curlew *Burhinus oedicnemus*, woodlark *Lullula arborea* and nightjar *Caprimulgus europaeus*. These birds share a preference for open ground with a component of bare soil and sparse, short vegetation. Conversion of heathland to forestry plantations and mixed farmland initially caused reductions in the populations of these birds which were exacerbated by reduced soil disturbance and grazing by rabbits on the remaining heathland after the epizootic of myxomatosis in the 1950s. However, at the same time that the numbers of pairs of woodlarks and nightjars breeding on heathland have been declining, these species have increasingly been making use of second rotation pine plantations during the early stages of growth, so that the number of pairs nesting on plantations now greatly exceeds the number on heathland. Unfortunately, the stone-curlew has not been a beneficiary of this recent access to a new habitat. Although stone-curlews have been recorded nesting on plantations, they do so only rarely.

Both woodlark and nightjar are among the bird species considered to be in need of special conservation action in Britain because of their small total population and recent history of decline (Batten *et al.*, 1990). Because the populations breeding on pine plantations in Thetford Forest represent substantial and increasing fractions of the national population, the research described in this chapter was commissioned by the Forestry Commission in order to find out more about the birds' habitat requirements and potential for management. Most of the conclusions reported in this study are based on results obtained in this recent research and, unless otherwise stated, are supported by material to be found in the project reports (Bowden and Green, 1991, 1992).

Such research is especially timely because a reduction in planting is anticipated as the felling of the first rotation crop is now well advanced. Hence, management methods are being sought which can enhance the numbers of woodlarks and nightjars on the smaller area of young plantations and permit viable populations of these birds to persist.

Woodlark and nightjar population trends

The increase in the number of pairs of woodlarks breeding on pine plantations has been monitored for almost 20 years by R.A. Hoblyn. The number of territory-holding males increased from 24 in 1975 to 83 in 1990. The counts show a long-term exponential upward trend, albeit with substantial annual fluctuations, with an underlying rate of increase of about 7% per year (Figure 11.1). An even more rapid increase in the number of woodlarks breeding on pine plantations has taken place in the Sandlings Forest of East Suffolk. By contrast, the number of woodlark territories found on heathland outside the forest in Breckland dwindled to 0-2 pairs in the late 1980s (Bowden and Hoblyn, 1990).

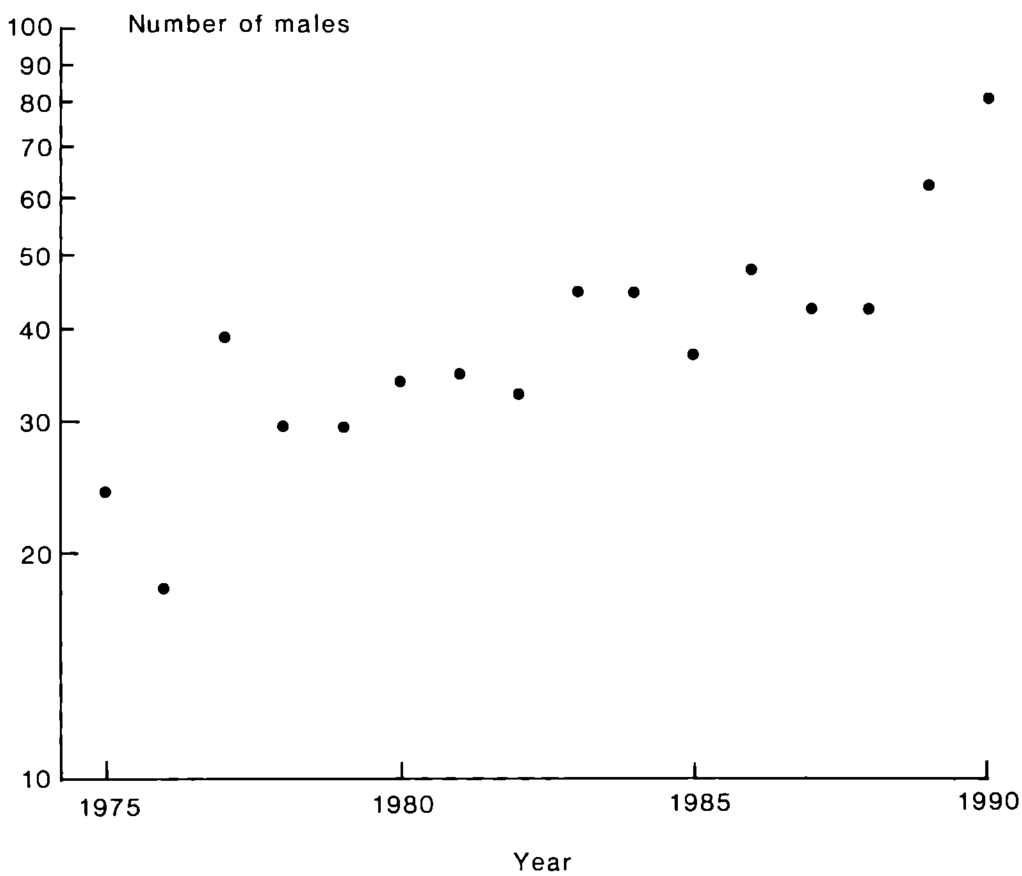

Figure 11.1 The number of male woodlarks holding territory on pine plantations in Thetford Forest 1975-1990. The vertical scale is logarithmic to show the underlying exponential trend in numbers

The most recent national population estimate for woodlarks is 350 pairs in 1988-91 (Sitters, 1993). The Thetford Forest population in 1990 represents 24% of this total. The population of nightjars on pine plantations has also increased. Pleasance (1982) estimated that the number of singing males increased from 90 in 1974 to 123 in 1978 and 168 in 1981. Surveys carried out in 1988-89 indicated a population of at least 293 males and probably over 300. The most recent population estimate for Britain and Ireland is of 2100 males in 1981 (Gribble, 1983).

Woodlark and nightjar populations in Thetford Forest have both increased by a factor of just over three between the mid 1970s and the late 1980s. The upward trends broadly parallel increases in the area replanted as the first rotation was felled (Figure 11.2). It is likely that the increases in bird populations are caused by the increase in the area of planting because both species utilise young plantations.

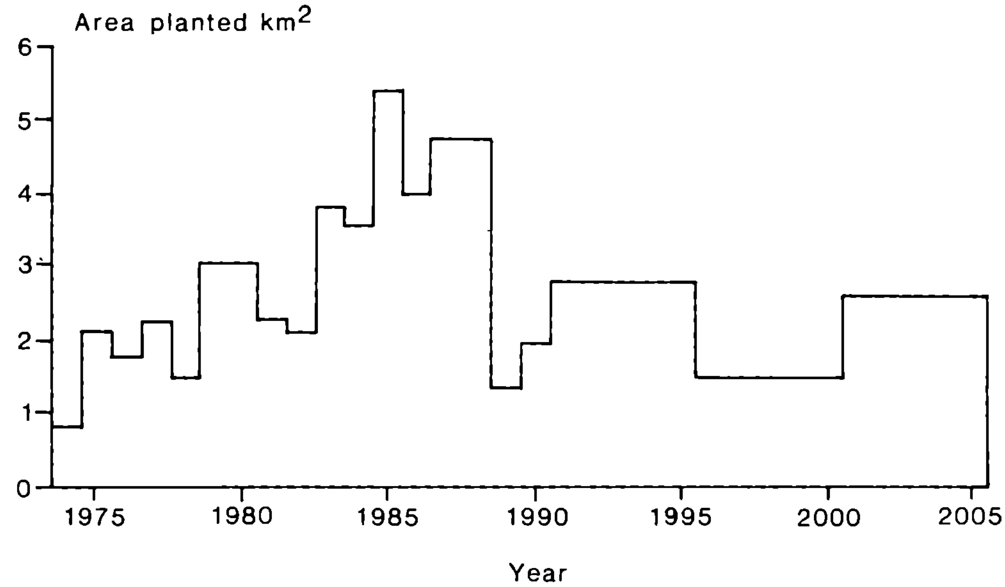

Figure 11.2 The area of conifers planted per year in Thetford Forest 1974-90 and the projected area up to 2005

Woodlark ecology

Woodlarks are spring and summer visitors to Thetford Forest and their wintering grounds are unknown. The nest is built on the ground in the cover of grass or bracken. The first eggs are laid in late March or early April. In Thetford Forest just less than half of the breeding attempts started to give rise to fledged young. Most failures are caused by predation. Additional clutches are laid after virtually all breeding failures early in the season and after some successful breeding attempts. On average 2.0-2.5 young are fledged per season.

Woodlarks individually colour-ringed as nestlings in Thetford Forest have been found on breeding territories up to 136 km away, but most individuals were detected on territories within the forest up to 11 km from the natal site. Once they had occupied a territory most adult woodlarks which returned did so to within 500 m of the same site in subsequent years. The return rate of adults was 50-60%.

Woodlarks feed on seeds and insects picked from the soil surface or from vegetation as the birds walk over bare ground or short vegetation. Insects, particularly lepidopteran larvae, predominate in the diet in spring and summer. Studies of the ranging behaviour of woodlarks with young in the nest showed that the adults foraged up to 400 m from the nest and selected areas with predominantly bare ground and short vegetation (<5 cm tall) (Bowden, 1990).

Woodlarks were most abundant on plantations one or two years after planting, but they occurred regularly on prepared but unplanted restock areas and on plantations up to five years old. Information on the distribution of woodlarks in the forest in the period 1986-89 was used in conjunction with surveys of ground vegetation on plantations up to five years old to generate multivariate regression models relating woodlark density to vegetation. Woodlarks prefer plantations with substantial areas of bare ground, fine woody debris, moss, short grass and bracken and avoid those with large areas of brash and shrubs. However, plantations with very large areas of bare ground and short vegetation are also avoided. There appears to be an optimal mixture of tall and short vegetation. The preference of woodlarks for plantations of particular ages is explicable in terms of vegetation change with time since preparation and planting. Plantations on soils of low pH hold higher densities of woodlarks than those on near neutral soils.

Management for woodlarks

The area of young plantations suitable for woodlarks is projected to decline (Figure 11.2) so it is suggested that special management is carried out to maximise the number of pairs that the remaining suitable areas of the forest can support. There are two ways in which this could be done. The first is to modify the management of plantations in such a way as to maintain ground vegetation of a suitable type for woodlarks for a longer period. Several ways of doing this have been studied. Experimental treatments with the herbicide atrazine in 1988 on 2- and 3-year-old plantations produced a measurable change in vegetation which was predicted to be beneficial for woodlarks and also produced an increase in the proportion of treated plantations used by woodlarks. However, this effect had disappeared 1 year after treatment and neither the change in vegetation nor the increase in woodlark incidence occurred when the trial was repeated in 1989. We believe that the effect of the herbicide may vary from season to season.

Woodlark density was found from survey data to be higher on plantations that had been treated before planting with a high dose application of the herbicide glyphosate. This effect was present until the plantations were 1 or 2 years old. However, as with atrazine, the effect seemed only to be present in some years.

Plot experiments to measure the effects of soil disturbance on the ground vegetation have produced much larger effects than either herbicide treatment. The treatment consists of ploughing shallow furrows between the rows of trees in February, having first mowed the ground vegetation with a tractor mounted swipe. It is estimated from the multivariate model of woodlark incidence in relation to vegetation that such treatment would approximately double the incidence of woodlarks in the year of treatment and a substantial effect in the following year also seems probable. Hence, we suggest that this type of treatment is likely to be the most reliable for creating suitable conditions for woodlarks. In view of the large home range size of woodlarks, we suggest that at least 5 ha would need to be treated to produce suitable conditions for a breeding pair.

A second type of conservation measure would consist of delaying the replanting of certain felled areas for a number of years. Treatment, such as the shallow ploughing described above, to retard the development of tall vegetation would be required. Such treatment would probably be required less frequently if the areas selected had soils of pH less than 5.0. If an area were to remain unplanted for a long period, it might be feasible to fence it and allow a rabbit population to develop and manage the vegetation by soil disturbance and grazing.

Nightjar ecology

Nightjars are nocturnal aerial insectivores. They are active for a relatively short period each day, mostly during the evening and morning twilight periods. At low levels of illumination they forage mainly by sallying from a perch or from the ground. At higher light levels they fly continuously and hawk flying prey. Moths are the main prey. The evening peak of nightjar activity coincides with a peak of abundance of flying moths which is not apparent during the early morning nightjar activity peak.

In Thetford Forest singing and displaying nightjars are most abundant on young plantations. Nightjar density declines with increasing plantation age to low levels by 15-20 years after planting. Multivariate analysis of surveys of singing males indicated that plantations occupied by nightjars are characterised by having greater areas of fine debris, moss, short grass, long grass, bracken and shrubs. Nightjars are more abundant on plantations of a given age class on acid than near neutral soils.

Radio-tagged nightjars flew up to 2 km from their nesting areas to forage, but most of their activity was within 1 km. Radio-tagged nightjars selected grass heathland and young plantations, especially those 3-5 years old, during periods of activity. Analysis of nightjar census data indicated that the chance that a plantation would be occupied by nightjars increased with the area of 3 to 5-year-old plantation within 1 km and decreased with the area of 11 to 15-year-old plantation within 1 km. These results are consistent with the hypothesis that the area of preferred foraging habitat close to a compartment influences the chance that it will be occupied.

The habitat preferences of nightjars are not readily explicable in terms of the abundance of their principal prey, moths, since these are just as abundant on old as on young plantations. It is suggested that shading by trees may interfere with the detection of prey and lead to avoidance of older plantations.

Management for nightjars

There are implications for forest management in the finding that nightjars forage over considerable areas and that their occurrence is influenced by the area of suitable foraging habitat within 1 km of a site. The felling of groups of compartments to provide a large area of suitable habitat for foraging may be better for nightjars than felling single compartments. Conservation and appropriate management of the remaining heathland areas and the creation of new heaths is likely to benefit nightjars by providing them with feeding areas.

Definite effects of ground preparation techniques and weed control treatments on the abundance of nightjars are difficult to identify because treatments have not been applied randomly with respect to vegetation and soil type. There was an indication that nightjar abundance increased with increasing numbers of previous sprays of glyphosate on 6 to 10-year-old plantations, but this result requires experimental confirmation before it can be recommended for management.

Since both woodlarks and nightjars show a preference for young, sparsely vegetated plantations, it is likely that the ground vegetation management techniques suggested for woodlarks would also benefit nightjars.

Conclusion

The early stages of growth of restocked pine plantations in Thetford Forest have become a nationally important habitat for woodlark and nightjar. Although their numbers have increased over the past 15 years, in line with increases in the area of young plantations, it is expected that populations will fall when the area of planting declines. Special management is recommended to increase the density of these birds on plantations. The management of ground vegetation by shallow ploughing appears to be a promising technique.

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Chapter 12

Small mammals in young and old pine plantations

Henry Mallorie and John Flowerdew

Summary

A population study of small rodents was conducted in two ages of pine plantation (7 and 56 years old). Wood mice were at lower densities than those usually found in deciduous woodland in both areas. The population had high rates of both mortality/emigration and immigration. Bank voles were at very low density in the young plantation, but in the old plantation average density was typical of that found in deciduous woodland. The population here was more stable and had lower rates of both mortality and immigration than those of wood mice. Field voles preferred the young plantation but even here were at low density compared to populations found elsewhere, and numbers declined to very low levels in the first year of the study. In the young plantation all three species were at higher density along lines of uprooted tree stumps than in the rest of the area.

Introduction

Small mammal population studies in mature woodland in Britain have concentrated on bank voles (*Clethrionomys glareolus*) and wood mice (*Apodemus sylvaticus*) in deciduous habitats (Flowerdew *et al.*, 1985; Mallorie and Flowerdew, 1994), almost completely neglecting coniferous woodland. Similarly, population studies of field voles (*Microtus agrestis*) in grassland have leaned towards rough grassland habitats (Richards, 1985). Thetford Forest, offering a wide range of coniferous woodland, therefore provides scope for population studies of all three species in habitats which have previously received little attention. One reason for this lack of previous work is possibly that mature coniferous woodland is often well shaded and not highly productive in the field and shrub layer, making poor habitats for wood mice and particularly bank voles, which prefer dense ground cover (Southern and Lowe, 1968). This was borne out by preliminary work at Thetford which showed that many of the mature plantations were poor habitats for small mammals, offering very low trapping success with only the occasional wood mouse (Mallorie, unpublished).

The present study concentrates on small mammal population dynamics in particular areas of mature (and young) forest where small mammals were relatively abundant. The work shows that habitat factors and possibly interactions with climate appear to have a strong influence on small mammal distribution and abundance.

Materials and methods

Study areas

The study was carried out in two areas, young and old pine plantations. The first (Figure 12.1) was of Corsican pine trees, 8-10 years old, 2-4 m tall, with the canopy not yet closed, with moderately good low (10-20 cm) ground cover in most of the area. The main ground cover plant species included grasses, heather, wood sage and some small patches of bracken. Lines of uprooted tree stumps were an important feature of this area. These were left over from the previous tree crop and ran through the plantation at intervals of 40-50 m. These gave better cover than in the rest of the plantation, both from the structure of the stump piles themselves and from the dense growth of herbaceous plants which grew up in the summer.

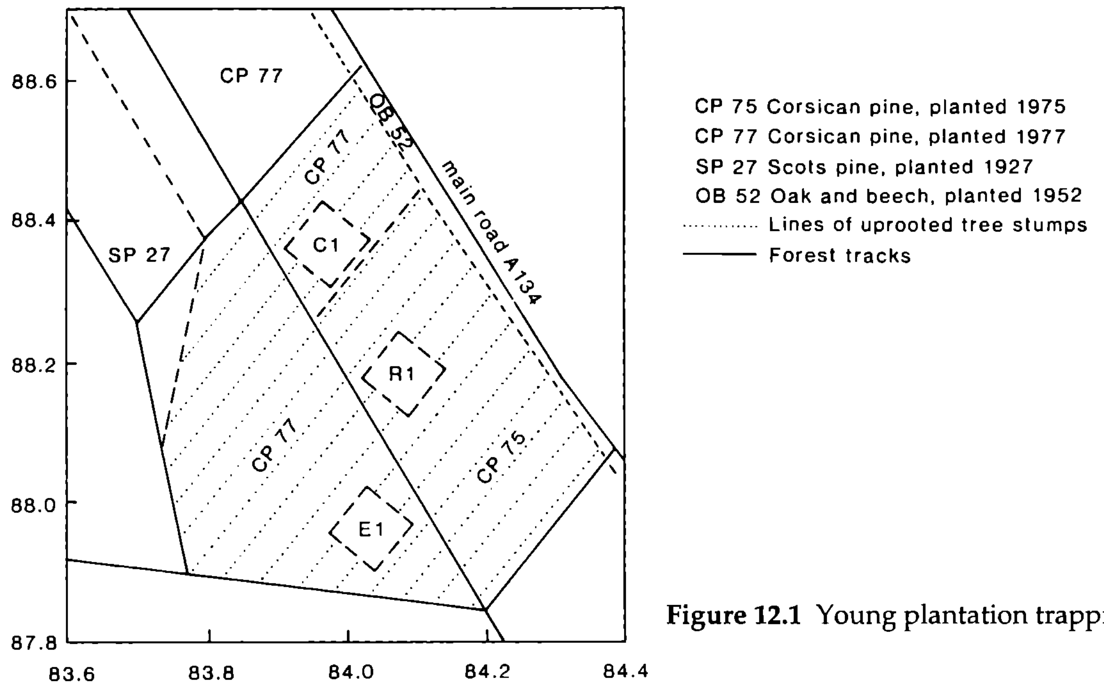

Figure 12.1 Young plantation trapping grids

Table 12.1 Main plant species in the two study areas

Species	Young plantation main area	Young plantation stump lines	Old plantation
Pinus nigra	C		
Pinus sylvestris			C
Acer pseudoplatanus			c
Fagus sylvatica			s
Ligustrum vulgare			s
Crataegus oxyacantha			s
Agrostis stolonifera		g	
Arrenantherum elatius		g	g
Calamagrotis epigeios			g
Elymus repens		g	
Festuca rubra	g		
Holcus lanatus		g	
Artinium lappa		g	
Calluna vulgaris	g		
Criisium spp.		g	
Geranium robertianum			g
Mahonia aquifolium			g
Rubus fruticosus		g	g
Rubus ideaus			g
Teucrium scorodonia	g		g
Urtica dioica		g	
Dryopteris Felix-mas			g
Pteridium aquilinum	g	g	g

C: main canopy tree, c: occasional in sub-canopy, s: occasional in shrub layer, g: ground cover.

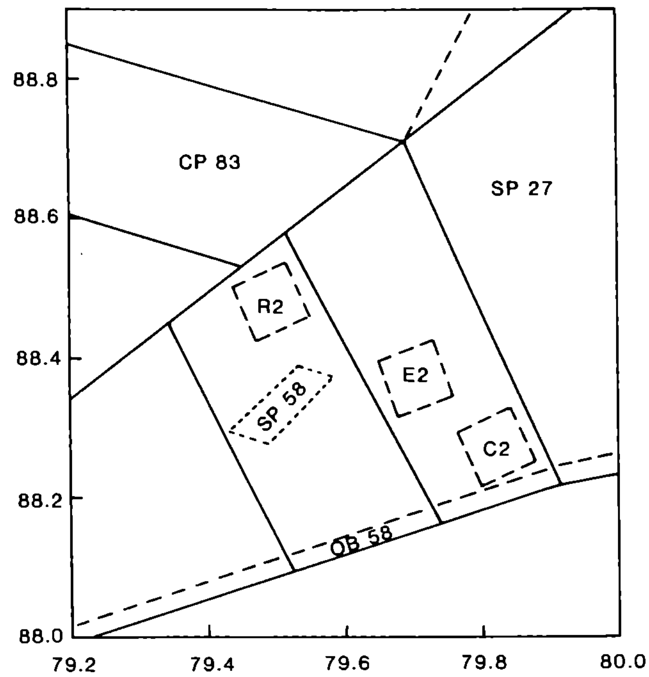

Figure 12.2 Old plantation trapping grids

The second area (Figure 12.2) was a 56-year-old stand of Scots pine. The trees in this area were suffering from disease and many had died, leaving an open canopy with only 30-50% cover. The ground cover was good, consisting mainly of Mahonia, brambles and patches of grass, bracken and ferns. There were no deciduous trees of fruiting size with the exception of a few sycamores. Unlike the young plantation there was no obvious large-scale heterogeneity. Table 12.1 gives a list of the main plant species in the two areas.

Trapping methods

There were three trapping grids in each area: a control grid (C), a removal grid (R) from which some animals were experimentally removed, and an extra feeding grid (E). Traps were set out on square grids of 8 x 8 points with 12.5 m between each point. Thus the grids were 87.5 m squares and covered an area of 0.766 ha. Two Longworth small mammal traps were set close together at each of the 64 points, giving a total of 128 traps per grid. The traps contained wheat and oats for food and hay for bedding. The traps were not prebaited but were set to catch on the first day of each session. They were checked in the morning for the next 4 days and checked and collected on the 5th day. On days 2-4 the traps were sometimes also checked in the afternoon, 4-8 hours after the morning round. This was done when there was a danger of trap deaths to voles through cold wet weather or, in the unshaded areas of young pine, in very hot weather. Afternoon checks were also made at times of high population density to lessen the effects of trap saturation.

Animals were marked by toe clipping. For each animal the following were recorded: species, sex, individual mark, weight (to the nearest 0.1 g), reproductive condition and point of capture.

Experimental treatments

Animals on grids E1 and E2 were given supplementary food from July 1984 to October 1985. Wheat, oats and carrots were put out every 7-10 days in cylindrical (15 cm x 15 cm) tins with suitable entrance holes in them; 10-15 kg of carrots and 10 kg of grain were used each time. The tins were put near the central 36 trapping points, if possible, in an area of dense cover.

Analysis of trapping results

The numbers of animals on each grid were estimated using the calendar of captures method (Petrusewicz and Andrejewski, 1962). In order to estimate population density, it was necessary to estimate the effective trapping area of a grid. This was done using a modified version of the 'inner square' method (Smith *et al.*, 1971) which assumes that the population density in the centre of the grids was the same as that along the edges. If this was the case, then:

$$N_c + A_c = N + A$$

where N_c = average number caught at 36 central trap points

A_c = area covered by 36 central trap points (0.56 ha)

N = average number caught on whole grid

A = effective trapping area of whole grid

If an animal was caught both in the centre and on the edge of a grid during one trapping session, then it was counted as being partly in both areas. For example, an animal caught once on the edge and twice in the centre counted as one-third of an individual in the centre and two-thirds of an individual on the edge.

Survival was estimated as the proportion of animals known to be alive on capture occasion i which were still present on the grid on occasion i+1. Thus, animals which did not survive could either have died or moved off the grid. All survival rates were standardised as the percentage of animals surviving per 28 days. This was done using the method of Chitty and Phipps (1966).

$$\log(s_{28}) = 28 \log(s) + t$$

where s_{28} = survival rate per 28 days

s = proportion surviving between two capture occasions

t = time interval (in days) between capture occasions

The breeding season was defined as the period when at least 50% of all adults (animals Ú14 g) were in breeding condition. Where the results of other studies are used for comparison, the same methods have been used to estimate population size, grid area and survival rate.

