Securing Biodiversity in Breckland

Guidance for conservation and research

First Report of the Breckland Biodiversity Audit

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Front cover: The Mining Bee *Andrena hattorfiana* (RDB: Rare) is one of many rare and declining species recorded in Breckland. It is thought to depend on Scabious, as shown here, and the pink pollen collected is stored in the pollen baskets on the legs. Therefore, it requires longer flower-rich ungrazed areas of only occasionally disturbed vegetation, but also requires open, bare or sparsely vegetated ground. Photographed near the river Wissey in STANTA © Nick Owens

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Executive Summary

An innovative approach to evidence based conservation
The Breckland Biodiversity Audit (BBA) has developed an innovative, landscape-scale and evidence-based approach to strategic delivery of biodiversity. It provides a working example of the implementation of an integrated approach to biodiversity delivery in a region. The BBA is founded on a broad partnership of stakeholders, and harnessed the expertise, knowledge and recording effort of very large numbers of amateur naturalists, without whom this project would not have been possible. Their collective endeavours provide a working example of civil society in biodiversity delivery.

- The BBA identified priority species for conservation in Breckland, including large numbers of BAP, RDB and range-restricted species.
- A key element has been to develop an evidence-based approach to understanding the requirements of these priority species and providing guidelines for their conservation.
- Ecological requirements of priority species for conservation in Breckland have been collated, and synthesised, integrating across numerous individual priority species to produce management guidance for multi-species assemblages.

Biological recording in Breckland
The BBA collated and examined over 800,000 species records, but highlighted a lack of integration into the planning system among national, regional and taxonomically based recording schemes.

As well as relatively well-known groups such as vascular plants, moths and carabids information was also collated for araneae, diptera, hemiptera, hymenoptera, molluscs, lichens and fungi and other groups.

Mapped recording effort at a 1km x 1km scale showed:
- Designated heathland and pingo sites are well covered.
- Distribution data in and across arable and forested landscapes are patchy and taxonomically biased, and further survey is needed in these areas.

Breckland is of major importance to biodiversity within the UK

The BBA has demonstrated the outstanding importance of Breckland for UK biodiversity. We have established that:
- At least **12,845** species have been recorded from Breckland.
- Of these, **2,149** are priority species for conservation in Breckland, many more than previously realised.
- **28**% of all the priority BAP species in the UK occur in Breckland.
- 72 species have their UK distribution restricted to or have a primary stronghold in Breckland. Although Breckland has long been recognised for its distinctive biodiversity, this is the first time that the number of regional specialist species has been quantified.

There have been worrying extinctions and recent declines in some priority species
Remaining habitat is fragmented, species are isolated in small sites, and the landscape is hostile to dispersal among these. Climate is demonstrated as already changing, with a loss of continentality,

milder winters and increased winter rainfall in recent decades. Nitrogen deposition is a severe threat, semi-natural habitats have received 1-2 tonnes of Nitrogen per ha over the last century.

- 15 species previously recorded in Breckland are believed to be extinct in the UK or England
- The BBA collated recent records for 10 other species considered to be extinct nationally, giving hope that these may survive in Breckland. These now need urgent survey to confirm their status.
- A further 25 species are thought to have been lost from the region (locally extirpated) although they persist elsewhere in the UK.
- For seven well monitored vascular plant taxa restricted to Breckland, more than half of the populations (54%) have been lost (since 1985).

The ecological requirements of priority biodiversity

- The BBA analysed the ecological requirements of the 2,000+ priority species for conservation in Breckland to provide management guidance for their conservation.
- The BBA has confirmed the importance of intensively grazed and physically disturbed habitats, as previously recognised.
- However, more priority species for conservation in Breckland depend on physically disturbed conditions in an ungrazed (or only lightly-grazed) context. These should be primarily conserved on farmland, on brown field sites, in the forest landscape and in large extensive heathland complexes. Species of physically disturbed and ungrazed conditions were significantly more likely to be considered extinct, than other priority species.
- Approaches to management have been too homogenous. Many species require structural complexity, including mosaics of different sward structure, juxtaposition of bare disturbed soil with intact swards, juxtaposition of grazed and ungrazed elements, or patches of scattered scrub in open habitats.
- Rare species of woodland, veteran trees and dead wood also occur in Breckland.
- Open standing water, littoral margins and open fen habitats are vitally important to Breckland biodiversity and support many more priority species than shaded wetland habitats (e.g. damp/wet woodland). Different priority species were associated with grazed and ungrazed fen conditions and a range of vegetation structures is required.

The effectiveness of BAP species as figureheads to deliver wider benefits for priority biodiversity

A large proportion of the guilds were represented by one or more figurehead priority BAP species. Overall, a series of habitat based prescriptions constructed on the basis of understanding the requirements of BAP species would provide conditions for the majority of priority species. However, there are notable exceptions, with a few specialist groups of species poorly represented by BAP figurehead species, particularly wetland species associated with deadwood or detritus, and dry terrestrial species associated with deadwood in open woodland or scrub mosaics.
The extent to which the known distribution of BAP species represents site priorities for their representative guilds requires investigation, but is likely to be congruent.

Current conservation management is not sufficient to support priority biodiversity

Recently fallowed brecks have been virtually