As indicated above, each grid in the young plantation had two lines of uprooted tree stumps running through them. These gave a distinct habitat from that in the main part of the grid. Of the 128 traps set in each grid, 32 were set along the stump lines and 96 in the main part of the grid. An animal was defined as using the stump lines if its average position of capture during a trapping session was within 6.25 m (half the spacing between trap points) of one of the lines of traps along a stump line. To measure the preference for each habitat the numbers of animals caught in each habitat were standardised as the number caught per 128 traps.

In the old plantation the habitat was patchy on a scale smaller than the spacing between trap points. Thus, trapping data were not suitable as a method of measuring habitat preference.

Results

Estimates of grid areas

Because of the preference for the lines of uprooted tree stumps shown by all three species in the young plantation, it was not possible to use the 'inner square' method for grids from this area. E2 was not used since the distribution of animals was affected by the addition of food to the central area of the grid. Table 12.2 gives the results of area estimates for the other old plantation grids (C2 and R2). Bank voles have the largest effective trapping area, 1.29 ha, wood mice slightly less, 1.25 ha, and field voles the least, 1.17 ha. This is equivalent to adding strips

Table 12.2 The effective area of grids C2 and R2, from the proportion of animals caught in the centre of the grids

	%C	Area (ha)	BS (m)
Wood mice	45.0	1.25	12.1
Bank voles	43.6	1.29	13.0
Field voles	48.0	1.17	10.3

%C: percentage caught in centre of grids.
BS: width of boundary strip.

of width 13.0 m, 12.1 m and 10.3 m respectively round the edge of the grid. To make results from other studies as comparable as possible, a boundary strip of 12.5 m was used to calculate the grid area for wood mice and bank voles; and a strip of 10 m for field voles. This was not done where the authors had made their own estimates of grid area using home range sizes.

Wood mouse populations

The average densities and survival rates of all three species in both areas are given in Table 12.3, where they are compared with the average values from other studies in more favourable habitats. Wood mice in both areas were at under half the density of typical populations in deciduous woodland. Survival rates were also lower. The

Table 12.3 Average population densities and survival rates of three species of rodent in conifer plantations and more favourable habitats

	Wood mice		Bank voles		Field voles	
	Population density	Survival rate	Population density	Survival rate	Population density	Survival rate
Young plantation	11	47	4	68	11	37
Old plantation	12	55	27	76	4	52
Typical habitat[a]	28	75	27	74	72	72

[a] Typical habitat: deciduous woodland for wood mice and bank voles, rough grassland or young conifer plantations for field voles.

Table 12.4 Population densities and survival rate of wood mice

Population density (ha^{-1})			Survival rate (% per 28 days)	Grid (ha)	Habitat	Reference
Av	Max	Min				
26 10	38 3	21 26	77 79	4.20 7.02	Yew wood Oak wood	Smal and Fairley (1982)
31 22	54 41	7 3	69	1.38 0.94	Deciduous woodland	Montgomery (1980)
59	140	12		2.00	Deciduous wood	Kikkawa (1964)
35	93	5	82	1.00	Oak wood	Gurnell (1981)
11				1.35	Deciduous wood	Southern and Lowe (1968)
16				1.32	Deciduous wood	Mammal Society[a]
8				1.32	Coniferous wood	Mammal Society[a]
28 13	70 34	11 4	71 71	1.44 0.98	Carmargue grassland	Jamon (1986)
5	17	0.7	55	2.56	Arable field	Green (1979)
11 12	25 27	0 0	47 55	1.27 1.27	Pine, 8 yr Pine, 56 yr	This study

[a] Unpublished records from woodland small mammal survey.

only other study with similarly low survival rates was that of Green (1979) in arable farmland, where the population density was even lower than in either plantation (see Table 12.4).

The changes in the numbers of wood mice on grids C1 and C2 are given in Figure 12.3. In the young plantation (grid C1) fluctuations in both years were typical of those found in deciduous woodland in years of poor tree seed crops, with peaks in early autumn. The breeding season in both areas (see Table 12.5) was also typical of wood mice (Flowerdew, 1985).

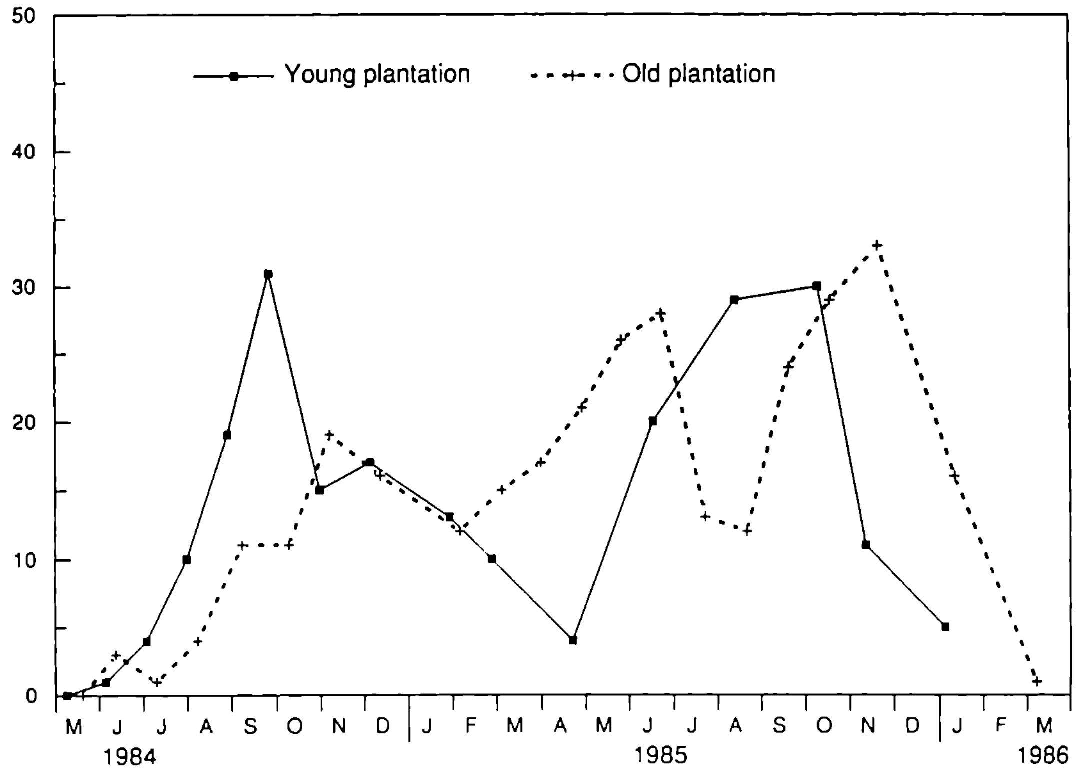

Figure 12.3 Numbers of wood mice known to be alive on the control grids in two different ages of conifer plantation

Table 12.5 The breeding season of rodents caught on the control grids in the two areas of conifer plantation in 1985

Species	Grid	Breeding season			Per cent breeding
		Start	Finish	Weeks	
Wood mice	C1	7 Mar	13 Sep	27	91
	C2	19 Feb	19 Sep	30	89
Bank voles	C1	20 May	13 Sep	17	100
	C2	12 Mar	24 Oct	32	95
Field voles	C1	25 Mar	10 Sep	24	86
	C2	18 Mar	3 Oct	28	100

In the old plantation (grid C2) population dynamics in 1984 were similar to those in the young plantation, but with a later, lower peak in numbers. In 1985 the changes were quite different, with the increase in numbers starting 3 months earlier (in February) reaching a peak in June, declining to a low of under half the peak density in July and August, then increasing again to a second peak in October. Although Watts (1969) noted a slight drop in numbers of wood mice in mid-summer it is unusual to have such a large decline at this time of year. Montgomery (1989a) found that there was less than 15% change in wood mouse numbers over two or more consecutive months in summer in most (71%) years.

The survival of wood mice in the two grids is illustrated in Figure 12.4. On grid C1 the decline in numbers each year coincided with periods of very poor survival. On grid C2 survival was poorest during phases of increasing numbers. The decline in early summer 1985 happened when survival was average.

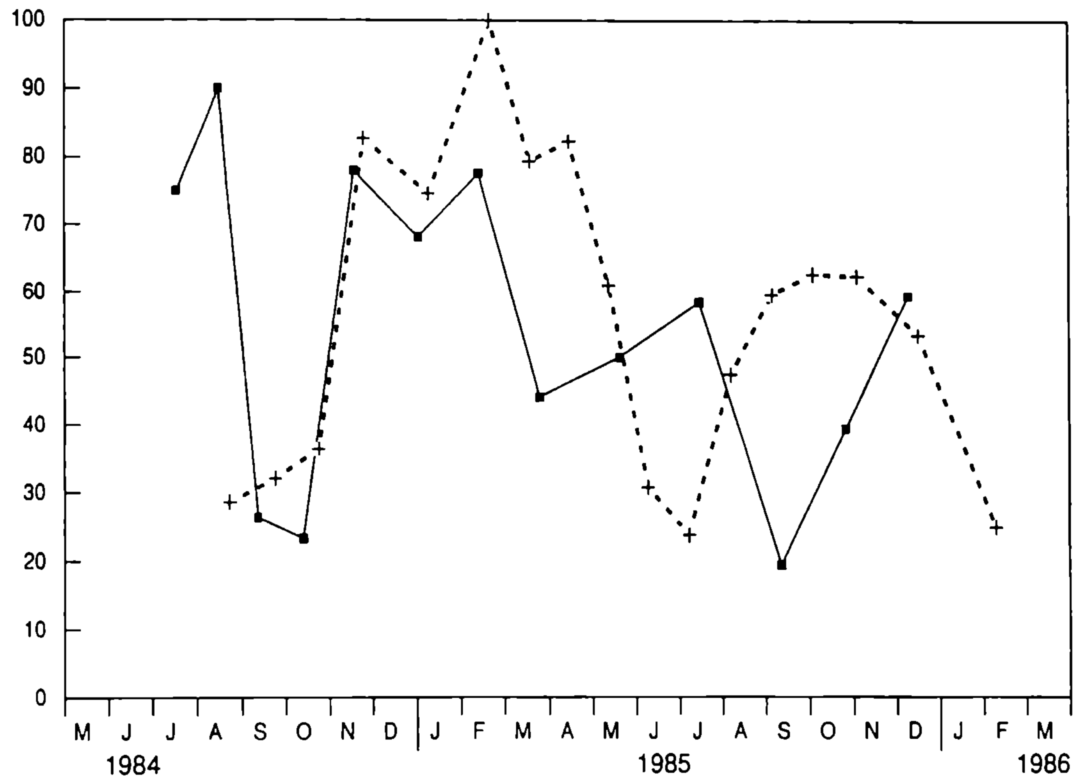

Figure 12.4 Survival of wood mice (per cent per 28 days)

The one feature that the population dynamics of both areas in both years had in common was that all increases in numbers were started by immigration of adults onto the grid; only 2-3 months after the start of each increase there were many young mice caught weighing less than 14 g. Table 12.6 shows that, in 4 of the 5 periods of population increase on the two grids, a higher percentage of newly caught mice weighed less than 14 g in the later part of the increase. The exception was the autumn 1985 increase on grid C2, where the proportion of juveniles remained low throughout. This increase was shorter than the others and seems to have been caused almost entirely by immigration.

Bank vole populations

The average density and survival of bank voles in a number of studies are given in Table 12.7. Unlike wood mice the density in the young plantation (4 per ha) was lower than that in the old plantation (27 per ha). The old plantation density was similar to that found in deciduous woodland (see Table 12.3), and higher than that usually found in coniferous woods. Average survival rates in both areas were comparable to those found in other studies. The breeding season on grid C2 was typical for the species in southern Britain (Alibhai and Gipps, 1985). On grid C1 breeding started 2 months later than normal; this was because there were no adults on the grid until June 1985.

Table 12.6 Weights of first capture of rodents during the first and second halves of each period of population increase

		Weight at first capture (g)			χ^2	p
		<14	≥14	%<14		
Wood mice, C1						
1984	Jun-Jul	3	9	25	15.28	<0.0001
	Aug-Sep	35	5	88		
1985	Apr-Jun	3	16	16	5.40	<0.025
	Aug-Oct	26	26	50		
Wood mice, C2						
1984	Aug-Sep	4	9	31	0.42	n.s.
	Oct-Nov	11	12	49		
1985	Mar-Apr	1	14	7	7.47	<0.01
	May-Jun	17	15	53		
1985	Sep-Oct	5	25	17	0.37	n.s.
	Nov	1	16	6		
Bank voles, C2						
1984	Jun-Jul	17	11	61	0.00	n.s.
	Aug-Nov	38	22	63		

χ^2 test is for the change in the proportion of newly caught animals weighing <14 g after the first 2 months of each period of population increase; (d.f. = 1).

The changes in numbers of bank voles in the two areas are given in Figure 12.5. There were very few bank voles on grid C1 except at the end of the study. In the old plantation the dynamics in the two years were different, with no noticeable peak in numbers in 1985. The annual fluctuations of bank vole numbers are usually less consistent than those of wood mice (Alibhai and Gipps, 1985).

The survival of bank voles on grids C1 and C2 is plotted in Figure 12.6. Survival was always better than 50% (except for October 1984 on grid C1). Although survival was higher on average on C2, the difference was not significant.

Bank vole numbers on grid C2 were less dependent on immigration than were wood mouse numbers. Table 12.6 suggests that the proportion of juveniles among newly caught bank voles was the same during the first two months of the increase in summer 1984 as it was during the last four months. Table 12.8 shows that a significantly higher proportion of bank voles than wood mice were first caught as juveniles.

Field vole populations

As expected from studies of habitat preferences (Gurnell, 1985), field voles were at higher density in the young plantation than the old. Figure 12.7 illustrates changes in numbers in the two areas. However, even in the young plantation the average density was low compared to that found in other studies (see

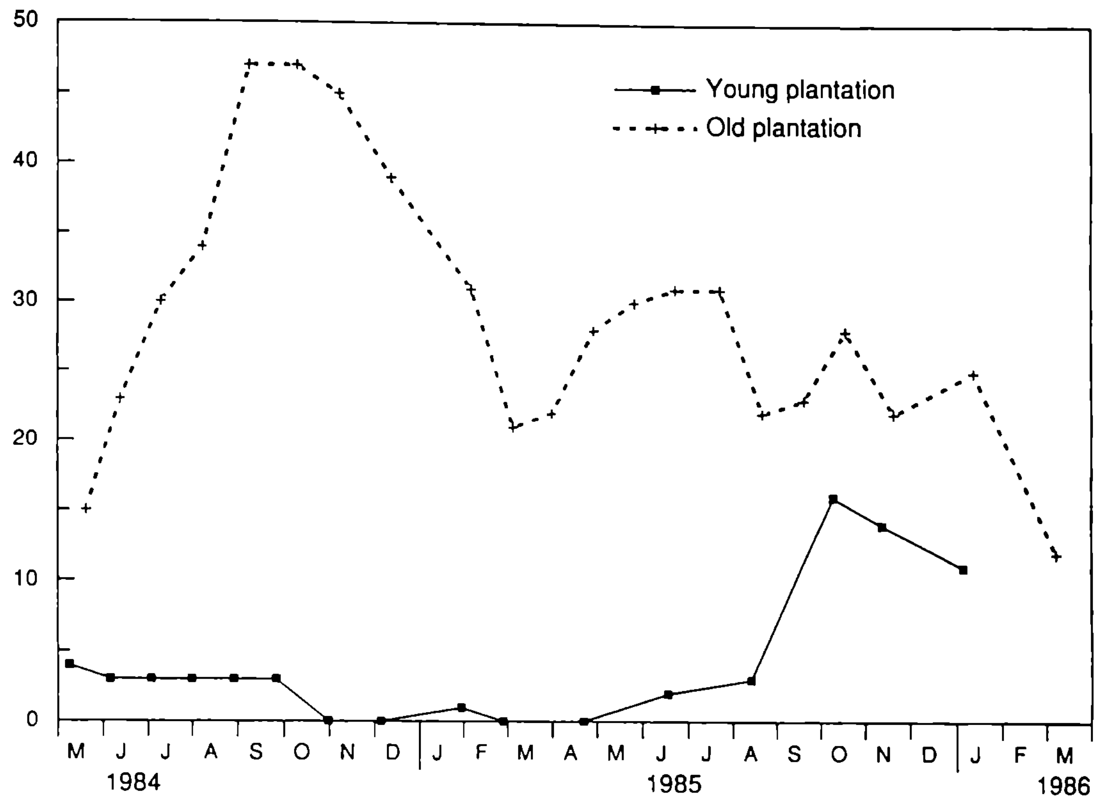

Figure 12.5 Numbers of bank voles known to be alive on the control grids in two different ages of conifer plantations

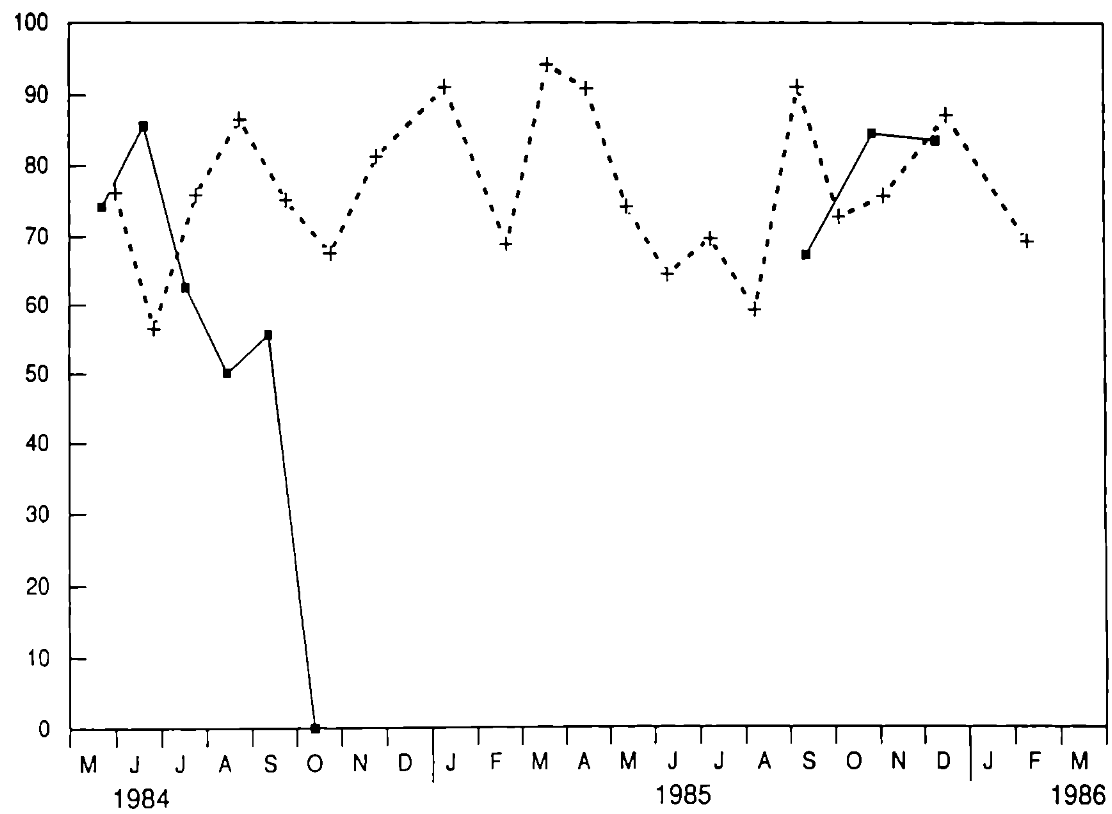

Figure 12.6 Survival of bank voles (per cent per 28 days)

Table 12.7 Population densities and survival rates of bank voles

Population density (ha^{-1})			Survival rate (% per 28 days)	Grid (ha)	Habitat	Reference
Av	Max	Min				
5	9	3	77	4.20	Yew wood	Smal and Fairley (1982)
0.6	2	0	89	7.02	Oak wood	
27	64	5		2.00	Deciduous wood	Kikkawa (1964)
24	61	3	66	1.00	Oak wood	Gurnell (1981)
36					Deciduous wood	Southern and Lowe (1968)
36	70	3	69	0.99	Mixed deciduous	Newson (1963)
47	121	3	70	0.99		
42				4.00	Mixed deciduous	Bujalska (1985)
12				1.32	Deciduous wood	Mammal Society
40			80	1.00	Grassland	Chitty and Phipps (1966)
3				1.32	Coniferous wood	Mammal Society
2				6.25	Pine, 40 yr	Ryszkowski (1971)
6				6.25	Pine, 140 yr	
11				6.25	Pine/oak, 140 yr	
14				6.25	Mixed wood, 50 yr	
4	12	0	68	1.27	Pine, 8 yr	This study
27	38	9	76	1.27	Pine, 56 yr	

Tables 12.3 and 12.9). Survival rates on both grids were also low, particularly on C1 (Figure 12.8).

On grid C1, numbers declined from 4 in May 1984 to only 1 in January 1985, and after this there were never more than 4 (Figure 12.7). The main reason for this decline was the survival rate which was poor and erratic (Figure 12.8).

The breeding season was normal for field voles (Gipps and Alibhai, 1991); in 1984 it ended in early October and 89% of adults caught were in breeding condition. There were enough new recruits to sustain the population had survival been 55% or above.

On grid C2 the population started very low, increased to a peak of 15 in early autumn

Table 12.8 Numbers of wood mice and bank voles first caught weighing less than 14 g or 14 g and above on grid C2

	Weight at first capture (g)			χ^2	p
Wood mice	44	114	28	16.01	<0.0001
Bank voles	86	86	50		

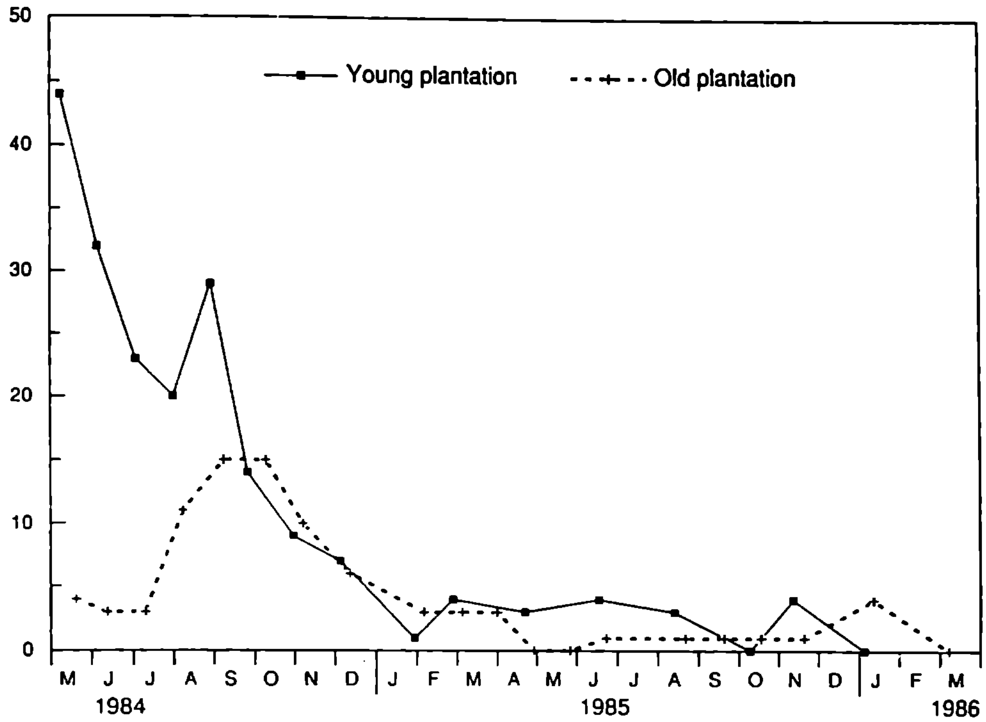

Figure 12.7 Numbers of field voles known to be alive on the control grids in two different ages of conifer plantation

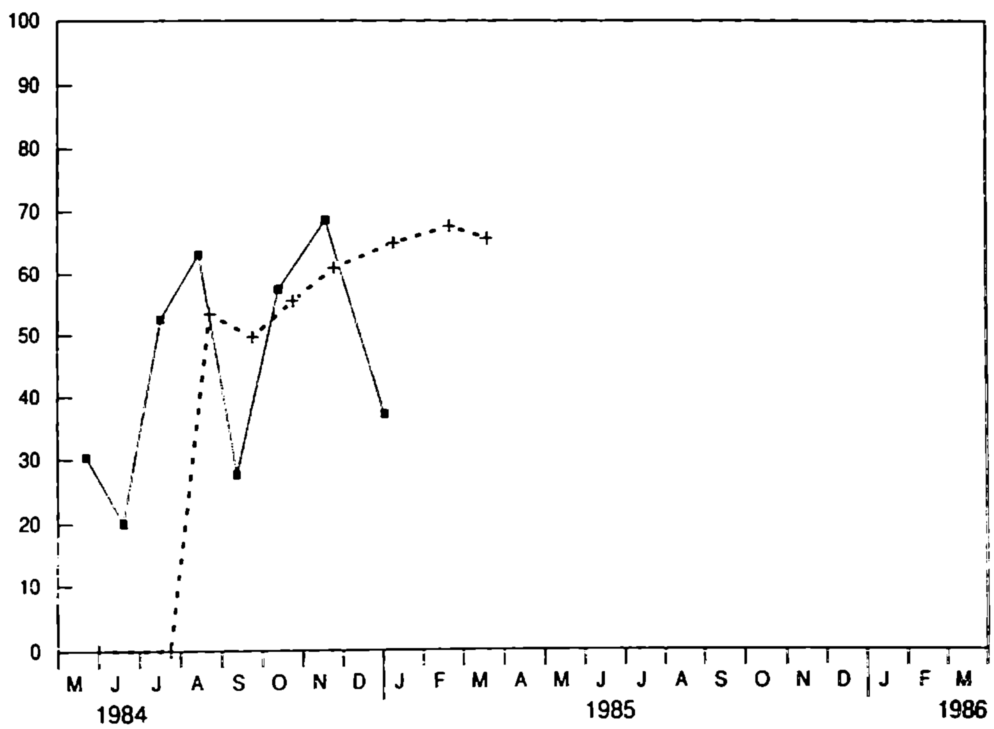

Figure 12.8 Survival of field voles (per cent per 28 days)

Table 12.9 Population densities and survival rates of field voles

Population density (ha^{-1})			Survival rate (% per 28 days)	Grid (ha)	Habitat	Reference
Av	Max	Min				
70	250	0	64	0.81		Chitty and Phipps (1966)
75	138	8		0.2	Rough grassland	Newson (1960)
80	153	23		0.2		Richards (1985)
75	135	23		0.2	Rough grassland	Richards (1985)
80	130	12		0.8		
65	123	28		0.5	Rough grassland	Richards (1985)
65	141	28		0.3	Plantation	Richards (1985)
65	120	6	78	0.64	Larch plantation	Ferns (1979)
11	38	0	37	1.16	Pine, 8 yr	This study
4	13	0	42	1.16	Pine, 56 yr	

1984, then declined and did not recover in 1985. The increase in 1984 appears to have been due to immigration. The field voles caught in the first 2 months were mostly adults weighing >25 g (see Table 12.10) and only later were many new recruits caught weighing less than this.

Table 12.10 Weights of first capture of field voles on grid C2 during the period of population increase

Month first caught	Weight at first capture (g)				
	<15	15-20	20-25	25-30	>30
Jun-Jul			1	2	3
Aug-Sep	2	10	7	1	
Oct-Nov	2	5		1	

Habitat preference in the young plantation

Table 12.11 gives the average numbers of each species caught per 128 traps along the stump lines and in the main part of the grid. All three species had a significant preference for the stump lines. This was most marked in bank voles and least in field voles.

Field voles were probably using the grassy patches alongside the stumps, but traps were spaced too far apart from this to be detected. The preference of the other two species could have been due either to improved cover or food. If it was food, then extra feeding should increase numbers more in the main part of the grid, whereas if cover was more important, the opposite should occur, with numbers increasing along the stump lines.

Effect of artificial extra feeding on habitat preferences

Table 12.12 presents the numbers of each species caught per 128 traps in each habitat on both the control (C1) and extra feeding (E1) grids, during the period of extra feeding (July 1984 to October 1985). It also gives the percentage difference between grids C1 and E1 for each habitat separately. On grid E1 wood mice were at 72% higher density than C1 in the main part of the grid, but at slightly lower density along the stump lines. For bank voles, by contrast, the difference between the grids was greatest along the stump lines. Although the density on E1 was 141% greater than C1 in the main part of the grid, it was still very low in absolute terms (equivalent to 3 voles per ha); whereas along the stump lines it was equivalent to 31 per ha. Field voles on E1 were at slightly more than double the control densities in both habitats.

Table 12.11 The average number of rodents caught per 128 traps in the two habitats in the young plantation

	Stump lines	Main area	%D	χ^2
Wood mice	20.6	8.9	192	45.31[b]
Bank voles	10.5	1.9	448	26.78[b]
Field voles	15.8	10.8	47	4.30[a]

%D: percentage difference between numbers caught per 128 traps along stump lines and elsewhere in the grid.

χ^2 test is for difference in number of animals caught per 128 traps (d.f. = 1); [a]$p<0.05$; [b]$p<0.001$.

Table 12.12 The average number of rodents caught per 128 traps in the two habitats in the young plantation

	Food	Control	%D	χ^2
Wood mice				
Stump lines	32.4	35.3	-8	9.66[b]
Main area	18.7	10.8	72	
Bank voles				
Stump lines	42.5	7.5	471	4.17[b]
Main area	4.2	1.8	141	
Field voles				
Stump lines	23.6	11.3	110	0.03
Main area	12.8	5.6	128	

%D: percentage difference between numbers caught per 128 traps on the control (C1 and R1) and extra feeding (E1) grids.

χ^2 test is for change in difference in number of animals caught per 128 traps with extra feeding (d.f. = 1); [a]$p<0.05$; [b]$p<0.01$.

Discussion

The wood mouse populations in both areas were dependent on immigration to sustain numbers. Unlike deciduous woodland populations, where increases in numbers are caused by improved survival of young mice (Watts, 1969), increases in both ages of plantation were caused initially by the immigration of adult mice. Both populations suffered from rapid declines in numbers caused by poor survival or, in one case, a lack of recruits in the middle of the breeding season. From a study on this scale, it is not possible to tell whether these were simply populations receiving emigrants from other more suitable habitats, or whether they were part of a large, highly mobile population which moved widely from area to area according to the availability of food. The latter seems more likely since there was not enough deciduous woodland nearby to produce the number of migrants which were observed. Also, wood mice are known to range widely (Wolton and Flowerdew, 1985) and may show spatial density dependence (Montgomery, 1989b). Adler and Wilson (1987) found a similar type of population dynamics in another habitat generalist (the white-footed mouse, *Peromyscus leucopus*) in Massachusetts. The low density populations had lower rates of survival, were more variable and showed little evidence of intrinsic regulation.

Bank voles were more habitat specific than wood mice. They also had lower rates of both mortality/emigration and immigration. The population in the old plantation appeared to be self sustaining and to have an average density and dynamics similar to deciduous woodland populations.

Field voles in the young plantation declined during the first year of the study. One possible reason for this was successional change in the habitat. Ferns (1979) found that field voles in a 3-year-old larch plantation declined from 97 ha^{-1} to 6 ha^{-1} over the subsequent 2 years. At this stage the trees had grown to such an extent that the grass was completely shaded and covered in a layer of needles. This had not yet happened by the time numbers declined on C1. Also, there was a simultaneous decline on grid R1, which was 2 years older than C1. Another possible cause could have been the dry spring of 1984, which would have reduced grass growth. Any shortage of water would have been exacerbated by the sandy soil and competition from the trees. The study by Ferns (1979) was in a much wetter area where competition for light may have been more important.

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Chapter 13

Conserving the red squirrel

John Gurnell

Summary

In 1991, it was believed that red squirrels were at risk of disappearing completely from Thetford Forest within 20 years or so. This was similar to the picture in much of England and Wales. The loss of red squirrels at Thetford and nationally is directly linked to the appearance of grey squirrels which continue to expand their range throughout Britain. Grey squirrels started to colonise Thetford Forest in 1968 and red squirrels decreased in numbers thereafter. Overall densities of red squirrels within the forest are now believed to be very low (<1 squirrel 10 ha^{-1}) with a very patchy distribution. This makes local populations very vulnerable to extinction. Grey squirrels are now well established but they also have a patchy distribution which is largely influenced by the distribution of broadleaf trees and the abundance of pine cone crops. Overall densities of grey squirrels in Thetford are low (<1 ha^{-1}) compared with broadleaf woodland (2-8 ha^{-1}). In this chapter the findings from several studies carried out on the ecology of red and grey squirrels at Thetford are discussed. It is argued that red squirrels are not a hopeless case and the first results from new conservation studies which started in September 1992 provide optimism for the future.

Introduction

Before the 1970s red squirrels were common and familiar animals throughout Thetford Forest. Grey squirrels first invaded the forest between 1968 and 1974, mainly along corridors of broadleaf trees (MacKinnon, 1978; Reynolds, 1985). This was followed by a period of consolidation and by 1985 the process of colonisation was complete. Grey squirrels are now found throughout Thetford Forest, and red squirrels are rarely encountered (Figure 13.1). Red and grey squirrels, therefore, have coexisted within Thetford Forest for 20 years or more, even though it is now believed that the red squirrels are distributed in a patchy fashion and occur at low densities generally. Following from this, it appears that certain attributes of Thetford Forest have enabled red squirrels to survive for some time alongside grey squirrels and it is important to try to understand what these attributes might be.

In many ways the changing status of red and grey squirrels within Britain mirrors the situation in Thetford Forest but on a larger scale. The decline in range of the red squirrel and its replacement by the grey continues, with many populations in England and Wales becoming increasingly isolated (see Gurnell and Pepper, 1993). At the time of this symposium in 1991 the outlook for red squirrels was not good. It was thought that red squirrels may become extinct in Thetford Forest, as indeed they might throughout central England and Wales, apart from some offshore islands (e.g. Isle of Wight, Brownsea Island), within 20 years or so. Furthermore, the range of the red squirrel continues to be eroded in the north of England, and grey squirrels appear from time to time in places which are well away from their main centres of distribution such as in north-east Scotland. It is possible that such pockets of distribution result from introductions as in the past, although it is also likely that they occur by natural processes (Staines, 1986). Shorten (1954) pointed out that individuals or pairs of grey squirrels may be found 30 km to 60 km away from a colony during the autumn, an important period for dispersal, 'while the country between remains free of them'. Grey squirrels are much more terrestrial than red squirrels (Gurnell, 1994; Kenward and Tonkin, 1986) and by making use of linear habitats such as hedgerows they have the ability to spread rapidly through

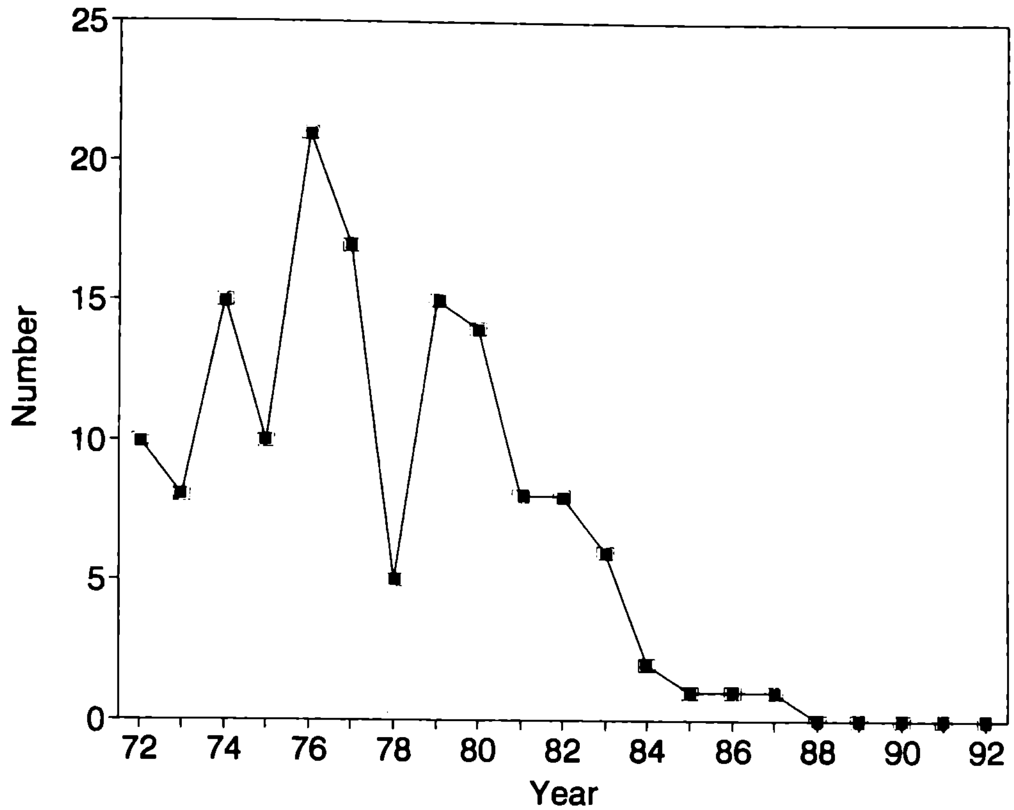

Figure 13.1 Number of sightings of red squirrels in Thetford Forest made during the annual drey survey each spring between 1972 and 1992 (Whitta, personal communication)

open areas and colonise remote habitats. Indeed, the spread of the grey squirrel in Britain has been described as a generally steady advance consisting of random dispersal with occasional major advances (Williamson and Brown, 1986).

Red squirrel populations had a history of large-scale fluctuations in numbers before the introduction of the grey squirrel (Middleton, 1930). These fluctuations have been influenced by loss of habitat, tree seed food availability and disease epidemics (e.g. coccidiosis, parapoxvirus), especially at times when animals were already undernourished and in poor condition (Gurnell, 1987). Despite this, there is no doubt that the grey squirrel is responsible for the demise of the red squirrel in Britain during the last 60 or 70 years. Ideas about why and how this has occurred are reviewed by Gurnell (1987), Gurnell and Pepper (1993) and Kenward and Holm (1993). At the symposium in 1991 various ways of conserving red squirrels were described, based in no small part on our understanding of squirrel ecology in Thetford Forest from several studies over a period of some 15 years (e.g. Reynolds, 1981; Gurnell and Taylor, 1988; Gurnell and Venning, unpublished). These conservation strategies and tactics have since been refined and reported by Gurnell and Pepper (1991, 1993) and will not be repeated here. However, this chapter will describe some of the results of the work carried out at Thetford where it is of particular relevance to red squirrel conservation and the ecology of red and grey squirrels in conifer forests. Problems of setting aside areas within which conservation efforts can be targeted are discussed, and the chapter ends by briefly setting out a new conservation initiative which started in 1992.

Periods of transition: grey squirrels replacing red squirrels

In the 1950s red squirrels were particularly abundant in Thetford Forest, and they were controlled until the mid 1960s. The main periods of colonisation of Thetford Forest by grey squirrels, based on Reynolds' (1985) 5 km square presence–absence distribution maps, were between 1968 and 1974. Expansion of the range of the grey squirrel into many forest compartments, at least within the Downham Highlodge Warren and Thetford Warren forest blocks, occurred between 1976 and 1979 (Reynolds, 1981).

In the summer of 1977, red squirrels had an approximate density of 1.13 ha^{-1} in compartment 3155 in Downham Highlodge Warren which at that time had not been infiltrated by grey squirrels (Reynolds, 1981). Throughout the latter half of 1977 and 1978, an occasional grey squirrel was seen near the area and by late 1978, greys were established about 0.5 km away in mixed woodland. The red squirrels seemed to undergo a population decline over this period. Seven red squirrels were found dead between August 1977 and May 1978, at least two with suspected but unconfirmed parapoxvirus. The last red squirrels seen in this area were two found dead in May 1978. Occasional sightings of red squirrels in the area were subsequently made but not until 1980 and 1981. Thus, there was a remarkable decline in red squirrels from a healthy population in the summer of 1977 to an apparent local extinction by the summer of 1978. Many animals were found dead and disease was implicated as a mortality factor. Over the same period, the greys seemed to encroach gradually on the compartment. This demonstrates one possible sequence of events whereby grey squirrels replace reds, that is, the red squirrels undergo local extinctions and the greys move in and replace them. It is known that red squirrels disappeared from many areas in Britain before the arrival of grey squirrels (e.g. Reynolds, 1985) and it seems clear that red squirrels were unable to recover from very low numbers in many places where the grey squirrels superseded them (Gurnell, 1987).

Another possible sequence of events occurs when greys move into an area occupied by red squirrels and they coexist for a time before the red squirrels disappear, leaving only grey squirrels present. It appears that such a situation was also seen by Reynolds (1981) who carried out observations in compartments 3166, 3167, 3170 and 3171 in 1978. Both red and grey squirrels were present in these compartments in 1978 confirming that this was a time of transition and species replacement. He counted and examined 58 dreys within the 68 ha, of which 15 had been occupied by red squirrels, 16 by grey squirrels and 27 by both species (but not necessarily at the same time). It seems that the red squirrels disappeared from the area some time after Reynolds had finished his studies. Interestingly, both species bred within this interface; they were seen feeding in close proximity but agonistic behaviour between the two was not observed. One theory that grey squirrels interfere with the mating behaviour of red squirrels (Bertram and Moltu, 1988) appears unlikely; Reynolds saw no interference in mating chases from these extensive studies in an area of population overlap and, as will be seen below, breeding periods in red and grey squirrels at Thetford did not always coincide. Reynolds' data also support the generally held view that the replacement of red by grey squirrel is not due to disease brought into the country by the grey squirrel or to the larger grey squirrel aggressively 'chasing out' the smaller red squirrel (Gurnell, 1987).

Status of red and grey squirrels in Thetford Forest 1985-1991

Distribution of red and grey squirrels

Extensive surveys of red and grey squirrels throughout Thetford Forest showed that grey squirrels had infiltrated every compartment of the forest, including small outlying copses, by 1985. Red squirrel sightings were more widespread in 1985 than in 1988 when no red squirrels were seen in the forest blocks to the north and east (Figure 13.2). It was feared that red squirrels had disappeared from these areas. However, and although specific surveys were not carried out in 1990, of five confirmed sightings of red squirrels within the forest, one occurred not far from Swaffham and two not far from Shouldham. Of course, not seeing a red squirrel is not proof that they are absent but repeated sightings of animals at particular locations support the idea that red squirrels are patchily distributed. Other studies (e.g. Wauters and Dhondt, 1985, 1989a, b), show that red squirrels live in preferred patches of forest such as those which provide the best seed supplies or the best cover. However, a detailed analysis of the age and species composition of compartments where red squirrels have been sighted (based on information from the Forestry Commission's Subcompartment database) did not reveal any particular preferences (Gurnell and Taylor, 1988). It is believed that a more detailed analysis of the habitat characteristics within the areas of the sightings, including food availability, is needed for preferences to be revealed.

Critically, poor seed supplies or a combination of poor seed supplies and severe winter weather has a marked impact on squirrel population numbers. For example, it can lead to poor overwinter survival and lower reproduction the following year (Gurnell, 1983, 1989). In turn, this can lead to greater spatial heterogeneity or

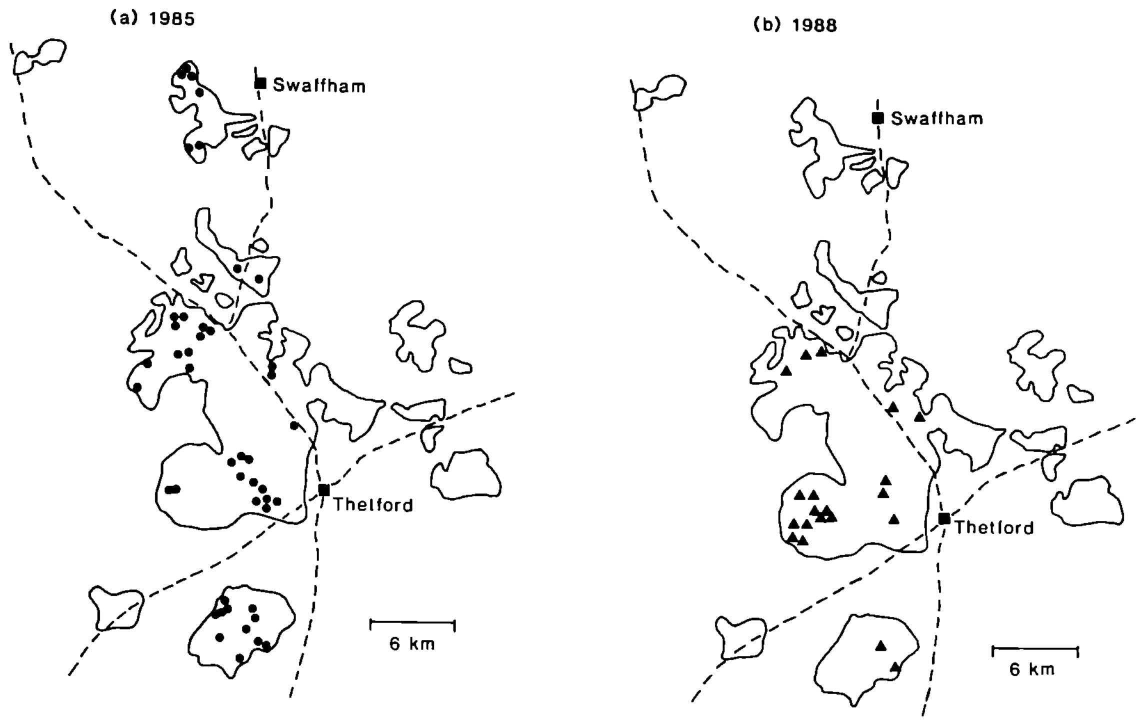

Figure 13.2 Distribution of red squirrel sightings made during extensive surveys in (a) 1985 (•) and (b) 1988 (▲) (Gurnell and Taylor, 1988)

fragmentation as described for red squirrels above. Unless the empty patches are recolonised within two or three years, a loss of genetic variance (adaptability), the possibility of inbreeding and demographic stochasticity may result in the extinction of the metapopulation at a later time (see Gilpin, 1987). The normal processes of local extinction and recolonisation rely on a continuity of suitable habitat. This may be interrupted by, for example, tree harvesting and it seems likely that the presence of grey squirrels, particularly in broadleaf or mixed broadleaf and conifer habitat patches, may reduce the flow of red squirrels between favoured (optimal) patches and increase the isolation of the local populations.

Density and demography of red and grey squirrels

Intensive live trapping and food availability studies were carried out at three sites within the main block at Thetford Forest between 1985 and 1988. Red squirrels were only captured on 11 occasions and it was not possible to get a true estimate of their density. Nevertheless, all the evidence suggests that overall densities were very low, <1 squirrel 10 ha^{-1}. The mean weight of red squirrels from all captures was 305 g (s = 19.4, n = 11). Of particular significance is the finding that red squirrels appeared to enter breeding condition normally (Table 13.1).

Table 13.1 Cone crops and breeding in red and grey squirrels at Thetford, 1986-1988

	1986	1987	1988
Previous year cone crop	Good	Very poor	Very good
First feeding on green cones	19 June	19 May	19 June
Spring breed			
Red	Yes, late	Yes, early	Probably
Grey	No	No	Yes, good
Summer breed			
Red	Yes	Probably	Probably
Grey	Yes, good	Yes, poor	Yes, good

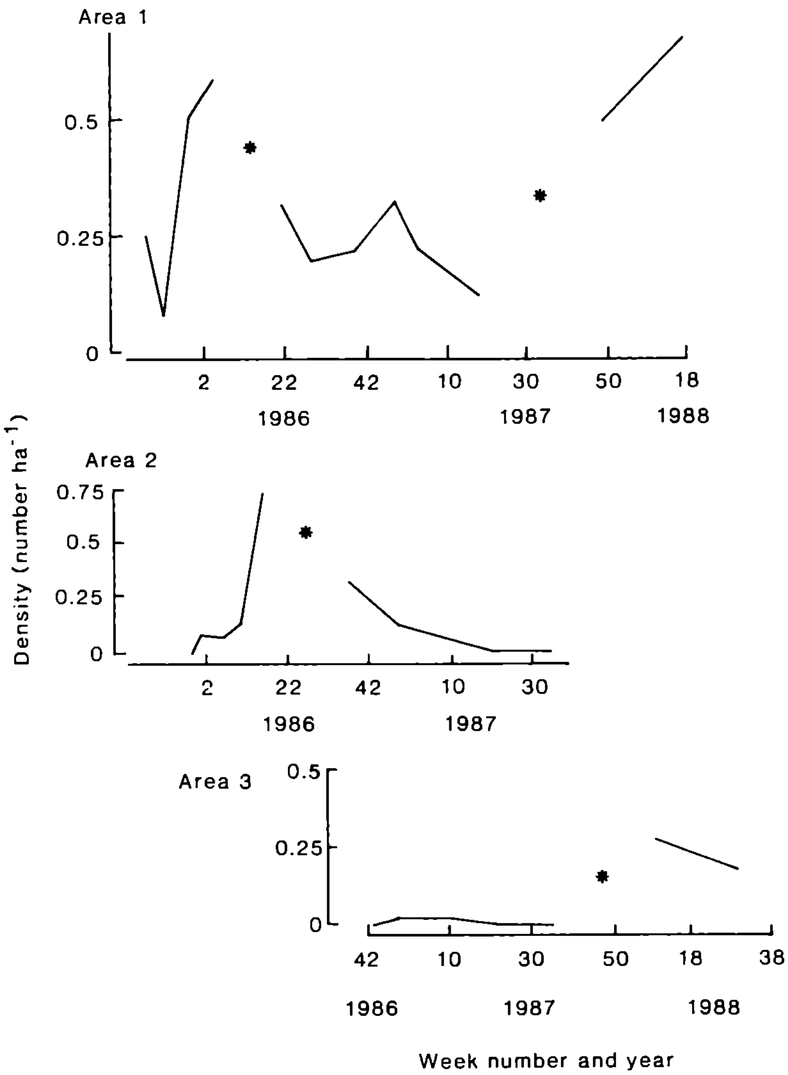

Figure 13.3 Approximate densities (number ha^{-1}) of grey squirrels in three study areas in Thetford Forest from live trapping studies between 1986 and 1988 (Gurnell and Taylor, 1988). Area 1: Cmpts 3035 and 3036 P26 Scots pine. Area 2: Cmpts 3138, 3140, 3157 and 3158, 3138 P65 Corsican pine with some larch and Scots pine and a border strip along one side of Scots pine, birch, beech and larch, 3140 P26 Corsican pine with understorey of beech with some Norway spruce and P38 beech along one side, 3157 and 3158 P 27 Scots pine and experimental field plots with a variety of tree species. Area 3: Cmpts 4009, 4010 and 4011 P32 Scots pine, with an understorey of grand fir in 4009 and part of 4010 and a border strip of beech and wild cherry. * Indicates no trapping was carried out at these times

Moreover, the breeding season of red squirrels started earlier than grey squirrels in spring 1987, at a time when seed supplies were poor and they may also have started breeding earlier in 1986 when seed supplies were better.

Grey squirrels were captured more frequently than reds although densities varied quite markedly through time and in different parts of the forest (Figure 13.3). Densities were low, considerably <1 squirrel ha^{-1}. This patchy distribution in space and time, and the habitat factors responsible for it, require further study to help identify the habitat characteristics which grey squirrels do not favour; this information could be used in the conservation management of red squirrels. Overall, their detailed demography seems to follow a pattern similar to the one that occurs in broadleaf woodland, although densities in broadleaf woodland are generally much higher, usually between 2 and 8 ha^{-1} (Gurnell, 1991b). An example of how the grey squirrels can take advantage of a very good cone crop was evident in 1988 when female squirrels produced litters in the spring and in the summer (Table 13.1) and had small, largely exclusive home ranges (Gurnell and Taylor, 1988). The mean range size of up to 10 adult breeding females monitored monthly between March and July was 2.5 ha (standard deviation (SD) = 2.32; the number of independent range estimates = 33).

For comparison, up to four males monitored monthly between March and May had a mean range size of 6.9 ha (SD = 8.24 ha; the number of independent range estimates = 9).

The results from these studies indicate that grey squirrels do not favour large, open stands of pine unless seed is reasonably abundant. The observation that grey squirrels did not come into reproductive condition as early as red squirrels when cone crops appeared to be poor suggests that the greys are not as well adapted to extensive conifer plantations as red squirrels in such conditions.

Red and grey squirrels in conifer and broadleaf forests

The Thetford studies have demonstrated that conifer forests have lower squirrel carrying capacities than broadleaf forests. However, red squirrels do not realise higher densities in broadleaf compared with conifer habitat whereas grey squirrels appear to be able to have sustainable populations in conifer forests, particularly those containing patches of broadleaves. Despite differences in the utilisation of vertical space, in body size and in population biomass (Kenward and Tonkin, 1986; Gurnell, 1994), the food and habitat requirements of red and grey squirrels are very similar. Resource competition for food is probably the most important factor affecting red – grey interactions within conifer forests.

It seems probable that red squirrels have the advantage over grey squirrels in areas dominated by large tracts of conifer forests, and vice versa. It is not as simple as this, however. Large areas dominated by conifer forest in central and southern England and Wales reflect the same pattern of increasing isolation and eventual disappearance of the red squirrel. Two factors appear to be important. The first is the amount of broadleaf trees which occur around and within conifer forest in relation to the size of the forest. There is an increasing tendency to intersperse belts of broadleaf trees with tracts of conifer forest, often for reasons of habitat diversification and conservation (e.g. McIntosh, 1988). This allows for the infiltration of grey squirrels into the heart of the forest. The initial invasion of grey squirrels into Thetford Forest, for example, was along belts of broadleaf trees. Once they have penetrated the forest, the grey squirrels can expand their populations into the conifer plantations when conditions are favourable (e.g. food supplies), or retreat back into the broadleaves when they are not. Thus, the numbers and distribution of grey squirrels expand and contract around these broadleaf 'survival' habitats. Birth and death rates in both red and grey squirrels are closely linked to tree seed availability (Gurnell, 1983). Exploitation competition between red and grey squirrels for food in these circumstances may result in lower birth rates and higher death rates which in turn may be critical when densities are very low, as in the case of red squirrels at Thetford Forest. Adequate nutrition is necessary for survival and successful reproduction (Wauters and Dhondt, 1989a, b), and this has been further discussed by Gurnell and Pepper (1993). There is no evidence that red squirrels are more conservative breeders than grey squirrels (MacKinnon, 1978); individual fecundity is similar in the two species. Rather, in broadleaf or mixed forests, red squirrels occur at lower densities than grey squirrels (Gurnell, 1991a, b) and net recruitment (per unit area) is lower. In conifer forests such as Thetford, the situation may be slightly different. When seed supplies are good, grey squirrels move in, breed and thus exploit the food with the consequence of lowering the reproductive success of any resident red squirrels which may be present.

Another possible difference between red and grey squirrels is in their social organisation. It has been suggested that red squirrels have evolved a social system that is closely linked to living in conifer habitats and based on larger inter-individual distances than grey squirrels, which originally come from large broadleaf forests in eastern North America. High densities of red squirrels (e.g. >2 ha^{-1}) are rare; they occur when there are exceptionally good cone crops (e.g. Shorten, 1954; Pulliainen, 1982) or in unusual circumstances such as on small islands with supplemental food (Kenward and Holm, 1989). Thus, in contrast to grey squirrels, red squirrels may be considered to be a 'low density' species irrespective of habitat (Gurnell, 1987). Interestingly, Wauters and Dhondt (1989b) have shown that red squirrels are more aggressive and have less range overlap in conifer compared to deciduous woodland.

Conserving the red squirrel in Thetford Forest: the red squirrel reserve

Ideas concerning the conservation of red squirrels have to a large extent evolved from the work carried out at Thetford Forest, and these have been reviewed by Gurnell and Pepper (1993) and Gurnell (1994). In the long-term, forest habitats should be managed in such a way that they enhance red squirrel numbers and, at the same time, discourage the presence of grey squirrels, and this is currently under investigation at Thetford. In the short-term, various tactics may be tried to recover a dwindling population or to replace a lost population of red squirrels.

Initially, however, in any recovery programme it is necessary to set aside a large area of conifer forest as a red squirrel protection area or reserve in which to target the conservation effort. The size of such a reserve is governed by two important considerations. First, the density of red squirrels and the minimum viable population size (MVP) (see Soule, 1987); the MVP for red squirrels is not known and requires detailed study, but for the purposes of illustration it can be suggested that it should be 200 animals. Now, average densities of red squirrels normally fluctuate between about 1 ha^{-1} and 1 10 ha^{-1}. Thus, 200 animals would require 2000 ha of conifer forest when numbers are low. Second, and as already discussed, forest habitats are naturally patchy and silvicultural practices introduce a further fragmentation of suitable habitat in commercial forests with, say, a third of the forest being unsuitable (e.g. stands <15 years old) at any one time. Thus, the population of 200 squirrels would require 2600 ha of commercial forest. Connected with this, and assuming that the reserve is not linked to outside populations of red squirrels, then the reserve must be self-sufficient (Pickett and Thompson, 1978) and must have a minimum area (the so-called minimum dynamic area, MDA) which will maintain the internal recolonisation process as local populations go extinct. Again, specific studies on the size of the MDA for red squirrels are required.

Although the details are not known, the conclusion from the above is that reserves should be large (for example 2000 ha or larger). Further, the shape of the reserve should be such that it has minimum edge: it should be round or square rather than long and thin. This is to minimise the possible incursion of grey squirrels. Grey squirrels can make foraging movements of a kilometre or further and, as seen above, can disperse over many kilometres. To help keep grey squirrels out, a buffer or border zone at the edge of the reserve must be established which consists of habitats that are unsuitable for grey squirrels. This could consist of conifer forest but more likely would incorporate open or agricultural land which does not contain large hedgerows or roadside verges with large trees. Urban habitats, parks and gardens would not be suitable. Thus, the reserve must be designed within the framework of the surrounding landscape and may require the co-operation of local landowners.

Recent conservation initiatives

In September 1992, a 1000 ha Red Squirrel Conservation Area at Thetford set up in the 1970s was enlarged to 1800 ha and designated a Red Squirrel Reserve. Within the Reserve, a new joint initiative by the Forestry Commission and English Nature (under its Species Recovery Programme) was started at Thetford with the twin aims of recovering the dwindling red squirrel population and researching three short-term tactics:

- supplementing the food of red squirrels
- removing grey squirrels
- reintroducing red squirrels to enhance recovery (Gurnell and Pepper, 1993).

These studies are ongoing and it is too early to make judgements about supplementing the food of red squirrels or reintroductions. However, there is reason to be optimistic. As a direct result of systematically removing grey squirrels from the Reserve, the first sightings of red squirrels occurred within 7 months of the beginning of the study and the first captures within 9 months. The number of known Thetford red squirrels within the Reserve has increased steadily since that time and by April 1994, 13 tagged animals were believed to be alive in the Reserve (Gurnell and Venning, unpublished). This is very encouraging and clearly points to the negative effects of grey on red squirrels and the benefits of removing grey squirrels or defending areas against the infiltration of grey squirrels. However, there have been some problems, most notably one red squirrel being killed by a goshawk and two dying of parapoxvirus. Recently confirmed cases of parapoxvirus have also been reported from Cumbria and Northumberland and new studies have recently begun to learn more about this worrying disease.

Conclusions

> 'There are no hopeless cases, only people without hope and expensive cases' (Soule, 1987).

Emerging from the work carried out on red and grey squirrels at Thetford Forest and elsewhere in Britain is the conclusion that the British red squirrel is not a hopeless case. However, in many places, time is running out for the red squirrel and action is urgently required. A way forward would be to establish a national red squirrel conservation plan, to co-ordinate a survey of red and grey squirrels in private and state forests throughout the country, and to establish conservation and research priorities.

The presence of grey squirrels is the ultimate reason why red squirrels disappear and worryingly this situation is occurring in north Italy at the present time (Gurnell, in press). In Italy the most expedient thing to do is to eradicate the grey squirrel while it is still possible. In the UK it is not possible to eradicate the grey squirrel and so, in the longer term, red squirrel conservation tactics concern the management of habitats in such a way as to encourage red and discourage grey squirrels. There may be particular problems in geographical areas containing large amounts of broadleaf forest since it may be difficult to defend these areas against the intrusion of grey squirrels (Gurnell and Pepper, 1993). Extensive conifer forests may be the only places where red squirrels will continue to flourish in Britain into the future. Forests of immediate concern are those with red squirrels but which are becoming increasingly isolated, including Thetford, and those at the edge of the dwindling range of the red squirrel in the north of England and Scotland. However, all forests with resident red squirrels should now consider whether their management procedures can be improved to favour red squirrels and deter the incursion of greys. In some cases, the forest manager may have other conservation priorities which may not be in accord with the requirements of red squirrels. Difficult decisions may have to be made and it is important that these decisions are known within the framework of a national conservation plan.

Work on conservation methods to try to recover the local red squirrel populations in Thetford Forest continues and valuable information is being gathered which will help the conservation effort in other parts of the country. Where appropriate, and in the short-term, grey squirrel control and supplementing the food of red squirrels are tactics which may benefit red squirrel populations, and it is looking as though captive breeding and reintroductions have important parts to play in a future national red squirrel conservation plan.

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Chapter 14

The history of the deer of Thetford Forest

Norma Chapman and Rex Whitta

Summary

All four species of deer with breeding populations within Thetford Forest Park have arisen from deliberate releases or accidental escapes during little more than the last 100 years. Although indigenous, roe had been exterminated over much of England but since the release of a few pairs west of Thetford in the 1880s this species has prospered and is by far the most numerous of the Forest cervids. Roe have radiated from this centre so are now distributed far beyond Breckland, through much of Norfolk and Suffolk and into Essex and Cambridgeshire. The other native species, the red deer, had also died out in the wild. The present populations originate from individuals left at large after hunting the carted deer during the last 40 years, an activity which continued in Norfolk until 1963.

As in so many parts of Britain, the fallow deer established in the King's Forest, and more recently in the main block of the Forest Park, are of park origin. Livermere Park, which was disbanded during the First World War, appears to be the source of the original stock although two other parks may have contributed to the feral population.

Reeves' muntjac began to colonise the Forest in the 1960s; now they are common throughout the area. Contradictory to common belief, the origin of the earliest pioneers was not by natural spread from Woburn Park, Bedfordshire, the main source of many feral populations.

Chinese water deer are not established within Breckland but in the past two years three have been killed on roads close to the Forest Park and one was seen crossing to the south side of the River Thet from Kilverstone Wildlife Park. Although conifer plantations would not provide a suitable habitat, these deer could probably find a niche within pockets of fen and carr in proximity to the Forest.

Introduction

Deer have a long history in East Anglia, with fossil forms dating from the Pliocene and Pleistocene. However, their presence has been discontinuous and the present abundance of deer has resulted from the introduction of native and exotic species during the last 100 years or so. Now within Thetford Forest Park four species of deer, roe, red, fallow and Reeves' muntjac, are resident and recently a fifth, Chinese water deer, has occurred occasionally in the vicinity.

The natural woodland of Breckland, in which hazel and birch predominated, vanished during the Neolithic period c. 2000 B.C. (Rackham, 1986). Breckland had virtually no woodland until the late 18th century when landowners began to create plantations to harbour game. Thus there were already areas of woodland within and around the expanses of sandy heaths which typified this region before the Forestry Commission (FC) plantings were begun, about 70 years ago.

Red deer (*Cervus elaphus*)

Early history and the development of hunting

During part of the Neolithic period, presumably before all the woodland was cleared, red deer must have been abundant in Breckland. Many hundreds of their antlers were used as picks to mine flint from the chalk at Grime's Graves over a period of around 400 years (Clutton-Brock, 1984). From then onwards, we know little of the deer until the medieval period when many deer parks were established in Norfolk and Suffolk where the nobility and ecclesiastics could hunt. None of these parks was within Breckland and fallow was the most usual deer species in parks, although some also held red (e.g. Melton Constable, Norfolk) and roe. The lack of a Royal Forest in Norfolk and Suffolk did not deter at least eight monarchs visiting Thetford. James I much enjoyed hunting from his lodge (now called the King's House) in Thetford. He acquired land in the area and appointed a keeper of the King's game at Thetford and also a keeper of the game of venery about Thetford (Macgregor, 1989). Before his visit in 1608, there was a request that stags were to be ready. These are likely to have been park rather than wild beasts. The nearest royal parks for deer hunting would have been at Dereham and Shipdham.

The years of the Civil War saw widespread destruction of deer and deer parks. The rise and fall of the parks over the centuries and their change from enclosed hunting grounds to attractive landscaped amenities around a grand house have been discussed by Shirley (1867), Farrer (1923), Cantor (1983) and Henshilwood (1989). The story of red deer in this region can be picked up from the mid-18th century. Much of the information available for the following century and a half was compiled by Harvey (1910) in *Deer hunting in Norfolk*.

In 1757 there was a reference to a pack of staghounds in Norfolk. At this date they probably hunted foxes and hares as well as deer which would have been few in the wild, probably escapees from parks. The lack of wild quarry must have prompted the birth of a new sport – hunting the carted deer. By 1793 this had begun in Norfolk: on 28 February a hind was released from the cart near Norwich, ran as far as Thetford, crossed the river and was taken in a barn at Shadwell.

In this form of hunting, the deer were not to be injured. When the deer was released from the cart it was given some minutes start before the hounds were released. At the end of the hunt, which might be 30 or more miles, the deer stood at bay and the hounds were expected to stand about six yards from the deer (Whitehead, 1980). The deer was then roped and escorted back to its cart for the ride home, where it was treated like a horse, given a straw bed, fed on oats, beans, hay and carrots and sometimes tied within a stall.

An exception to the 'take alive' policy occurred on 5 March 1829 after the stag was let out of the cart at Watton. In the next four hours it took a route over much of Breckland, went as far south as Barton Mills, and then back towards Brandon where it was killed. Perhaps this deer was injured.

During the 19th and early 20th century, a number of packs hunted carted deer, especially in Norfolk but also in neighbouring parts of Suffolk. The pack, known (between 1911 and 1922) as the West Suffolk Staghounds, had their deer paddock at Nether Hall, Bury St Edmunds. One of the Norfolk packs was the Westacre Staghounds which existed between 1821 and 1829. Their deer were kept in a paddock at Swaffham Heath. A contemporary painting (Duleep Singh Collection, Thetford Museum) shows the assembled hounds and horses outside High House waiting the appropriate time as the deer speeds away across the fields. In 1822 two Corsican red stags were presented to this pack. They were described as being superior to the British red deer, able to endure extreme fatigue and make great leaps (Harvey, 1910). At that time this deer occurred in all the mountainous parts of Corsica and Sardinia. Now this sub-species, the smallest of all the red deer, is endangered and no longer exists in the wild on Corsica (Dolan, 1988).

The deer had names (e.g. Lady Ethel, Wild Duck) and individuals were selected for each hunt. Sometimes two were put into the cart, the second in case the first chose not to run or ran only a short distance without giving the riders adequate sport. Usually no one deer ran more than a few times in one season but some old faithfuls ran for more than ten seasons. Although the pack was always called 'staghounds', the quarry could be a stag (with antlers removed), or a havier (i.e. a castrate) or a hind.

While hunting the carted deer was in its hey-day, what was the rest of the deer scene in Breckland? The number of deer parks had declined. In 1892 Whitaker recorded 21 parks in Norfolk and Suffolk but only five held red deer and none of those was near to Breckland but he may have overlooked two, Didlington and Ampton, which, according to Clarke, were extant in 1897. The former held red and fallow deer. Dutt, in his 1906 book, *Wild life in East Anglia,* stated that red were no longer present except in a few parks and Harvey (1910) believed that wild red deer remained only in Scotland, the Cornwall/Devon border and parts of Ireland and that the only deer in Norfolk were within nine parks, of which two held red deer.

The Norwich Staghounds assumed that name in 1900, having previously been known by a succession of names depending upon the previous Master or Regiment that owned the pack. The locations at which they met in south Norfolk were widespread, from north of Norwich to the River Waveney and from Shipdham in the west to Beccles in the east.

On some occasions a deer was not taken at the end of the day. Such was the case on 28 February 1901 when a deer led the field from Harling via Euston, Fakenham Wood, Honington to Livermere, only a few miles from Bury St Edmunds, by which time darkness was falling so the deer was left at liberty. Some hunts, for example, the Gunton Staghounds which hunted the whole of Norfolk, used to allow one of the two deer carted to a meet to take itself off, without any pursuit. On a future occasion, when its location was known, they would draw for this outlying animal.

Establishment in the wild

In 1950 eight to ten outliers were known to be around West Harling and Kimberley within the Forest area and about the same time a stag turned up in Newmarket on the Suffolk/Cambridgeshire border (Page, 1954). Three years later there were five red deer near Diss, a few miles from where the staghounds had their deer paddock at Winfarthing. This group was believed to consist of uncaptured hinds and their progeny, presumably conceived before the last hunt because by this time the pack pursued only hinds. The only other enclosed herd in Norfolk then was at Melton Constable and in Suffolk only Helmingham Park held red deer.

In most counties hunting the carted deer ceased before the Second World War but the Norwich Staghounds continued longer than any other pack in England, until 1963. By the time the pack was disbanded probably several more red deer remained at large. The plantations of Thetford Forest then were providing plenty of suitable habitat and during the 1950s small groups of red deer had established themselves in all the eastern blocks. In 1961, 20 stags and an unknown number of hinds were recorded in Thetford Chase (as the main block of the Forest was then called) mostly in the Mundford, Fowlmere and Langmere area (Page, 1961). Between 1956 and 1959 at least eight fine stags had been shot within the Chase (Whitehead, 1960). In 1961, 12 were shot by the FC and ten were killed in road traffic accidents yet, despite these losses, the population the next year was estimated at 64, with residents in five beats and visitors at least occasionally in all other beats within the Forest. By 1963, the population was believed to be 72 (after 10 had been shot) but presumably poaching and/or dispersal occurred before the next year, when the estimate was down to 40 (Forestry Commission deer questionnaires, 1962-64).

Both the deer and the FC were under pressure from farmers on land adjacent to the Forest who did not appreciate seeing such large animals devouring their crops or damaging fences. One farmer at Riddlesworth claimed that 34 deer were doing damage on his land, including causing his dairy cattle to stampede (*Eastern Daily Press*, 6 December 1967). Inevitably farmers shot many deer indiscriminately (e.g. 6 hinds in one field in one night) and by 1970 their numbers were believed to be low. The FC recognised the desirability of conserving these splendid animals and instituted a 'no shoot' policy within the Forest until the numbers built up. They even provided feed (e.g. carrots) in some areas to tempt the deer away from the most vulnerable fields.

The Breckland Red Deer Group was established with the aim of getting landowners together annually to monitor the situation and to urge each owner to census the red deer on his land on a specified date in March each year so that the combined population, on and off Commission land, could be ascertained. From 1971 until 1990 the annual census by the Rangers within the Forest has fluctuated between 28 and 157 which has represented between 34 and 74 per cent of the total recorded Breckland population.

Exceptional stock

The Breckland red deer are regarded as the finest in the country, huge in comparison with Scottish hill deer and superior to other English feral herds in both body and antler size. Some stags have produced 20 or more tines and achieved medal status on the C.I.C. formula (Whitehead, 1960). A 23 pointer was seen in 1990. The skull and antlers of a 21 pointer found dead about 1963/64 at Hockham weighed over 9 kg. A 10 point cast antler found at Roudham about 1971 weighed 4.5 kg. As an example of body weights, a stag shot after rutting for a week in 1962 weighed (after being gralloched) 208 kg (Morrison, 1962) which compares with 89-103 kg for Scottish stags aged 4-8 years in coniferous plantations in Scotland (Staines, 1991).

How do we account for these exceptionally good heads and weights? Bearing in mind the origin of the population from the carted deer hunts, we need to investigate their source of supply. From 1947 until their disbandment, the Norwich Staghounds were kept at Winfarthing Park. The original stock was from Woburn Park and the following year four more hinds were obtained from Warnham Park. By 1949, one stag and 27 hinds were enclosed. Previously, 1932-42, the carted deer were kept at Rackheath, near Norwich. (Probably there was no hunting during the latter part of the Second World War or immediately afterwards.) At least some of the Rackheath stock had come from Richmond Park, Surrey, and from Blickling Park, Norfolk, and both of these parks had received some Warnham red deer previously. Warnham red deer are renowned as the finest park specimens, attaining large body weights and heavy, many-tined antlers with well-developed crowns and a wide span. Twenty to thirty tines are commonplace. People well acquainted with the antler form recognise 'Warnham-type heads' in other herds containing some Warnham blood and such claims have been made for Thetford antlers. However, genotype alone will not produce large animals and antlers and as Vogt showed in the 1930s (see Geist, 1986) nutrition is more important than inherited character.

Red deer have also dispersed to found populations elsewhere in Norfolk, Suffolk and Essex (Chapman, 1977; Cham, 1984).

Roe deer (*Capreolus capreolus*)

Roe, like red deer, are indigenous and have a continuous record in Britain from the Pleistocene to the present day. Their remains have occurred in archaeological sites of all ages and fine specimens of antlers have been found in several peat deposits on the edge of Breckland (Lubbock, 1879). However, it seems that by the late 18th century the only areas of Britain in which roe survived were Scotland and northern England (Whitehead, 1964).

Reintroduction

In 1800, roe were reintroduced to Dorset and later to Sussex, Berkshire and Essex (Whitehead, 1964). Between 1880 and 1885 (the date usually quoted is 1884), three to six pairs were brought to Santon Downham, an estate owned by William Dalziel Mackenzie but occupied by his brother, Edward. The site of Downham Hall was close to the present Forestry Commission District Office and was surrounded by well-timbered grounds. The deer were obtained from Würtemberg. Could there have been some long association between local landowners and this part of Germany or was it just coincidence that it was to the Prince of this province that King James had exhibited his cormorants, catching and disgorging eels, at Thetford 270 years earlier? (Macgregor, 1989).

The roe were enclosed west of Thetford and close to the present golf course, on the Norfolk/Suffolk boundary in the area north of the Warrener's Lodge and south of the Little Ouse. The site is within Thetford Forest Park. Mr E. Baker of Brandon was employed to feed them hay (Page, 1952) in the deer pen which was about 200 metres from the river (F.J. Taylor Page, unpublished data) within the 324 ha of Great Queen's Wood. The wood had been planted with mixed species by the owner (Rope, 1911) whose father had purchased the estate in 1870 (Kelly, 1883). After an unknown interval, the roe were released and began to extend their range to the rest of the young Warren woods. Parts of the estate included juniper, birch, pine, bracken, heather, rushes and grasses (Noble, 1903).

Population expansion

Initially movement was mostly to the south, so by 1903 (Rope, 1911) they were rarely seen north of the river. Surprisingly, Clarke (1897) made no mention of them in his account of mammals within a six mile radius of Thetford. By about 1903 they were recorded at Elveden and had reached Mildenhall before 1914. The spread northwards then was also well under way, to Grime's Graves, Mundford, High Ash, Cranwich and Didlington. Trapping and snaring had begun before 1919 (Page, 1954). When the Forestry Commission acquired much of Breckland in 1922, 20-30 roe were being killed each year and some sought refuge in reed beds within plantations at Feltwell, Methwold and further north-west (Page, 1954).

The 1930s brought further reports from various directions and Taylor (1939) regarded them as numerous in the neighbourhood of Brandon, Thetford, Mildenhall and King's Forest, but subsequently a heavy slaughter policy was pursued until the outbreak of war. In an interview with the provincial newspaper (*Eastern Daily Press*, 28 April 1950) a warrener 'employed by the Forestry Commission to control vermin' proudly spoke of his dog's prowess at catching deer and of his being able to snare a few young deer. When reading such reports we should remember the achievements of the late Herbert Fooks, who became the Commission's first Game Warden in 1956. His influence was responsible for the introduction of humane methods of deer management throughout Forestry Commission forests at a time when deer were snared, peppered with shot during shot-gun drives, and had no close seasons. Outside Commission forests deer continued to be the victims of appalling suffering until the enforcement of the Deer (England and Wales) Act 1963.

In Taylor's (1948) second survey a decade later, roe were recorded as 'not numerous' within the same areas; nevertheless, their spread continued. By 1951, they had reached the A45 between Newmarket and Bury St Edmunds and in subsequent years crossed that road and established populations in several localities on the Suffolk/Cambridgeshire boundary and also in north-west Essex (Chapman, 1977). The Forestry Commission deer questionnaire 1964/65 estimated King's as having the largest (100) population within Thetford Forest with the other 15 beats each having between five and 45, giving a total estimate of 467. In two beats (Swaffham and Harling) the roe were regarded as visitors rather than population breeding.

In the mid-1960s, concern over road accidents involving deer (not just roe but red too) led to the erection of warning signs (Graves, 1965), the forerunners of the present nationally used highway sign. Soon afterwards stainless steel reflector plates, already tried successfully in America, Holland and Sweden, were erected along the most accident-prone stretches of road. The plates cost five shillings (£0.25) and proved to be very durable. Some of the plastic reflectors (£5 each) erected along the Thetford bypass in the early 1990s proved an attraction to vandals before their deer deterrent value could be assessed!

Through the 1970s and 1980s roe continued to increase. A total Norfolk population of about 6000 was estimated in March 1988 (Flynn, 1989), of which the Thetford Forest figure was 1733. From small beginnings little more than a century ago, roe have been very successful, not only in Thetford Forest but well beyond. They are widespread from north to south through much of west Suffolk. In Norfolk, they have reached as far as is possible to the north, to Kelling Heath, just short of the sea near Sheringham, and have penetrated into Broadland as far as Surlingham (a few miles east of Norwich). Within the arc of woodlands between these two locations roe are now established in many places (Hancy, 1988).

Fallow deer (*Dama dama*)

Fallow deer were present in Britain before the last glaciation but apparently did not survive that period and failed to recolonise before the English Channel formed. During the 11th century fallow were reintroduced by the Normans (Chapman and Chapman, 1975) who established them in many forests and hunting parks.

Through the centuries, parks experienced declines and revivals. At the beginning of this century there were 11 parks in Suffolk and 10 in Norfolk, all of which had fallow deer (Whitaker, 1892). He probably overlooked Didlington (Norfolk) and Ampton (Suffolk) which were mentioned by Clarke in 1897. A herd of fallow at Ampton was recorded by Morley in 1892 (see Farrer, 1923) and by Rope in 1911, in addition to the adjacent Livermere Park. The Ampton herd was disbanded before the 1914-18 war. Within the following half century, many of these parks gave rise to feral populations (Page, 1954; Cham, 1984) but the parks relevant to the Thetford Forest fallow were Livermere and possibly Ampton and Ickworth.

When the land which comprises the King's Forest was purchased in 1934 a little over 10% was woodland, comprising about 12 deciduous or mixed plantations, belts and coverts dating from the previous two centuries. Close by were over 200 ha of the well-wooded Culford Park and scattered copses in the direction of Livermere Park just 3 km away. The fallow had escaped from this Park in 1915 (Andrews, 1930) and most had been shot. Apart from a few records around Livermere and Ampton in the 1920s and 1930s little is known of their presence before they established themselves in the King's Forest. This stock may have been supplemented by deer from Ickworth, 8 km south of the Forest. Most of the Ickworth deer escaped about 1940 (R. Blake, personal communication, 1982) but Whitehead (1950) recorded 130 present in 1950.

This herd certainly gave rise to feral populations to the south, east and west but some may have moved north towards the King's Forest.

Until some fallow moved northwards to the High Lodge area within the main block of Thetford Forest seven years ago, the King's was the only part to have resident fallow. Their status changed from 'visiting' to 'breeding' between September 1962 and March 1963 (FC Deer Questionnaires). Table 14.1 shows the estimated population and cull figures from 1971. Until 1984 the figures refer solely to the King's Forest.

Table 14.1 Thetford Forest fallow deer

Year	Census	Year	Census
1971	25	1981	41
1972	34	1982	17
1973	29	1983	73
1974	34	1984	60
1975	13	1985	76
1976	44	1986	44
1977	55	1987	70
1978	26	1988	72
		1989	122

Known RTAs reached double figures (14) for the first time in 1989. The numbers culled ranged from 0 to 10.

Reeves' muntjac (*Muntiacus reevesi*)

Muntjac gradually spread from their first place of liberation, Woburn in Bedfordshire, early this century but there were also additional unrecorded releases. Whitehead (1964) suggested that muntjac were translocated to Breckland by troops, first stationed in Bedfordshire and then posted to the Stanford Battle Area which was acquired for military training in 1941. The first confirmed report from the Breckland was of three muntjac in the Santon Downham area, between the Little Ouse and Lynford in the summer of 1953. This was a few years after a known release of several muntjac near Elveden (Chapman *et al.*, 1994). There seem to have been no further records until 29 January 1961 when a buck was killed by dogs at Elveden Gap (TL 836810) on the Norfolk/Suffolk boundary on the southern edge of the main block of Thetford Forest. A painting of this animal hangs in the Elveden Estate museum.

The Norfolk Mammal Report for 1962 reported sightings of muntjac in the vicinity of Thetford Forest at West Tofts, Lynford, Roudham, Didlington and RAF Barnham, but the Forestry Commission mammal bird damage questionnaire for that year reported no muntjac in any part of the Forest. A further indication of their probable absence in the King's Forest at this time comes from the writing on the wall inside a shed at West Stow. Forest workers kept a tally of roe and fallow found dead but there is no mention of muntjac.

The 1963 Forestry Commission questionnaire recorded muntjac as 'visiting' King's and the following year's report stated 'one present' but no indication of number was given in subsequent years. By 1967, the deer questionnaire recorded muntjac from the King's Forest and Croxton beat but no other parts and Hitchmough and Morrison (1968) addressing members of the British Deer Society in that year mentioned that 'muntjac have been reported from time to time'. From then onwards they increased and extended their distribution not just within King's but in the rest of Thetford Forest. They reached Swaffham Forest about 1979 and now occur throughout the Forest and over much of Suffolk and Norfolk.

Annual census figures are not available but road traffic accidents have been recorded since 1971 and culling has been carried out since 1984-85.

Chinese water deer (*Hydropotes inermis*)

A mention of Chinese water deer is included because it is important to record the early days of what might subsequently prove to be the colonisation by a species new to the region. Water deer were reported at Stanford Battle Area in the 1970s (Stevens, 1979) but the adult buck killed at Wangford, on the road between Brandon and Lakenheath in January 1987, was probably the first for which there was no possibility of misidentification. This corpse was delivered to a Forestry Commission Ranger, Desmond Green. Within half a mile on each side of this road there are areas of fen (e.g. Pashford's Poor Fen) and willow scrub interspersed by arable fields which would make a suitable habitat.

On 26 May 1989 a water deer was seen to cross the River Thet (TL 892838) from Kilverstone Wildlife Park to the carr on the south bank (N. Gibbons, personal communication). The park owner had drawn attention to its presence. The wildlife park, only 2 km from the centre of Thetford, has had water deer since it opened in 1973. Now several dozen water deer live in paddocks by the river which forms the southern boundary of the park. Although water deer are established in the Norfolk Broads, there seems little doubt that the recent sightings around the Forest originate from Kilverstone.

Also in 1989, on 27 November, a male water deer, aged 5-6 months, was delivered to Thetford Police Station. Unfortunately, the location of the road accident in which it had been involved was not recorded. A year later (8 November 1990) a female water deer was involved in a road traffic accident on the Newmarket Road within the built-up area of Bury St Edmunds. This is a minimum distance of 19 km from Kilverstone.

Water deer are primarily grazers, selecting rushes and sedges as well as grasses, which thrive in damp habitats. Although coniferous plantations are not a suitable environment, there are in the vicinity of the Forest areas of fen with reed beds, willow carr and damp grassland in which water deer might be able to establish themselves. Given the right conditions, their strategy of multiple births gives them the potential to build up numbers quickly (Middleton, 1937) but neonatal mortality at Whipsnade Animal Park was estimated to be 50% in 1986 (Hofmann *et al.*, 1988). The population at Woodwalton Fen, Cambridgeshire, experiences high losses in harsh weather (Farrell and Cooke, 1991) and following the severe winter with prolonged snow cover in 1962-63 the feral population in Hampshire died out (Carne, 1964).

A number of species discussed in this publication are Breckland species which have adapted to survive changes from open heaths to forest. For the deer the situation is very different. This mainly coniferous forest, with its ecologically and aesthetically valuable belts, blocks and fringes of broadleaves, has provided East Anglia with a highly suitable stronghold for deer, where four species, each with a different origin, co-exist.

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Chapter 15

The performance of roe and red deer at Thetford Forest

Philip Ratcliffe

Summary

Red deer at Thetford Forest are of large body size and high reproductive performance. Roe deer are small and of poor performance. This is probably because roe are sedentary and occupy poorer habitats than red. Current estimates of deer numbers are based on unreliable methods, but roe deer numbers probably exceed 2400. At least 130 red deer habitually winter in the forest. Roe deer suffer high intra-uterine losses which result in about one embryo per doe by the end of February. The current level of culling of roe deer appears to be exerting control. Future management should include the use of dung counts to determine densities, annual counts of kid: doe ratios to estimate recruitment, and age determination from lower jaws for the retro-spective determination of minimum population size.

Introduction

Compared with other British populations, red deer in Thetford Forest are large and roe deer are small. Indeed, Whitehead (1964) suggested that 'their quality (red deer) is probably the best to be found anywhere in the British Isles. On the other hand, roe deer . . . are poor in quality, perhaps the worst in England'. This is borne out by comparative data on carcase weights from a number of British populations. Against this background, reproductive performance and densities are compared for both species at Thetford and with other data from elsewhere. Finally, management guidance is offered.

Body weights

Carcase weights are presented from three roe deer populations in southern England, northern England and northern Scotland, from two red deer populations on open-range in the central Highlands and western Scotland, and one from woodlands in south-west Scotland. These are given with data for roe and red deer from Thetford Forest for comparative purposes (Table 15.1).

Table 15.1 Mean carcase weights of adult roe and red deer (kg)

Location	Roe				Red			
	Male		Female		Male		Female	
Pickering, North Yorkshire	18.6	(20)	17.3	(20)				
Alice Holt, Hampshire	17.9	(7)	19.4	(15)				
Craigellachie, Moray	14.5	(20)	12.9	(20)				
Glenfeshie, Highlands					83	(691)	50	(562)
Scarba, Argyll					65	(86)	45	(121)
Galloway, south-west Scotland					103	(32)	70	(49)
Thetford, Norfolk	12.9	(779)	11.4	(758)	79[a]	(12)	72	(42)

Weights are live weights minus blood and abdominal viscera.
Parentheses indicate sample sizes.
[a] In addition to 12 adult males sampled, 4 stags > 195 kg shot during 1958-61.
Pickering, Alice Holt and Craigellachie data from Staines and Ratcliffe (1991). Glenfeshie, Scarba and Galloway data from Staines (1991).

Carcase weights of roe deer at Thetford are clearly much lower than those of the other English populations in Yorkshire and Hampshire, and are apparently lower than those from northern Scotland. Red deer weights from Thetford are similar to those in Galloway, south-west Scotland and some stags at Thetford far exceed the weights of those in Galloway. The Thetford deer are very much heavier than the deer from open-range populations in Scotland.

Deer numbers

Since 1970, roe and red deer have been counted systematically and almost simultaneously (within a few hours of each observation) by teams of rangers each year (Figures 15.1 and 15.2).

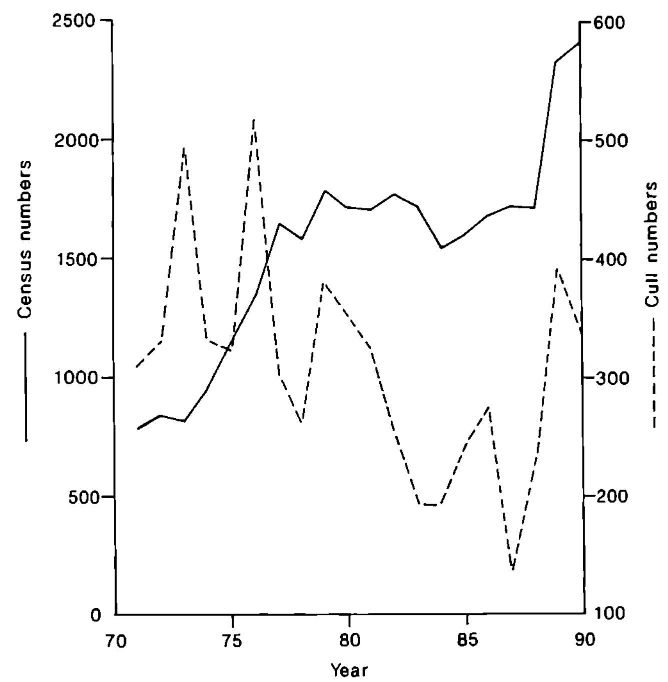

Figure 15.1 Roe deer census and cull in Thetford Forest

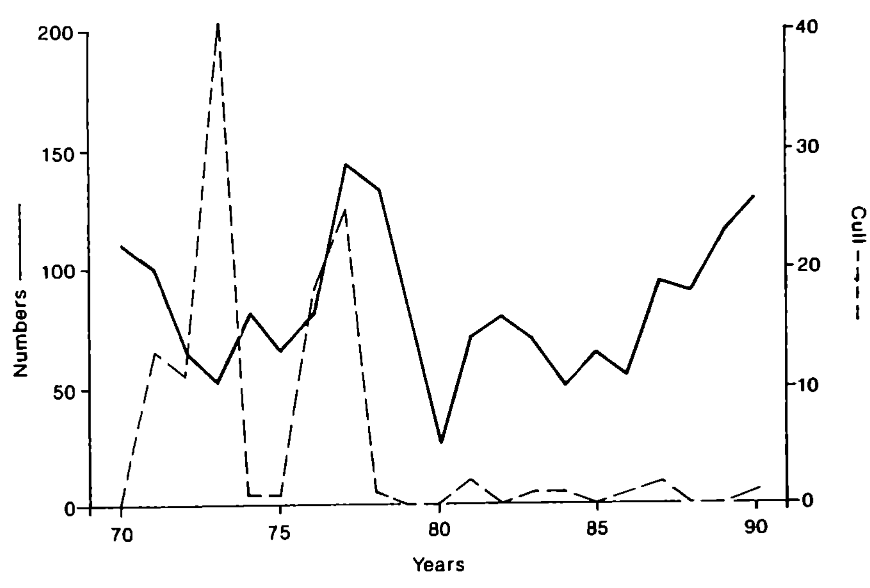

Figure 15.2 Red deer census and cull in Thetford Forest

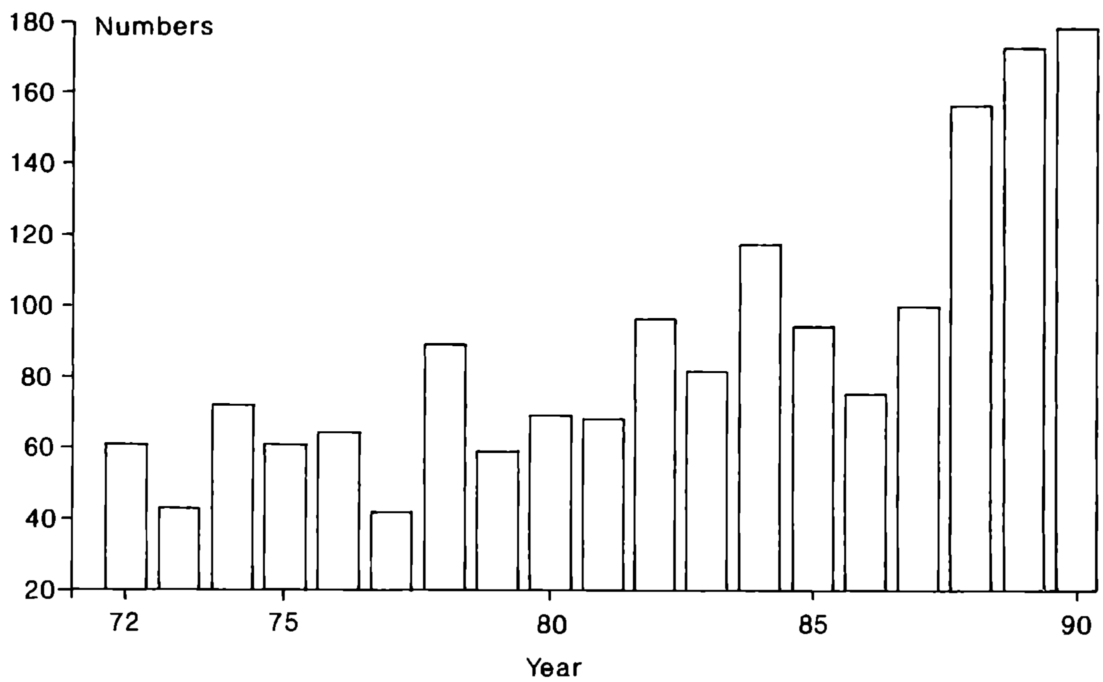

Figure 15.3 Road accidents involving roe deer in Thetford Forest

The census is carried out by rangers who visit open spaces in the forest known to be frequented by deer on predetermined days each spring. This census method is unlikely to give a reliable estimate of absolute numbers in concealing woodland habitats but does provide a minimum value and may indicate trends from year to year. However, temporal changes in habitat structure of the rapidly growing early-growth stages of forests make apparent trends also difficult to interpret.

The changes recorded in numbers of roe deer demonstrate large increases from about 775 in 1971 to 1800 in 1979, with an apparently stable phase between 1979 and 1988, followed by a rise again in 1989-1990 to about 2400 deer.

Cull data are superimposed in Figures 15.1 and 15.2, and it is evident that roe deer culls have fluctuated rather widely but fell to an all-time low of about 150 in 1987 and have since risen to nearly 400 (Figure 15.1). The increase in population size suggested by the census is supported by the increasing number of road casualties recorded: 60 in 1972 to 180 in 1990 (Figure 15.3).

Red deer numbers counted in the census have fluctuated widely between around 25 in 1980 and over 100 in 1970, 1977, 1978, 1989 and 1990. Culls have also fluctuated widely with peaks of 40 in 1973 and 25 in 1977 (Figure 15.2). It seems likely that numbers of red deer will fluctuate more widely than roe deer due to their high mobility and larger range sizes relative to roe.

Dung counting is probably the most reliable method available for estimating densities of deer in concealing habitats (Ratcliffe, 1978a; Staines and Ratcliffe, 1987; Ratcliffe and Mayle, 1992). Unfortunately, this method has not been widely applied at Thetford, one exception being the density of roe deer in the outlying King's Forest which was estimated in this manner in 1986 (S. Harris, personal communication).

Additionally, Ratcliffe and Rowe (1985) estimated densities based on the territory size of bucks but the uncertainties of numbers of non-territorial animals and in estimating buck territory size and variability throw suspicion on this method. The densities obtained by these methods have been converted to numbers by simply multiplying by the forest area of 200 km^2 for comparison with the census data (Table 15.2).

There is questionable justification for using the King's Forest density as a basis for estimating numbers over the whole forest, and there are some doubts over estimates based on buck territory size. The census is likely to yield a minimum value, supporting the view that numbers are certainly in excess of 2400 (Table 15.2). It is also felt that in spite of the shortcomings of the method used by Ratcliffe and Rowe (1985) this method was also likely to yield an underestimate, and so the number of roe could exceed 4000.

Table 15.2 Roe deer numbers in Thetford Forest Park

	Density	Numbers
Dung counts: King's Forest (1986) (S. Harris, personal communication)	10.61	2120
Estimates based on buck territory size (Ratcliffe and Rowe, 1985)	20.0	4000
Census (R. Whitta, personal communication)	12.0	2400

No useful estimates can be made of red deer numbers, largely due to the widely fluctuating census data and the known high mobility of the deer (R. Whitta, personal communication). In spite of the census figures, red deer are believed to be increasing and the traditional movement of deer away from the forest hardly occurred in 1991, with many over-wintering deer remaining (R. Whitta, personal communication).

Reproductive performance

Reproductive performance in roe deer is assessed here by estimating fertility from counts of corpora lutea and by estimating potential births from counts of embryos. These data are also compared as a measure of intra-uterine losses. Again, comparative data are included (Figures 15.4 and 15.5).

Roe deer at Thetford are only slightly less fertile than deer at Pickering, North Yorkshire, and Alice Holt, Hampshire. They are considerably more fertile than deer from the populations in the Scottish Borders (Kershope and Spadeadam) and from North Scotland (Craigellachie and Queens Forest, Figure 15.4).

However, intra-uterine losses appear to be rather high at Thetford, resulting in a mean presence of embryos of close to one for both adults and yearlings (Figure 15.5). Embryos are expressed as a percentage of corpora lutea (from Figure 15.4) to give intra-uterine losses; and only Queens Forest, North Scotland has a higher loss (68%) among adults than Thetford (41%) (Figure 15.5). Losses among yearlings are greater at Pickering, Kershope and Queens than at Thetford (38%).

Owing to the low number of female red deer shot at Thetford no pregnancy data are available, though observations of hinds and calves (R. Whitta, personal communication) suggest rather high recruitment rates compared to Scottish hill populations.

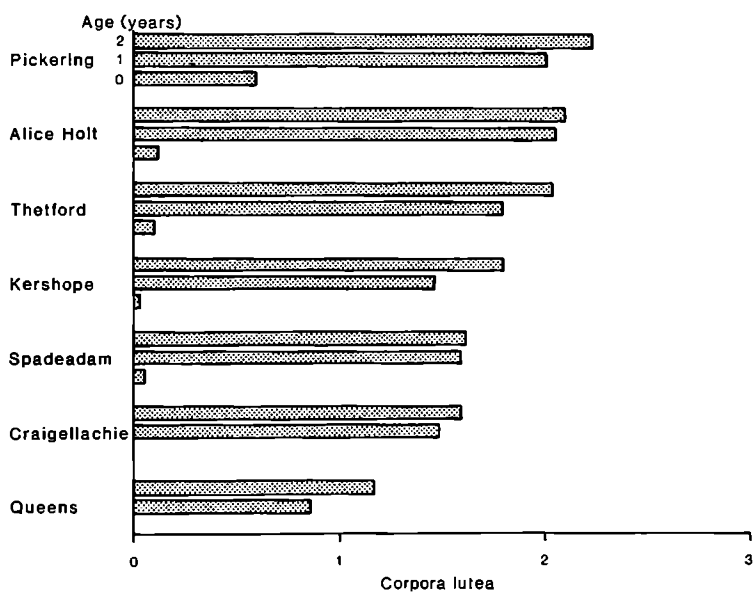

Figure 15.4 Mean number of corpora lutea for three age classes of roe deer

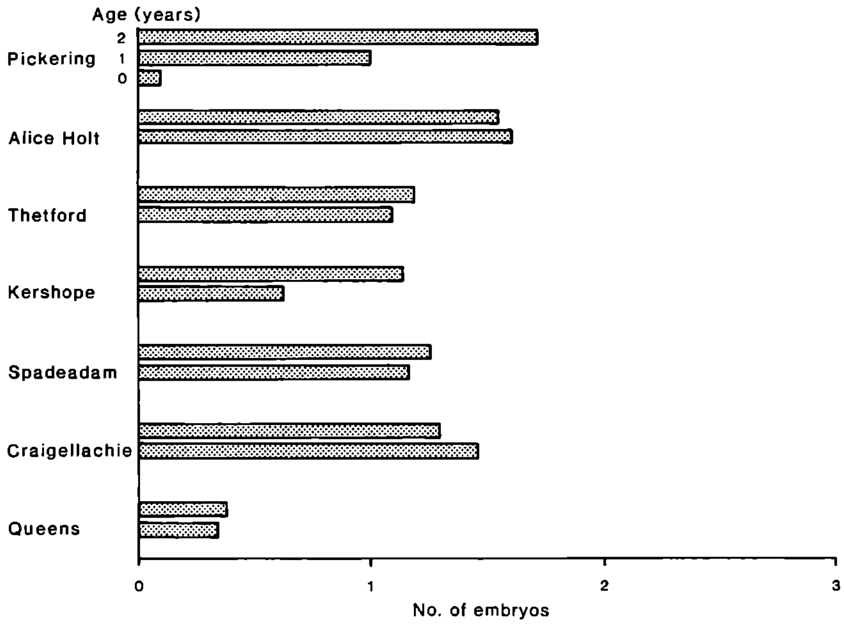

Figure 15.5 Mean number of embryos for three age classes of roe deer

Discussion

It is clear that red deer at Thetford can be characterised by large individual size and quality while roe deer are small and of poor quality. A possible explanation for this difference is that roe deer are more sedentary than red and are largely confined to the wooded areas on rather poor vegetation. Conversely, red deer are highly mobile, having large range sizes, and can exploit the rich mosaic of farm land more effectively than roe. Also, the larger population size of roe may be incurring density-dependent pressures on individual body size.

This hypothesis is supported by the poor reproductive performance and high intra-uterine mortality found in roe at Thetford, and perhaps the deer are under high nutritional stress following implantation of the blastocyst in January when food is scarce. It also seems likely that such stress is likely to continue into late pregnancy and therefore intra-uterine mortality could be much greater than reported here.

Clear felling is taking place on an increasing scale and the subsequent replanting of cleared areas will undoubtedly improve the habitat for roe, creating a mosaic of thickets, valuable for shelter, and pre-thickets and well-vegetated open areas providing rich feeding areas.

Future management

The objectives of management must be clearly defined. It is assumed here that they will include limiting the impact of deer on vegetation, agriculture and forestry, and the provision of a recreational resource for naturalists and hunters.

It is clear that insufficient information is currently available on the numbers and population dynamics of roe and red deer at Thetford on which to base their management. It is suggested, therefore, that the systematic collection of data on roe deer densities and autumn-winter kid:doe ratios (Ratcliffe and Mayle, 1992) is started so that this can be added to the information already being collected (pregnancy data, road traffic accidents). Additionally, all jaw bones from dead deer should be collected and identified to provide information on approximate date of death, location, sex of each animal. These data, along with the age of the animal which can be determined from dental examination of the jaw, can be subsequently used in cohort analyses on which retrospective reconstructions of minimum population size can be made (Ratcliffe, 1987a, 1987b; Ratcliffe and Mayle, 1992).

Until these data are available, the cull rates required to prevent a population increase can be estimated from generalised information on performance related to density (Figure 15.6). It is probable that the actual density of roe deer at Thetford is between 10 and 25 deer km^{-2} which suggests a culling rate for a low performance population of 0.5-3.5 deer km^{-2} (Figure 15.6). The current culling rate plus road traffic casualties is 2.75 deer km^{-2}, which falls at the upper end of this range (Figure 15.6), suggesting that the population will probably be prevented from increasing if this level of cull is maintained. However, it is most important to obtain more reliable data on densities and performance so that these estimates can be improved upon. If the actual density exceeds 20 deer km^{-2}, then the cull plus RTAs is unlikely to be controlling the population.

The wide-ranging behaviour of red deer necessitates the co-operation of neighbouring land managers for their management. A Deer Management Group (DMG) is a necessary forum at which management objectives and strategies can be discussed and agreed upon. The concept of land managers occupying fragments of the red deer range is a useful one in emphasising the absolute necessity of co-operation. Without it, the fundamental objective of safeguarding the deer population and land-use interests in perpetuity must be in jeopardy. Within the forum of a DMG the principles of red deer management in upland forests suggested by Ratcliffe (1987a) can be applied.

Acknowledgement

I am deeply indebted to Rex Whitta, Forestry Commission Head Ranger, who provided much information on the Thetford deer.

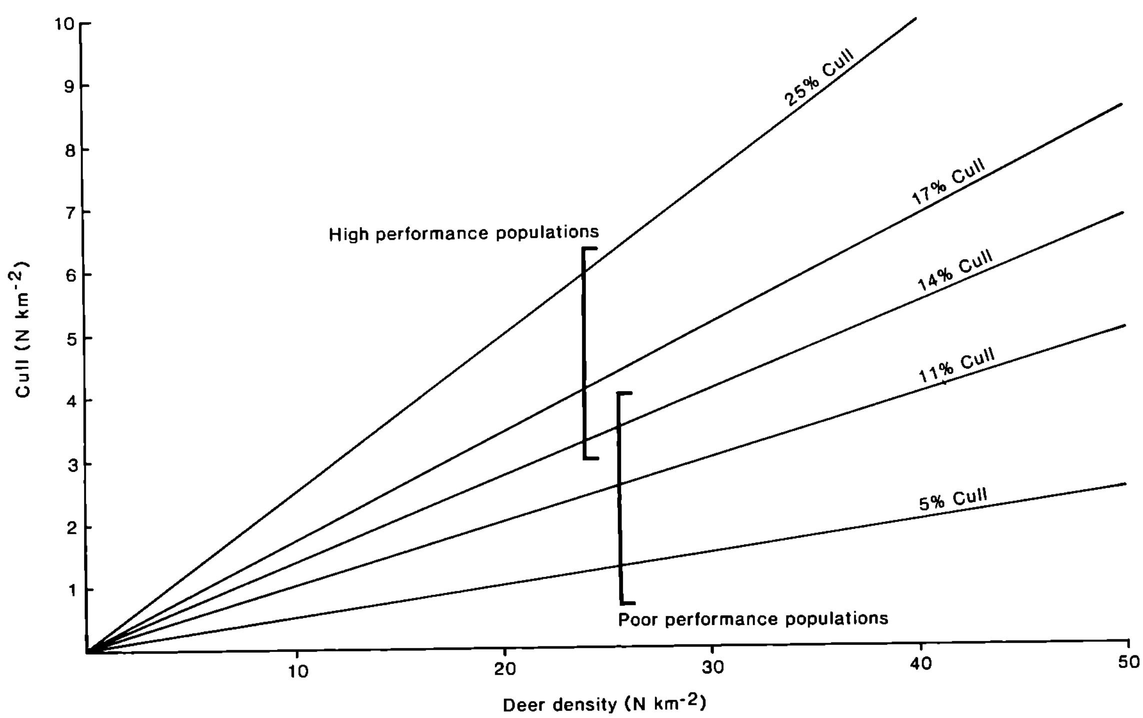

Figure 15.6 Cull requirements for roe deer populations showing the probable relationship between density and cull requirement at Thetford Forest

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Chapter 16

The role of Thetford Forest as part of the River Little Ouse

Peter Barham

Summary

A number of aspects of the Thetford Forest affect the River Little Ouse. In comparison with other land uses, such as arable farming, the effects are less evident and in a number of cases beneficial. The forest requires no irrigation for example, and therefore there is no pressure on local ground water levels which may adversely affect river flows or the Breckland Meres. There has also never been pressure to carry out land drainage works in the forest area, unlike much of the rest of the catchment, and consequently the channel has remained largely undisturbed.

Land adjacent to the river is important as a buffer zone; it comprises unused poplar plantation and grazing and has considerable conservation value both in its own right and as part of the catchment as a whole. The fact that the Forestry Commission view the land as a conservation resource also means there is no pressure to drain it or change the land use in the future. It was also concluded that this land was of major significance in reducing the adverse effects of afforestation that have been observed elsewhere.

Introduction

The Little Ouse is approximately 60 km long, arising at the Suffolk/Norfolk border near Lopham and Redgrave Fen. The river runs through woodland and largely arable farmland until it reaches the town of Thetford, at which point it picks up its major tributaries, the River Thet and the Sapiston River (or Black Bourn). From Thetford, the river travels westwards, across the Brecks, passing through the Thetford Forest and the town of Brandon before it reaches its confluence with the Great Ouse at Brandon Creek (Figure 16.1).

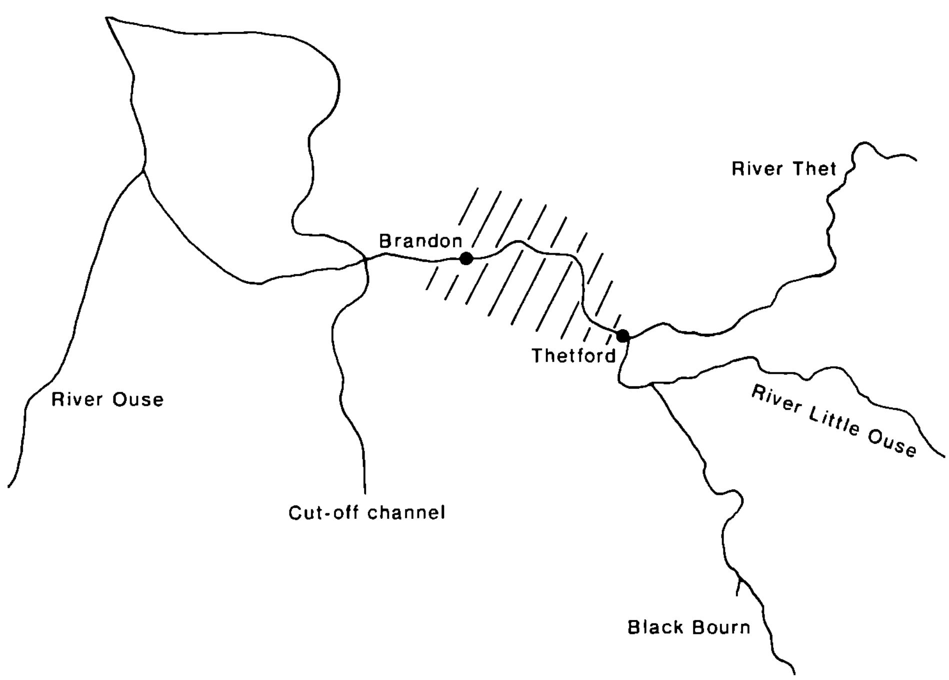

Figure 16.1 Map showing the River Little Ouse and its tributaries

The river drains a variety of different topographies which, in addition to accommodating differing land uses, also affect the physical nature of the river itself. For example, when the river meets the low lying land of the Fenland basin, it loses its gradient and as a consequence slows down, becoming much wider, navigable and more turbid, resulting in a completely different ecology. It arises in a valley fen area, where it is closely linked to ground water levels, but when it reaches the Brecks and the Thetford Forest its drainage patterns alter radically.

Breckland is notorious for its light, sandy soils which drain freely, giving rise to heathland communities and providing a suitable site for afforestation. Although associated with dry conditions, water plays an important part in the ecology of the area, which not only contains the Little Ouse and its tributaries but also the River Wissey and the Breckland Meres. The meres in particular are dependent on ground water levels and any factor which excessively lowered levels may adversely affect the ecology of them or the rivers. The demand for water depends on the land use and this will also affect its fate. For example, rain falling on undrained permanent pasture overlying chalk will largely percolate downwards, boosting ground waters and ultimately re-emerging at springs. Rainfall landing on developed ground, however, will run off as surface water, gaining access to rivers via drainage channels. Land-use changes will therefore have significant effects on drainage patterns, especially where land drainage improvements have been carried out to accelerate run off from land into adjacent rivers.

In addition, differing land uses will have different requirements for water and in an area such as the Brecks this demand is largely met by sinking boreholes and irrigating with ground water. This causes no problems until the reduction in ground water level has an impact on the wetlands which they support. The continuing change from pastoral to arable crops (especially vegetables and root crops) may affect the well-being of the Breckland Meres and rivers, and the effects upon drainage and the demand for water in Thetford Forest, as a large part of the area, will be of major importance.

Rivers support a wide variety of wildlife and are considered to be of great importance as 'nature corridors'. As with drainage, adjacent land use will also be important in determining the ecological diversity of a river. If arable crops are planted up to the river bank, the potential for riverine flora and fauna is greatly curtailed but, if the land is managed as flood meadow, it may support very diverse floras. As the total length of river through the forest is some 10 km (15% of the length of the river), it will have a major role in determining the value of the river as such a corridor.

Finally, the nature of the local geology will also determine the substrate of a river and the sandy nature of the Brecks is reflected in the bed of the Little Ouse, which is almost totally dominated by sand. This has distinct consequences for the river's ecology in limiting habitat diversity. Historically, the effects of the local soils have also been very significant to the behaviour of the river. The phenomenal sand storms of the 17th century were said to have completely filled the river with windblown sand in a number of places, which may well have caused the river to alter its course (NRA engineer, personal communication). The effects of differing topographies and land uses will also have different effects on the management of the river by the National Rivers Authority (NRA), and may affect a number of functions for which the NRA is responsible. These include flood prevention, water resources, conservation, recreation, fisheries and water quality. The effect of Thetford Forest on each of these is examined and how the river, by being affected, becomes an integral part of the forest and its ecology.

Flood prevention

Land drainage and the prevention of flooding has been a major responsibility of drainage authorities since their inception. This has largely been carried out by the widening and deepening of channels and has led to considerable deterioration (or complete loss) of the river flora and fauna and associated wetlands (Brooks and Gregory, 1983). Although in recent years there have been major changes in the approaches adopted by river engineers which have been far more sympathetic to the environment, there remains a legacy of reduced ecological diversity, with far-reaching effects on both rivers and adjacent land.

The scale of this loss, however, will be dependent on the degree to which the original flow regime of the river has been altered, and this itself will be dependent on a number of factors, of which two in particular have major relevance. The first of these reflects the initial cost/benefit analysis and as a consequence the land identified for agricultural improvement, which in turn affects the amount of drainage work done. In general, where potential benefits were greater there was a natural tendency to concentrate effort, resulting in greater physical disturbance to the original channel. Such is the case, for instance, in the clay catchments of the River Cam, where land drainage work has resulted in almost complete conversion of adjacent land to arable crops, with the consequent loss of flood meadowland. The second factor is that the degree to which work was carried out was partially determined by the type and size of machinery available. When the Land Drainage Act 1929 was passed, dredgers were much smaller than those of the 1960s and 1970s, so the level of ecological damage will, to a degree, depend on the time as well as the extent of dredging. A river which underwent 'improvement' in the 1960s is far more likely to show major impact than one that was 'improved' in the 1930s. The size of machinery available in 1967/8, for example, allowed an improvement scheme on the River Welland in Northamptonshire and Leicestershire to remove sufficient material that the bed level was lowered by well over 1 m for a length of over 20 km (NRA engineers, personal communication). This factor, however, will to some extent be obscured by the rate of recovery of a river from dredging work.

In the catchment of the Little Ouse there is a history of major improvement works but these have largely been carried out on the Sapiston River and lower Little Ouse. Within the confines of the Thetford Forest there is little or no evidence of anything other than maintenance works. That is, although there has been sufficient financial benefit to justify land drainage/improvement schemes in some stretches of the river, afforestation has not required capital work programmes. Consequently, the forest has had a significant effect on the way the river has been managed since planting, and continues to do so. Present day engineers see little need for work on the river for flood prevention purposes other than weed-cutting (NRA engineers, personal communication).

Changes in adjacent land use by the Forestry Commission also enhance this view. Poplars planted in the adjacent land as a species tolerant of wet conditions have not been felled as a crop and the land is now considered to be part of the forest's conservation resources, and therefore has a further reduced priority for flood prevention work. In addition, where there is grazing land alongside the river, there is no pressure by the FC to reduce flooding; if anything, the opposite is the case (F. Currie, personal communication).

Water resources

The effects of afforestation on rivers have been shown elsewhere to cause significant alterations to the flow regime when drainage patterns have been modified to enhance tree growth. There is no evidence that this is the case for flows in the Little Ouse and it may well be that the presence of the adjacent belts of now disused poplar plantation and grazing land act as very effective barrier zones. In recent years there has been increasing awareness of the benefit of strips of land adjacent to rivers which would help to maintain or enhance ecological diversity. These include water quality aspects (nutrient sinks), maintenance of wider river corridors and the smoothing of discharge patterns. If the planting of coniferous trees does have an effect in accelerating run off, then it is likely that the adjacent land is helping to regulate discharge. This effect is enhanced if the 'barrier zone' is undrained which, as discussed above, is the case through much of the forest.

The demand for water has increased steadily in recent years and this factor combined with below average rainfall for 28 out of the previous 31 months at the time of writing means that river flows throughout East Anglia are suffering (NRA Anglian Region internal report). In addition to causing problems within the river channel, low flows will also have significant effects on wetlands supported by rivers or ground waters. While it is acknowledged that this has caused problems in other catchments, flows in the Little Ouse are maintained by a recharge scheme which ultimately transfers ground water from the Thet catchment, via the Little Ouse, to pumps at Hockwold and finally into the River Stour in Essex. As this scheme is designed specifically to operate in periods of low flow, it means that the flows of the Little Ouse are guaranteed throughout the year.

Conservation

In assessing the conservation value of rivers and hence the management requirements for conservation, there are two main aspects to consider. The first includes those sites of recognised conservation value such as SSSIs, and the second involves what are often referred to as the wider aspects of the countryside, that is, everything else. Table 16.1 lists the major

Table 16.1 List of major SSSIs, NNRs, LNRs, SPAs and Ramsars within the area[a]

Site status	Site name	Grid reference	Size (ha)	District
SSSI	Islington Heronry	TF568159	1.20	W. Norfolk
SSSI	Wiggenhall St Germans	TF588139	5.10	K. Lynn and W. Norfolk
SSSI	Setchey	TF633132	32.03	K. Lynn and W. Norfolk
SSSI	Hilgay Heronry	TL635992	1.82	W. Norfolk
SSSI	Blackborough End Pit	TF670145	13.54	K. Lynn and W. Norfolk
SSSI	Hunstanton Cliffs	TF672413	4.50	W. Norfolk
SSSI, Ramsar	Dersingham Bog	TF675289	159.10	W. Norfolk
SSSI	Heacham Brick Pit	TF679364	0.87	W. Norfolk
SSSI	Bawsey	TF680194	1.27	K. Lynn and W. Norfolk
SSSI	Wretton	TL685992	19.90	W. Norfolk
SSSI, Ramsar, NNR	Roydon Common	TF685225	194.00	W. Norfolk
SSSI	Snettisham Carstone Quarry	TF685349	10.60	W. Norfolk
SSSI	Ringstead Downs	TF691401	7.00	W. Norfolk
SSSI	Leziate Sugar and Derby Fen	TF693207	86.30	W. Norfolk
SSSI	East Winch Common	TF702158	25.60	W. Norfolk
SSSI	Boughton Fen	TF718015	15.00	W. Norfolk
SSSI	East Walton Common	TF734164	49.70	W. Norfolk
SSSI	Narborough Railway Embankment	TF750118	7.90	Breckland
SSSI, NNR	Weeting Heath	TL757884	140.80	Breckland
SSSI	Foulden Common	TF762002	136.80	Breckland
SSSI	Cranwich Camp	TL775942	12.64	Breckland
SSSI	Didlington Park Lakes	TL777963	25.90	Breckland
SSSI	Gooderstone Warren	TF799014	21.95	Breckland
SSSI	Castle Acre Common	TF802152	17.70	W. Norfolk
SSSI	Grimes Graves	TL815900	64.90	Breckland
SSSI	Field Barn Heaths Hilboro'	TF819017	18.56	Breckland
SSSI	Hooks Well Meadows	TF838011	16.06	Breckland
SSSI	Thetford Golf Course and Marsh	TL845838	119.60	Breckland
SSSI	Great Cressingham Fen	TF848022	13.69	Breckland
SSSI	Old Bodney Camp	TL848991	32.30	Breckland
SSSI, LNR	Barham Cross Common	TL865813	67.27	Breckland
SSSI	Stanford Training Area	TL870940	4597.00	Breckland
SSSI	River Nar	TF897198	233.84	K. Lynn and W. Norfolk
SSSI	Wretham Park Meres	TL902918	27.47	Breckland
SSSI	East Wretham Heath	TL910882	141.07	Breckland
SSSI	Bridgham and Brettenham Heath	TL924865	467.00	Breckland
SSSI	Wayland Wood, Watton	TL925996	30.84	Breckland
SSSI	Thompson Water, Carr and Co.	TL930955	156.00	Breckland
SSSI	Cranberry Rough, Hockham	TL934936	81.40	Breckland
SSSI	Scoulton Mere	TF985014	33.72	Breckland
SSSI	Devil's Ditch Garboldisham	TL988817	6.00	Breckland
SSSI	Middle Harling Fen	TL989852	12.70	Breckland
SSSI	East Harling Common	TM000879	14.90	Breckland
SSSI	Swangey Fen, Attleborough	TM015932	82.30	Breckland
SSSI	Keninghall Fen	TM041875	48.90	Breckland

Site status	Site name	Grid reference	Size (ha)	District
SSSI	Old Buckenham Fen	TM048920	34.80	Breckland
SSSI	New Buckenham Common	TM094908	20.00	Breckland
SSSI, NNR	Martham Broad		59.00	W. Norfolk
SSSI, NNR	Blakeney		1097.00	N. Norfolk
SSSI, NNR	Scolt Head Island	TL345999	737.00	Breckland
SSSI, NNR	Brettenham heath	TL456999	236.00	Breckland
SSSI, Ramsar, SPA	N. Norfolk Coast NNR	TF690443	7700.00	K. Lynn and W. Norfolk
SSSI	Hunstanton Park Esker	TF695409	17.11	K. Lynn
SSSI	Syderstone Common	TF834315	42.50	W. Norfolk
SSSI	Holkham Brickpits	TF862428	0.45	W. Norfolk
SSSI, NNR	Holkham Lake	TF883435	–	W. Norfolk
SSSI	Horse Wood Mileham	TF922186	7.10	Breckland
SSSI	Wells Chalk Pit	TF929429	5.70	N. Norfolk
SSSI	Honeypot Wood	TF932144	9.03	Breckland
SSSI	Holly Farm Meadow	TF936131	2.50	Breckland
SSSI	Warham Camp	TF944409	5.04	N. Norfolk
SSSI	Horningtoft Wood	TF948238	9.05	Breckland
SSSI	Dillington Carr Gressenham	TF971158	49.00	Breckland
SSSI	Dereham Rush Meadow	TF976140	20.60	Breckland
SSSI	Potter's Carr Granworth	TF980041	5.70	Breckland
SSSI	Beetley and Hoe Meadows	TF982174	11.70	Breckland
SSSI	Cockthorpe Common	TF985430	6.90	N. Norfolk
SSSI, NNR	Swanton Novers Woods	TF987328	83.36	N. Norfolk
SSSI	Morston Cliff	TF990441	0.86	N. Norfolk
SSSI	Badley Moor Dereham	TG013117	18.10	Breckland
SSSI	Wiveton Downs	TG023433	29.60	N. Norfolk
SSSI	Bilsey Hill	TG023416	2.48	N. Norfolk
SSSI	Sea Mere, Hingham	TG035012	36.25	S. Norfolk
SSSI	Rosie Curston's Meadow	TG041124	2.33	Breckland
SSSI	Glandford, Letheringsett	TG043411	0.98	N. Norfolk
SSSI	Glandford, Hurdle Lane	TG054416	7.89	N. Norfolk
SSSI	Foxley Wood	TG056227	122.70	Breckland
SSSI	Costen Fen, Runhall	TG062066	7.30	S. Norfolk
SSSI	Hockering Wood	TG073144	87.72	Breckland
SSSI	Salthouse Heath	TG074425	93.10	N. Norfolk
SSSI	Whitwell Common	TG088206	19.17	Broadland
SSSI	Holt Lowes	TG088374	49.30	N. Norfolk
SSSI	Kelling Heath	TG101420	88.20	N. Norfolk
SSSI	Edgefield Little Wood	TG107342	5.50	N. Norfolk
SSSI	Shelfanger Meadows	TM110828	10.70	S. Norfolk
SSSI	Weybourne Cliffs	TG111437	39.80	N. Norfolk
SSSI	Booton Common	TG113230	7.73	Broadland
SSSI	Weybourne Town Pit	TG114431	0.60	N. Norfolk
SSSI	Alderford Common	TG129184	16.80	Broadland
SSSI	Lower Wood Ashwellthorpe	TM140980	36.00	S. Norfolk

Site status	Site name	Grid reference	Size (ha)	District
SSSI	Swannington Upgate Common	TG148181	20.03	Broadland
SSSI	Aslacton Parish Land	TM156918	4.30	S. Norfolk
SSSI, LNR	Sheringham and Beeston Region	TG164424	23.99	N. Norfolk
SSSI	Forncett Meadows	TM166926	5.00	S. Norfolk
SSSI	Beeston Cliffs	TG167434	11.00	N. Norfolk
SSSI	Britons Lane Gravel Pit	TG169415	20.90	N. Norfolk
SSSI	Cawston and Marsham Heath	TG170235	125.70	Broadland
SSSI	Buxton Heath	TG175218	67.03	Broadland
SSSI	West Runton Cliffs	TG183432	17.56	N. Norfolk
SSSI	Flordon Common	TM183971	10.05	S. Norfolk
SSSI	East Runton Cliffs	TG194430	19.70	N Norfolk
SSSI	Felbrigg Woods	TG196401	162.50	N Norfolk
SSSI	Pulham Market Big Wood	TM205896	4.70	S. Norfolk
SSSI	Sweet Briar Rd Meadows	TG208097	9.53	Norwich
SSSI	Eaton Chalk Pit	TG209064	0.16	Norwich
SSSI	Gunton Park Lake	TG221345	18.40	N. Norfolk
SSSI	Fritton Common	TM224921	19.80	S. Norfolk
SSSI	Overstrand Cliffs	TG227419	57.43	N. Norfolk
SSSI	Catton Grove Chalk Pit	TG229109	0.05	Norwich
SSSI	Caistor St Edmund Pit	TG239048	23.80	S. Norfolk
SSSI	Shotesham Common	TM241998	19.60	S. Norfolk
SSSI	St James Pit	TG242094	3.28	Norwich
SSSI	Gawdyhall Big Wood	TM250850	30.00	S. Norfolk
SSSI	Sidestrand and T'ham Cliffs	TG252408	68.00	N. Norfolk
SSSI	Shotesham-Woodton Woods	TM253975	40.90	S. Norfolk
SSSI	Bryant's Heath, Felmingham	TG259294	17.56	N. Norfolk
SSSI, LNR	Southrepps Common	TG261350	5.30	N. Norfolk
SSSI	Crostwick Marsh	TG263165	11.20	Broadland
SSSI	Westwick Lakes	TG273274	9.55	N. Norfolk
SSSI	Bramerton Pits	TG295060	0.50	S. Norfolk
SSSI	Sexton Wood	TM299916	37.55	S. Norfolk
SSSI	Hedenham Wood	TM314946	34.00	S. Norfolk
SSSI	Mundesley Cliffs	TG317365	28.70	N. Norfolk
SSSI	Smallburgh Fen	TG327246	7.30	Northampton
SSSI	Tindall Woods Ditchingham	TM327935	41.00	S. Norfolk
SSSI	Yare Broads and Marshes	TG330063	735.83	Broadland
SSSI, Ramsar, NNR	Bure Broads and Marshes	TG337166	736.50	Broadland
SSSI	Ducans Marsh, Claxton	TG339027	3.60	S. Norfolk
SSSI	East Ruston Common	TG340280	38.30	N. Norfolk
SSSI	Broad Fen, Dilham	TG343255	36.86	N. Norfolk
SSSI	Alderfen Broad	TG355195	20.63	N. Norfolk
SSSI, NNR	Ant Broads and Marshes	TG362213	735.11	N. Norfolk
SSSI	Poplar Farm Meadows	TG370021	7.23	S. Norfolk
SSSI	Happisburgh Cliffs	TG379314	5.90	E. Norfolk
SSSI	Hardley Flood	TM380997	48.10	S. Norfolk
SSSI	Leet Hill, Kirby Cane	TM381929	6.62	S. Norfolk
SSSI	Upton Broad and Marshes	TG390137	194.00	Broadland
SSSI	Geldeston Meadows	TM396916	13.43	S. Norfolk
SSSI	Limpenhoe Meadows	TG399031	11.60	Broadland

Site status	Site name	Grid reference	Size (ha)	District
SSSI	Shallam Dyke Marshes	TG399165	71.70	Broadland
SSSI	Decoy Carr, Acle	TG405090	55.36	Broadland
SSSI, NNR	Ludham/Potter Heigham Marshes	TG410178	99.00	N. Norfolk
SSSI	Calthorpe Broad	TG412258	43.50	N. Norfolk
SSSI	Damgate Marshes, Acle	TG413097	63.90	Broadland
SSSI	Priory Meadows Hickling	TG417254	24.00	N. Norfolk
SSSI, Ramsar, NNR	Upper Thurne Broads and	TG430210	1159.15	N. Norfolk
SSSI	Stanley and Alder Carrs	TM434928	43.50	S. Norfolk
SSSI	Halvergate Marshes	TG435060	162.00	
SSSI	Burgh Common and Muckfleet	TG440117	118.00	Gt Yarmouth
SSSI, Ramsar, NNR	Hickling Broad-Horsey Mere	TG445215	382.00	Broadland
SSSI	Hall Farm Fen, Hemsby	TG481170	9.00	Gt Yarmouth
SSSI, NNR	Winterton-Horsey Dunes	TG490210	427.20	N. Norfolk
SSSI, LNR	Breydon Water	TG500075	306.50	Gt Yarmouth
SSSI, SPA	Great Yarmouth N. Denes	TG533100	92.40	Gt Yarmouth
SSSI	Potter and Scarning Fens	TG982120	5.53	Breckland

[a]SSSI: Site of Special Scientific Interest, NNR: National Nature Reserve, LNR: Local Nature Reserve, SPA: Special Protection Area (statutory site designated by the Department of the Environment/Welsh Office for their international importance for birds), Ramsar: Ramsar site (statutory site designated by the Department of the Environment/Welsh Office for their international importance for wetland communities).

(a)

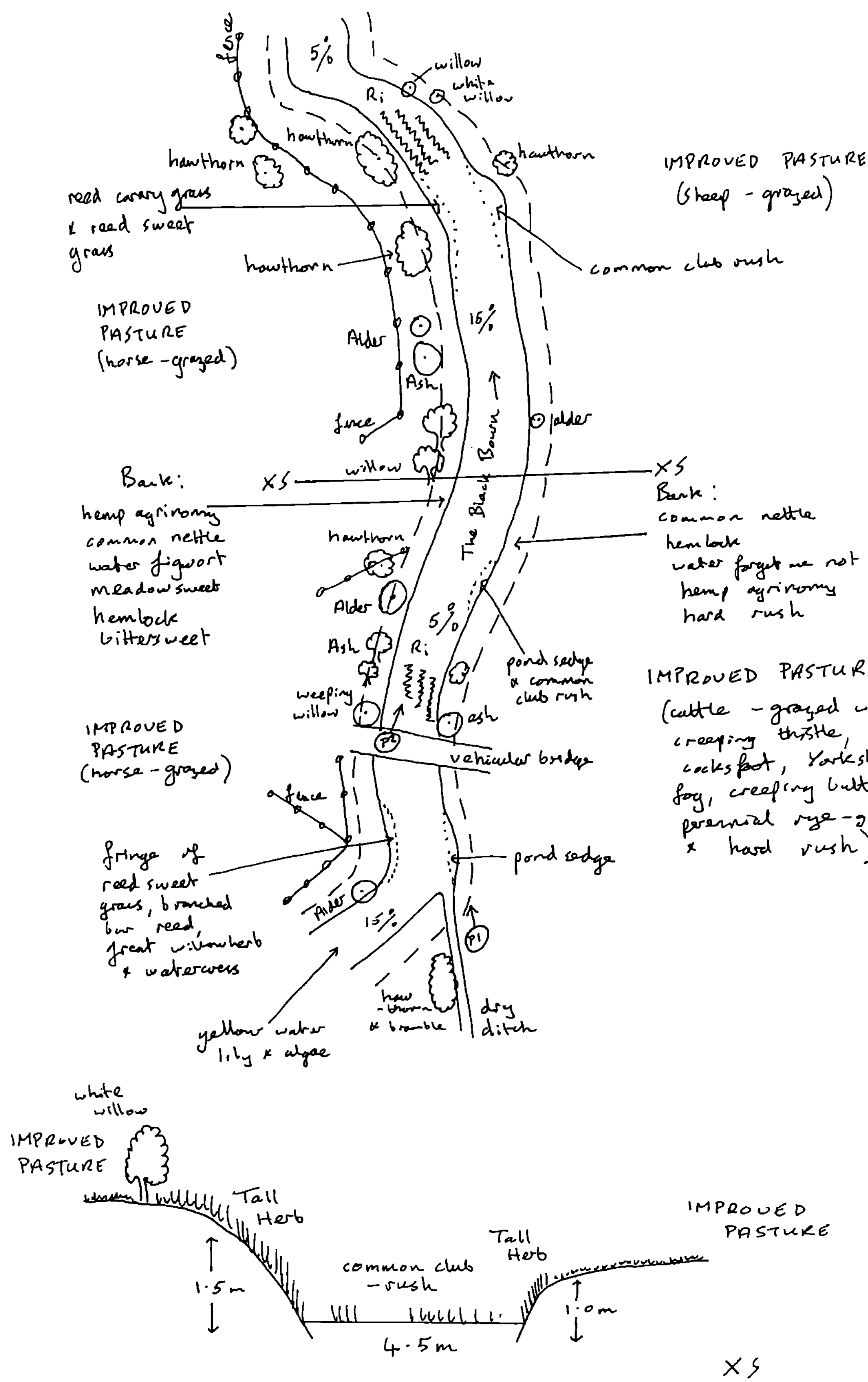

Figure 16.2(a) Example of a river corridor sketch map for one 500m section of the Sapiston River (Black Bourn). (b) Example summary sheet of river corridor data for one 500m section

(b)

CSAP 033

Plant communities

A gently meandering section of river with improved pastures on the left and right.

The left bank, with much hawthorn, ash, willow and alder tree and shrub cover, is dominated by hemp agrimony, nettle, water figwort, meadowsweet, hemlock and bittersweet. There are fringing patches of reed canary grass, reed sweet grass, branched bur-reed, watercress and great willowherb.

The right bank, open apart from a little willow, hawthorn and alder, is dominated by nettle, hemlock, water forget-me-not, hard rush, hemp agrimony, creeping thistle, Yorkshire fog, cock's-foot, perennial rye grass and creeping buttercup. There are fringing patches of common club-rush and greater pond sedge.

The channel has 5-15% cover of fringing vegetation with algae and yellow water lily.

Seventy-seven species recorded.

Birds

Twenty-eight species were recorded. Of these, 21 species (little grebe, mallard, moorhen, coot, woodpigeon, collared dove, turtle dove, wren, dunnock, robin, blackbird, song thrush, sedge warbler, lesser whitethroat, garden warbler, willow warbler, spotted flycatcher, blue tit, chaffinch, greenfinch and linnet) probably held breeding territories which included the river corridor. One species (teal) occurred on passage and six species (tufted duck, lapwing, house martin, mistle thrush, great tit and yellow hammer) fed in the corridor but bred elsewhere.

The main habitats for birds include the mixed trees and bushes along the left bank and the patch of fringe along the right bank.

Other species

Water vole.

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conservation sites within the area and it is clear from this that a significant proportion of these are wetland in nature, dependent on either the river or ground waters to maintain water level. Given the high concentration of recognised conservation value within the catchment, any further wetland resources are not only of value in themselves but also in extending the overall value of the river as a whole. This aspect is of extreme importance in determining the conservation value of the river and is the reason why such emphasis is placed on rivers as nature corridors. An almost unbroken stretch of approximately 10 km of relatively undisturbed land through the forest therefore represents a valuable conservation resource in its own right, as well as being a significant part of the river. Land use elsewhere rarely allows such a length of species rich wetland to be maintained as a continuity; in a catchment such as that of the Little Ouse, it represents a major contribution to conservation.

The needs of conservation are accepted as an integral part of work planning within the NRA. The length of river through the forest has therefore been identified as one which will require little or no maintenance from a flood prevention point of view but may require serious consideration in terms of ecological management. This approach is given greater emphasis by the fact that the NRA also has a duty under the terms of the Water Resources Act 1991 to consider, wherever possible, the inclusion of conservation enhancements. For this reason, the NRA is currently considering ecological enhancements in conjunction with the Forestry Commission.

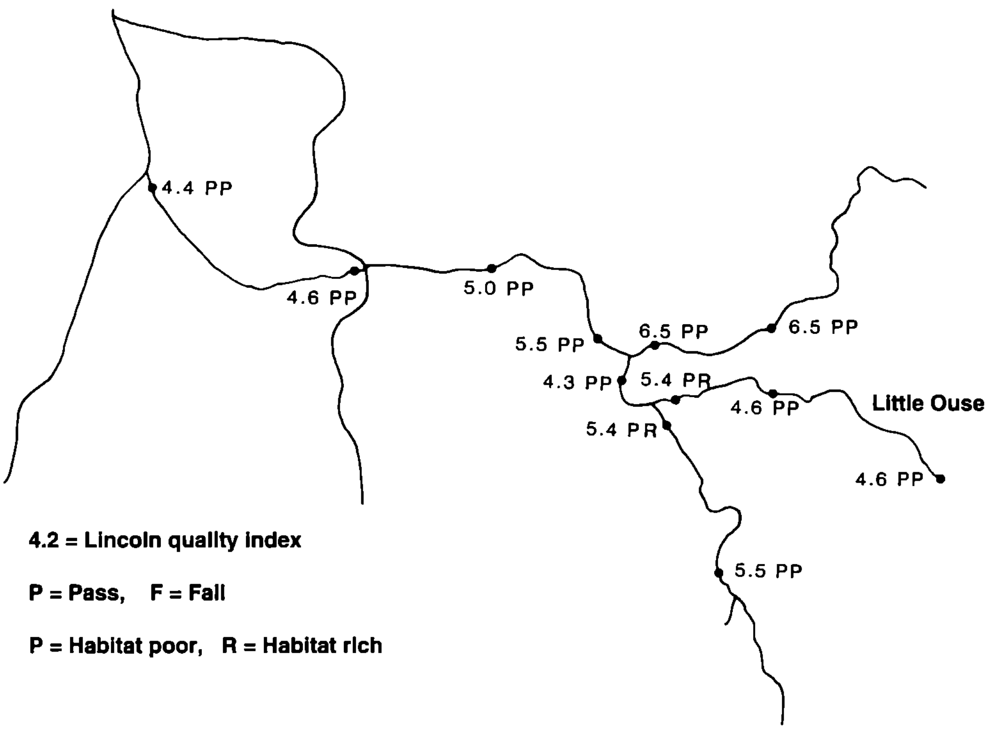

Figure 16. 3 Biological sampling sites: invertebrate samples taken throughout the Little Ouse system represented in the form of a standard index to demonstrate water quality

To determine what enhancements are appropriate, an understanding of the ecology of the river is achieved through strategic and reactive surveys. That is, some information is collected to create databases which can be used in future planning while other data are collected in response to specific requirements, such as when dredging is carried out to alleviate a flooding problem. The Anglian Region of the NRA carries out both sorts of survey and is currently undertaking a 3-year strategic programme to accumulate plant and bird data for all the Region's rivers onto a single database. Figure 16.2 shows an example of the field data collected during this work. This information allows the optimum management for each section of river to be discussed with the relevant engineer, thus minimising ecological damage. In addition, examination of the combined data for a whole river or collection of rivers will allow a fuller understanding of the overall natural history of the river and the ecological damage which has resulted from unsympathetic engineering. It is then possible to determine appropriate enhancements which could be incorporated into future works.

The sort of enhancement opportunity applicable to this section of river includes the shallowing of river banks to allow a greater period of transition between land and water, limited reconstruction of the riffle/pool system, bankside planting of tree species such as alder *(Alnus glutinosa)* and the creation of wet shelves or berms, which would allow more diverse marginal vegetation to grow. In addition to recreating the natural environment, bat boxes, barn owl boxes and artificial otter holts all provide wildlife benefits from the river and its adjacent land. In the case of otter holts, however, the likelihood is that sufficient cover already exists along this stretch of river to negate the need for artificial holts, and consequently they are not recommended (Philip Wayre, Otter Trust, personal communication).

Water quality

Essential to the well-being of any river is that the water is of suitable quality. The effects of afforestation and possible acidification on other rivers has been looked at elsewhere. The pH data obtained for a number of sites upstream, through and downstream of the forest can be used to determine whether any effects can be detected. At all sites pH values remain constant, the river starting alkaline and remaining so throughout its course. Other determinants are designed to measure the effects of organic enrichment, from sewage treatment works in particular; but like pH these show good consistency at very low levels, indicative of high water quality (NRA Anglian Region internal report). In any area of intensive land use there is also the possibility of contamination by chemicals such as herbicides and pesticides. It is impossible to screen for all chemicals currently available but any presence of chemicals which have an effect on ecology or prevent the water being used for prescribed objectives means that the water is polluted. For this reason, biological information is also used routinely to determine the health of water.

Of all the biota which colonise rivers, invertebrates are most commonly used for a number of reasons. They have variable tolerance to different levels and different types of pollution so can be of use in diagnosing the type of any pollution as well as quantifying it. They are easy to catch with a pond net and are also relatively immobile, meaning they must tolerate all prevailing conditions, not just those which exist at the time of sampling. Finally, the variety of aquatic invertebrates is very large and the information derived from sampling data can also be of major use in conservation assessment (Smith *et al.*, 1990). Figure 16.3 shows summary data for invertebrate samples taken throughout the Little Ouse system and represented in the form of a standard index used throughout the Anglian region to demonstrate water quality (Extence *et al.*, 1987).

The results indicate changes in biological quality as the river travels downstream but quality remains high throughout the forest length. Habitat obviously plays an important role in invertebrate distribution and the advantage of the Lincoln Quality Index used here is that it takes the effect of habitat on invertebrate distribution into account. This is important in determining whether poor biological quality is the result of bad dredging (causing habitat loss) or poor water quality. In the case of the Little Ouse, however, sections of the forest river are classified as habitat poor even though, as discussed above, there is no record of excessive engineering. The reason for this is that the substrate is dominated by sand, which is very inhospitable to invertebrates, reducing both diversity and biomass (Smith *et al.*, 1990).

Water quality is largely unaffected by the presence of the forest but the light, sandy soils of the Brecks have a distinct effect overall in lowering the habitat diversity of the channel. The effects of this are that the food available to predators such as fish and wildlife is much lower than might be expected, and consequently the whole ecology of the river is altered. In setting water quality standards for the river, this aspect therefore needs consideration to ensure that biological expectations are not set at unattainable levels.

Recreation

The Water Resources Act, 1991, gives the NRA increased duties regarding recreation and this is taken to extend beyond the two big user groups, namely anglers and boaters, to include less formal aspects such as walking and general access to the river. Although recreation is often linked with conservation, the potential for major conflicts is great if the planning is not carefully considered. For example, if increased access to the river increased the level of disturbance to otters, it may be that they would abandon their holts, in which case the cost to conservation would be excessive.

In planning access to the river, it is therefore essential that the possible consequences for conservation are understood as well as they would be for proposed flood defence work. In the case of Thetford Forest, existing trails take the walker near the river and the potential exists to dramatically increase their number. The use of conservation data gained from surveys will help to ensure that this does not incur environmental loss. In addition, the presence of increased numbers of footpaths can be included within the management requirements of the NRA, ensuring that when work is carried out footpaths are properly maintained. Increased access near the Santon Downham area with its existing network of trails could be very useful. Proposals to this effect have been suggested by the Commission and initial discussions have already been held with the NRA.

Discussion

The catchment of the Little Ouse comprises a mosaic of different habitat types, of which the forest forms a significant part. In recent years parts of the river have undergone land drainage schemes to improve drainage, while at the same time farming has become far more intensive. In many areas these operations have had major effects on both the ecology of the river and riparian land, especially where arable crops have replaced pasture or woodland. Through the Thetford Forest, however, adjacent land use is restricted to grazing or disused poplar plantation with significant conservation value. The management of this land requires little emphasis from flood prevention engineers and is largely left undisturbed, apart from weed-raking. That this management is welcomed by the land owners is of considerable value in assuring future light maintenance only.

Increasingly, management of rivers is based on better understanding of the assets of a river and the factors required to maintain or enhance them. In addition, it has been recognised that to manage a river effectively, planning must be on the basis of the whole catchment, not individual stretches. To do this, however, requires information on each of the constituent features and the importance of these to the catchment overall. The forest adds greatly to the diversity and value of the river corridor and, as such, becomes a major consideration in determining management requirements. In addition, it is also important that management of the river is based on the objectives required of it, and these have been examined in respect of the various functions for which the NRA is responsible. Hence, although there is little requirement for flood alleviation work, the high conservation value of both the river and adjacent land highlights the need for extensive conservation planning, both to protect existing value and to enhance it. Work elsewhere in the catchment is currently evaluating the potential to re-establish wet meadows in areas where landowners are content to restrict land use to permanent grass. This will further allow a reduction in pressure to increase channel capacity as the newly restored wet meadows will act as flood storage areas.

By considering each of the functions for which the NRA is responsible, it has become clear that the forest has a considerable beneficial impact on the river and that the presence of the river in the middle of the forest greatly increases its ecological diversity as well as its conservation, recreation and aesthetic value. By examining the requirements of river engineers and foresters, ecological diversity is not only maintained but also enhanced when future work is carried out.

Acknowledgements

The assistance of Gary Murphy and Lucy Bazeley during the preparation of this chapter is gratefully acknowledged.

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Chapter 17

Thetford Forest Park management plan: an update

Brian Roebuck

Summary

The Thetford Management Review was undertaken to provide ways in which the landscape and value for wildlife, game and conservation could be improved. From the preparation of separate single purpose plans covering nature conservation, wildlife and game management, considerable progress has been made in integration and the delivery of the multiple benefits which forests can provide.

Introduction

In 1979 the Thetford Management Review was set up in recognition that clear felling and restocking of the forest would provide an opportunity to adjust the management of this major timber production unit with a view to improving its landscape and its value for wildlife, game and conservation generally. The purpose of the Thetford Management Review was to examine and propose ways of achieving this aim while accepting that the primary function of Thetford Forest must continue to be the production of timber (Simpson and Henderson-Howat, 1985).

In 1980 three bodies, the Nature Conservancy Council, Game Conservancy and Forestry Commission Forest Design Branch, prepared separate single purpose plans showing how they would like to see a defined section of the forest managed for their own particular interest.

It was found that there was considerable scope for improving the landscape and enhancing the game and wildlife value of the forest without major penalty to timber production. This could be achieved especially by concentrating the investment in areas where such conservation and landscape benefits could be maximised. This chapter describes the action which has been taken to implement the review recommendations.

Nature conservation

The *objectives* stated by Dr Radley (Breckland Officer of the Nature Conservancy Council) were:

1. *To create or maintain stable areas of different habitats to cater for the less mobile or less adaptable species.*

2. *To manage the rest of the forest to make it as attractive as possible for species able to survive the periodic upheavals of clear felling.*

Dr Radley said that these objectives could be met by:

- Providing special reserve areas for the maintenance of wetland, heathland, especially valuable areas of broadleaved woodland, disturbed ground communities and particularly rare species.
- Retaining some areas of conifer well beyond rotation age.
- Retaining some broadleaved woodland; and natural regeneration under shelterwood.
- Managing selected rides as conservation rides.
- Recognising the conservation value of small scale features such as wet hollows, ponds, compartment corner clearings and other unproductive areas, maintaining them and where practicable managing them to enhance their interest.

For the second objective, relating to the general management of the forest, the proposals were as follows:

- To promote the formation of a deciduous understorey during the first rotation was important and the recommendation was that the canopies of plantations should be kept as open as possible during the later stages of the rotation.

- The value of recent clear fells for ground nesting birds was clearly established, and it was desirable to maintain a continuous supply of newly felled areas.

Landscaping

The landscaping report was prepared by Clifford Tandy, the Forestry Commission external landscape consultant, and Oliver Lucas, Forestry Commission Design Branch. The general approach advocated in the section on design principles was to diversify the forest landscape as seen from public roads. Specifically, the proposals were:

1. The scale of fellings to create stands of varying age should be bold but generally not exceed 10 to 20 ha within 300 m of public roads or 40 ha elsewhere.

2. The typical broadleaved roadside belts should be retained where they were thick enough to form a woodland feature but felled where they were weak or untidy.

3. It was recommended that the present proportion of broadleaved woodland (about 10%) should be maintained but that it be redistributed to create larger concentrations.

Game

Nigel Grey of the Game Conservancy prepared this section of the report. Virtually all of his suggestions were compatible with suggestions made by the Nature Conservancy Council for retaining wildlife habitats.

There was considerable overlap between the recommendations of the three single purpose plans. For example, the implications of some recommendations would enhance the landscape as well as providing conservation benefits for game and the wildlife.

Financial implications

The opportunity cost as a percentage of maximum discounted revenue for the survey area was just over 3% providing that the main forest design proposals were confined to roadsides and the railway. Elsewhere, the landscape design would be more broadly based using landform, other landscape features and crop diversity to create an interesting internal landscape without incurring major cost.

Policy prescriptions

The policy that emerged was broadly in line with the proposals for the survey area.

1. Management of conifer plantations.

   (a) Within compartments adjacent to public roads (and the railway), follow the general landscaping principles set out by Forest Design Branch.

   (b) In the rest of the forest delayed and advanced felling should be used to improve coupe shape and emphasis landform. Additional landscaping may be undertaken close to recreational facilities where this does not detract significantly from timber production.

   (c) Regard would be paid to the general conservation principles set out by the Nature Conservancy Council.

2. Management of broadleaved areas.

   (a) Maintain present proportion of broadleaved woodland using natural regeneration wherever possible.

   (b) Manage broadleaved woodland for timber production but with conservation and amenity as important secondary considerations.

   (c) Manage roadside broadleaved belts on the basis of Forest Design Branch's recommendations.

3. Management of rides.

   There are basically three types of ride:

   (a) Rides which need cutting periodically to prevent them becoming completely overgrown.

(b) Rides which for management purposes need to be kept open by annual cutting.

(c) Certain identified rides which would have their margins developed as shrub layers.

Implementation of the recommendations

Nature conservation

- An informal Thetford Forest Conservation Group, which was started in the 1970s when John Fletcher was District Officer, has been built on to include representatives of most, if not all, of the conservation interests. An annual meeting, chaired by the Forest District Manager, is held at Santon Downham to consider reports from the different interest groups, discuss future proposals and advise management on conservation issues. There are 18 non-Forestry Commission representatives who are invited to attend the meeting (and most do).

- In 1991, a conservation panel, made up of a small group of individuals with specific conservation expertise, was formed to provide expert advice to the Forest District Manager on a wide range of conservation interests.

- Following the division of the Forestry Commission into Forestry Authority and Forest Enterprise in 1992, Forest Enterprise was charged with managing its woodlands for multipurpose forestry. The remit of the Conservation Panel was extended to cover a wider range of environmental issues. Additional members were appointed to include landscape design, archaeological and recreation expertise. This larger group was renamed the Thetford Forest District Environment Panel.

- The first Thetford Forest Conservation Plan was completed by Gerry Haggett in 1987, approved as amended by Conservator in March 1988 and presented to the FC conservation consultant, Dr John Morton Boyd, who also gave his seal of approval to the plan during a visit to Thetford. The plan was updated and amended in 1992.

- There are eight sites of special scientific interest (SSSIs) within the forest, all of which have management plans agreed with English Nature.

- The Santon and Little Ouse Valley Forest Nature Reserve has a separate management plan which includes management prescriptions and a 3-year rolling programme of work which is included in the Forest District business plan.

Conservation management prescriptions

Creating or maintaining stable habitats for less adaptable species

The first major prescription, aimed at creating or maintaining stable areas for less mobile or less adaptable species, has been implemented in the following ways.

- Special reserve areas have been established providing for the maintenance of wetland, heathland and valuable areas of broad-leaved woodland and particular rare species. Ten types of sites have been identified in the Forest District Conservation Plan, all of which are covered by management prescriptions.

- Some areas of conifer have been identified for retention well beyond normal rotation age. Forest Design Plans, which have been prepared for the whole of Thetford Forest, have allocated over 1000 ha for long-term retention, a significant proportion for conservation reasons, which means that some trees will be retained to their biological rotation. About 20% of the productive forest area is scheduled for retention past the normal optimum economic rotation length of 50 to 55 years for Corsican Pine and 65 years for Scots pine.

- This restructuring of the forest to improve the age class diversity and its conservation value is one of the primary objectives of the multipurpose Forest Design Plans which seek to:

  - obtain a sustained production of quality timber and other forest products;

  - maintain species diversity, conserve semi-natural and old woodlands, maintain and improve the woodland environment and the overall conservation value;

- increase the use of the forest for public recreation;

- improve the design of the forest as the first rotation crops are felled and restocked. This will permit open ground to be extended where this is appropriate, e.g. some reversion to Breckland Heath.

- Retaining broadleaved woodland. There are no planned fellings other than those necessary for safety or landscape design. All broadleaves, except those areas over which felling is constrained, will be thinned to encourage understorey development.

- Selected rides will continue to be maintained and enhanced for conservation purposes. There are over 70 miles (112 kilometres) of conservation rides, i.e. 1 mile to every 300 hectares, covered by a variety of management prescriptions, many of which involve the widening of specific sections linked to areas of open ground. The main objectives are:

  - To provide a habitat where Breckland plants may flourish.

  - To provide a woodland edge.

  - To offer habit diversity within the forest, both conifer and broadleaved.

  - To provide a reservoir of nationally or locally rare plants and corridors of seed sources.

  - To link important conservation areas, e.g. SSSIs, local and national nature reserves.

- The management prescriptions and mowing regimes for conservation rides have been kept as simple as possible and the following are those most adopted:

  - Mow alternate sides in alternate years (grass heath communities).

  - Mow alternate sides every fourth year (heath and woody shrubs).

  - Mow for central access from June onwards, then alternate sides each year in October (fen and lush grass).

  - Scarify at long intervals where heather is being overgrown or where important 'bare ground' Breckland species occur.

General management of the forest

The second major prescription, relating to the general management of the rest of the forest, was implemented in the following ways.

- The formation of a deciduous understorey was considered important. While this may be achieved using normal thinning practices, it makes sense to concentrate most efforts in those areas of the forest where the response will be greatest.

- The maintenance of a continuous supply of newly clear felled areas. This is normal management practice and the success of the woodlark and nightjar indicates that this is working and that there is little justification, other than in exceptional circumstances, to carry out additional special measures.

Landscaping

The approach recommended was to concentrate on the diversification of landscape area as seen from the public roads.

It has been found more difficult than was perhaps envisaged to meet the requirements of scale and diversity and, while the general principles outlined above have been followed, the effect of the 1987 windthrow and premature felling to reduce losses from fungi have been significant constraints. There are examples of success in modifying straight edge effects but this is an aspect which has been given greater emphasis in the Forest Design Plans.

New proposals have been drafted for the management of roadside belts which take full account of the prescriptions made by the landscape architects. The proposal to maintain the existing 10% of broadleaved woodland and improve its concentration has been incorporated in the Forest Design Plans and Conservation Plan to form an integral part of management practices. Efforts to increase the size of individual broadleaved areas will be continued and future prescriptions will identify the areas where the greatest benefit is likely to be obtained. Where it occurs, natural regeneration of suitable species will be encouraged, supplemented as necessary with planting of native species.

Game

Nigel Grey's recommendations have been considered and included when appropriate in the Forest Design Plans.

Research

The forest will continue to be used for research purposes by Forestry Commission and non-Forestry Commission bodies. Some of the current projects will continue and new projects will be encouraged provided they are compatible with the management of the forest. For example, a joint initiative with English Nature was started in 1992 with the aim of arresting the decline in the red squirrel population as part of English Nature's Species Recovery programme.

Constraints

Two constraints which have affected the implementation of some aspects of the Management Plan were the need to fell Scots pine crops which were badly infected by *Peridermium pini* and the 1987 windthrow. Both have had a major influence on the location and scale of felling operations. Not all of these have been negative but in some part of the forest the size, shape and sequence of felling coupes have varied significantly from the normal prescriptions contained in the Forest Design Plans, particularly in relation to landscape design. However, the opportunity has been provided to study the behaviour of animals and birds in relation to the changed environment and to extend research to see the response of deer.

The Forest Park

The creation of the Thetford Forest Park in 1990 recognised the well-established value of the forest for recreation purposes and a visitor centre was opened in 1992. Thetford is a good example of multiple purpose forest management which means that operational plans also have to be multiple purpose. Increasingly forest managers have to plan for all the varied activities that take place in the working forest and conflicts, where they exist, must be recognised and accommodated in the implementation of plans.

Full-time professional staff are employed on the development of public recreation in the Forest District Park. A forest recreation strategy now incorporated in the Forest District Recreation Plan was written by the Recreation Manager, and a wide range of publications, including a map showing recreation facilities, are available. Around 200 specialist events including orienteering, horse riding, carriage driving, car rallies, cycling and motor cycling take place each year. Husky dog racing/training takes place every year and nearly 300 permits are issued for the activities outlined above.

A sport-free (game shooting) area has been established within the forest in an attempt to avoid the conflict between shooting and public recreational use, but naturally there remains a potential conflict between the need to control deer populations and public use of the forest. These conflicts are resolved in the main by good liaison and co-operation between the different interests, the importance of which cannot be overstressed. A good example is the liaison and consultation which takes place with the members of the Thetford Forest District Conservation Group and the Environment Panel.

There are plans for increased community involvement, where this is appropriate, in the management of woods within the Forest District. This has worked well elsewhere and has resulted in mutual benefits to the local community and the Forestry Commission.

Costs and benefits

Clearly there are significant costs to the Forestry Commission in respect of forest recreation activities, conservation measures and revenue losses, for example the sport-free areas, but equally there are also significant benefits. Following studies carried out by Dr Benson and Dr Willis of Newcastle University (Benson and Willis, 1989), the Forestry Commission Development Division has suggested that £2 per visitor is a reasonable figure to value the non-market benefits of recreational use of the forest. The Treasury have agreed £1. Applying this to an estimated 1 to 1.5 million visitors to Thetford and adding it to the surplus of income over expenditure for the forest in 1991, for example, resulted in a net forest surplus of around 4.5 million pounds.

The working forest

The annual Thetford Forest District harvesting programme is around 200 000 m^3, which is the second largest in the Forestry Commission, and approximately 350 ha are restocked each year.

Over the last 3 years mechanised harvesting systems, which now account for 70% of the annual harvesting programme, have been introduced and developed. This change has not had adverse effects on the ecology of the forest; it has required, like any other harvesting system, careful planning to take full account of all environmental considerations. Thetford is the only forest in the country which has a fully mechanised restocking system and this, combined with the mechanisation of harvesting, makes it the most highly mechanised Forest Enterprise forest.

The compilation of Forest Design Plans for the forest has taken full account of the Forest Enterprise commitment for multipurpose forestry and established the pattern for the long-term operational management of the forest.

The future will see increased pressures on Thetford Forest from all of its users. We welcome the increasing public involvement in our forests and the challenge to demonstrate that this forest can remain highly productive, profitable and a successful example of what a multiple purpose forest should be. By good liaison, tolerance and co-operation with and between the forest users and careful planning and management by forest staff, the unique ecosystem of Thetford Forest Park will improve as it evolves.

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Chapter 18

Thetford Forest Park symposium: a summary

Philip Ratcliffe and Stephen Harris

One of the largest lowland forests to be planted since the establishment of the Forestry Commission was Thetford Forest, which covered 25% of the Brecklands. Of the rest, about 70 km^2 (7.4%) is heathland, and the remainder is covered by arable land and other developments. The Breckland area is an anthropogenic heath developed in Neolithic times by the clearance of woodland and scrub. From 3000 BC until the early part of this century was a period of exploitative use and continuous resource impoverishment, and it was not until the 18th century that the Brecks grew trees again in any numbers. In the 1870s, farming in Britain fell into a serious depression which lasted into the 1930s, and the consequences were particularly devastating on agriculturally marginal land such as the Brecks. As a consequence, many estates were offered to the fledgling Forestry Commission and more land was available than the Commission had funds to buy.

Planting of the Breckland Forest began in 1922 and the first rotation was completed in 1950. Of the 23 000 ha acquired by the Forestry Commission, about 18 000 ha were planted, the rest being farms, forest workers' holdings, nurseries, etc. The main crop species originally used was Scots pine but more recently this has been changed to Corsican pine, which has a greater growth potential and is more resistant to disease.

These first plantings have now reached the end of their first rotation and many are being clear felled and replanted. Thetford Forest now produces 200 000 m^3 of wood a year largely for the building industry and this gives an income of about £4 million with a positive cash flow of well over £1 million per annum. This production level will continue for the next 20 years. In addition, there are 1 million day visits a year to the forest, which has great amenity value, and holiday developments in the area are likely to increase visitor pressure. The importance of Thetford Forest as a multi-use forest was recognised by granting it Forest Park status in 1990.

The first plantings were very much a pioneer exercise and while the Forestry Commission created a new ecosystem on the Brecklands, their original objectives gave little thought to the conservation or amenity value of the forest. The onset of the second rotation provides an opportunity to manipulate the ecosystem to increase its diversity, and particularly to enhance its conservation and recreational value. The latter potential is great; if the recreational value is estimated to be about £1 per person per day, a very modest estimate, then the amenity value of the forest already equals the cash flow generated by the timber crop. The conservation value is impossible to quantify in cash terms, but is substantial, since the Brecklands is the home of many rare and endangered species.

John Morton Boyd, former Forestry Commission Conservation Consultant, has described Thetford Forest as a kaleidoscope of change, into which new form and diversity can be added by reducing the size of planting coups, randomising the positions of plantings, increasing the area of open space and broadleaved plantings and returning some plantings to senescence for the benefit of their epifauna and epiflora. Many of these aims were already recognised by the Forestry Commission when they compiled the *Thetford Forest management plan – a conservation review*. This plan was published in 1985 and is currently being updated but already 5% of the forest (900 ha) is to be retained well beyond its rotation age, and 550 ha have not been assigned a felling age; some will last to their biological age. In addition, there are 125 km of conservation rides, approximately 1 km per 175 ha. For these, there are over 50 different management prescriptions.

Originally the Brecks was a very disturbed habitat, and much of the endemic flora associated with the Brecklands consists of species of ephemeral habitats. The rabbit population was important in maintaining this disturbed habitat and, since they grazed close to the ground level, they maintained the impoverished nature of the soil. John Sheail and Mark Bailey showed that at their peak about 6000 ha (6%) of the Brecklands was occupied by rabbit warrens, although it was not until the 18th century when the destruction of the commercial warrens and the increase in game preservation and consequent predator removal enabled rabbits to survive in the feral state. It was this failure to prevent rabbits spreading from their warrens that significantly reduced the scope of farmers to change to other forms of land use and helped contribute to the agricultural depression at the turn of the century that paved the way for the Forestry Commission to acquire some of the cheap land that was available. To plant the new forests, the Forestry Commission had to fence the area against rabbits.

However, the management of the forest was not so intense as for the surrounding arable land, so the forest area acted as a refuge for a number of Breckland plants and plant associations. Although some stable areas need to be created for less mobile or less adaptable plants, the majority of species can survive the periodic upheaval of clear felling. In fact, since most of the plants thrive on disturbed land unlike many other conifer forests, the management problem is not ensuring that the native flora survives clear felling but that the soil seed bank can survive 50 years of closed canopy. To achieve this, the rides can be managed in a similar manner to the old Brecks; annual cutting and removal of the cut vegetation, with occasional rotavation, will help the survival of Breckland flowers. However, although species can survive in the forest, possibly better than on the more intensively managed areas of the Brecks, the original plant communities cannot do so without the creation and management of open areas within the forest.

Disturbance, largely by rabbits, helped support a rich lichen flora which has a continental element, as do the flowering plants. The lichens include a number of species rare or absent elsewhere in the British Isles. However, Chris Hitch and Peter Lambley reported that in recent years there has been a marked decline in the quality of the Breckland lichen communities, with those on calcareous soils worst affected. Many of the grasslands have become rank following the cessation of grazing; this has also encouraged the spread of pine seedlings from adjacent plantations, and these have altered the microclimate. However, declines have occurred in areas where pine invasion is not a problem and it may be that the two-fold increase in nitrate levels in rainfall is a causal factor. While the removal of pine seedlings and the reinstatement of grazing may partly restore the habitats for lichens, pollution may still cause the gradual loss of species from the Breckland flora.

Many species of animal are also dependent on the disturbed habitats in the Brecklands. The Brecks held significant populations of stone curlew, nightjar and woodlark. The stone curlew suffered as a result of habitat loss with the planting of Thetford Forest and the same probably applies to the woodlark and the nightjars, which are characteristic species of heathland. The little heathland that persists on the Brecks is undergrazed and no longer provides suitable habitat for the woodlark; however young conifer plantations with a mosaic of open ground and tussocky vegetation fulfil this requirement. Rhys Green showed that the Thetford Forest population of woodlarks has risen to 83 pairs out of a British population of only just over 200 pairs. With careful management, the nightjar population in the forest has also risen, from 160 pairs in 1981 to over 300 pairs in 1990, compared to very few on the surrounding Brecks. These successes have been due to the continuing availability of suitable habitat. However, the amount of young plantations available is predicted to decline early in the next century, and this is likely to lead to a decline in both woodlarks and nightjars. In order to avoid this, management strategies are under consideration which involve rotation plantings and winter ploughing between tree rows to maintain the amount of open ground.

In Britain, there are 466 species of aculeate (stinging) wasps and bees and they are the most seriously declining groups of insects; 5% are already extinct and 28% are in the Red Data Book. Seventy per cent are ground nesters; a third of these will only use sand and many of the rest prefer or will use sand. Generally, they also prefer open ground. Not surprisingly, the

Brecklands are particularly important for aculeates. In one 700 m length of sandy path in Thetford Forest, Jeremy Field collected 40% of the British aculeate fauna in one summer ; he found that about 25% of the species found pre-afforestation have not been recorded since, with 36% of aerial nesters being lost compared with only 16% of ground nesters. Clearly, forestry management practices have been partly responsible but much can be done to improve the situation, particularly by leaving dead wood *in situ* at the forest edge and by providing wide rides and paths.

While we have little long-term data on the changes in the hymenopterans, since they have not been extensively studied, the lepidopteran fauna of the area was well known by the end of the last century, and so the effects of afforestation on the butterflies and moths is better known. Some species with specialised food requirements have been lost from the Brecks generally since their specialist food plants have become very rare. However, the secondary habitat provided by the plantations has encouraged a multitude of common species of undemanding life cycle. These species exploit the ruderal ground plants, broadleaved shrubs and trees that have moved into the Scots pine crops and some areas now have particularly abundant butterfly faunas. However, Scots pine is a light-crowned species on the Brecks, thereby allowing the establishment of a rich ground flora. The Corsican pines now being planted have denser crowns and the more complete establishment of the tree crop restricts the ground flora and hence is likely to reduce the numbers of butterflies and moths. To help maintain the number of butterflies and moths in the forests, Gerry Haggett and Mike Hall stressed the need for creating calcareous heath reserves within the Forest Park, the widening of rides, particularly on calcareous and heather sites, the creation and enlargement of open spaces and the maintenance of Scots pine on as many sites as possible.

Scots pine is also favoured by both crossbills and red squirrels. The latter is the symbol of the Forest Park but is in need of urgent conservation if it is to survive here. Grey squirrels first colonised the forest between 1968 and 1974, a process that was completed by 1985. The effects of grey squirrels on reds in Britain has been widely documented and resource competition seems to be the major factor leading to the replacement of reds by greys. Grey squirrels have a considerable competitive advantage over reds in broadleaved forests where they can exploit the nut crops more effectively. To maintain red squirrels in Thetford a large area (about 20 km^2) free of large-seeded broadleaved trees is needed, with most of the crop being Scots pine. This species is favoured by red squirrels and it seeds more regularly. Some crops must be retained past their felling age. As explained by John Gurnell, the financial implications for such a plan could be very high but such action in forests such as Thetford, Cannock and some of those in Wales, will be important in helping to conserve the red squirrel outside Scotland.

Thetford Forest supports a wide range of mammalian herbivores. Most abundant are roe deer, which were reintroduced to the area at the end of the last century and subsequently spread throughout the young forest. However, the roe deer do not perform particularly well on the impoverished Breckland soils. Compared to other areas, they are small and the intrauterine loss of embryos is twice that seen in most roe populations. In contrast, the red deer do very well. They are the descendants of escaped carted deer; the stags are some of the biggest in Britain, and of comparable size to the best animals in continental Europe. Phil Ratcliffe attributed this difference to the roe being sedentary in large blocks of conifers where they cannot exploit the best habitats, while the red deer are very mobile, ranging over large areas, and presumably thereby exploiting a variety of good habitats. The same may apply to the fallow deer; originally the descendants of escaped park deer, they were confined to the southern block but they are now increasing in numbers and spreading throughout the forest. While muntjac are also spreading, they are less mobile and are largely confined to the calcareous areas where the ground flora is richest.

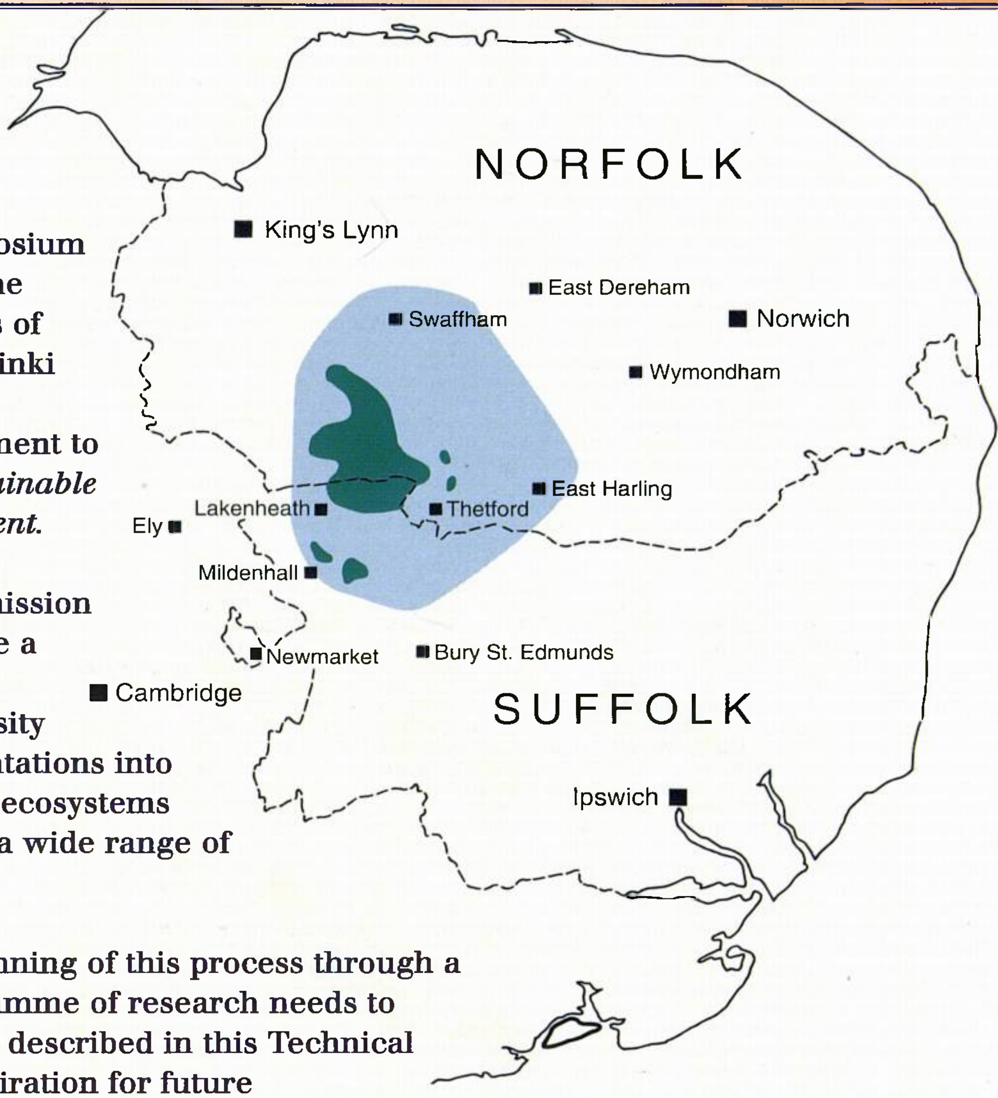
The other species of large herbivore present is the brown hare. This is perhaps surprising since hares are usually associated with agricultural land. However, the densities of hares recorded in one part of Thetford Forest equal those in some of the best agricultural habitats. Other conifer forests in Britain have also reported an increase in hare numbers over the last 20 years or so; on agricultural land hare numbers have been declining over the same period. Niche partitioning between the various species of herbivores is especially important in helping to understand the likely population changes as the forest enters its next rotation and the impact of the various species of herbivore on the management of the forest.

The creation of a large conifer forest in such an ecologically important area as the Brecklands has generated a great deal of controversy. While the full impact of afforestation on the Breckland ecosystem will be difficult to evaluate, the symposium on Thetford Forest Park has shown that there are many positive aspects. Had the forest not been planted it is likely that much of the land would have been brought back into agricultural use, and the heavily managed farmland surrounding the forest is of little value as a habitat for many of the endangered species that survive and even prosper in the forest. The presence of afforestation has also been beneficial to the River Little Ouse which runs through Thetford Forest. Peter Barham showed that had the land been used for agriculture the river would have been much improved and the river flow and the ground water levels reduced as a consequence of irrigation for vegetable crops. Instead, about 10 km of the river looks much as it did hundreds of years ago and, since the Forestry Commission maintains pasture rather than forest near to the river, there is a buffer zone that neutralises any acid water draining from the forest so that the river pH is unaffected by the forest. As far as East Anglian rivers go, the Little Ouse is very diverse and has great potential for further management to exploit its conservation value to the full.

Many of the studies started in Thetford Forest were autecological studies and the result of personal interest rather than a desire to understand how the forest should be best managed as an important ecosystem in its own right. While these specialist studies have helped forest managers, they have caused some confusion by producing a wide range of *ad hoc* management procedures geared to the requirements of individual species or species groups. Phil Ratcliffe stressed the need for a more holistic view in planning research programmes based upon the sustainable delivery of agreed outputs.

The management of Thetford Forest is a complex task that must be viewed in the context of the management of the Brecklands as a whole. Since the balance between forestry, heathland and arable land is unlikely to be changed in the near future, the principle aims of conservationists must be to manage the resources that are available to the best effect. In *New Scientist* (12 January 1991), Paul Dolman and Bill Sutherland argued that 'it should be possible to restore Breckland to its former glory'. However, John Barkham argued that this area of recently man-made drifting sands is the nearest we will see to desertification in this country. Phil Ratcliffe agreed that this was just one temporal stage in a continuum of change on the Brecklands during the past 3000 years. John Barkham argued that we need a much broader management aim for Breckland, reinstating a variety of the former habitats seen in the area. The presence of Thetford Forest Park has been important in adding to the diversity of habitats available on the Brecks, and in acting as a refuge for a number of nationally rare species. It clearly has an important role to play in future nature conservation plans for the Brecks, and a range of opportunities are now available to the Forestry Commission to maximise the benefits of creating a unique ecosystem. As John Morton Boyd concluded at the meeting, while the flow country became a *cause célèbre* between forestry and nature conservation, which is still having repercussions, it undoubtedly also produced a watershed from which *rapprochement* will follow. Thetford Forest is a very good example of forestry and conservation working together.

The Thetford Symposium in 1991 pre-dated the international events of Rio (1992) and Helsinki (1993), which gave powerful reinforcement to the concept of *Sustainable Resource Management.*



The Forestry Commission is continuing to take a leading role in enhancing biodiversity and converting plantations into mature sustainable ecosystems capable of yielding a wide range of public benefits.

The sound underpinning of this process through a co-ordinated programme of research needs to continue. The work described in this Technical Paper provides inspiration for future managers and researchers.

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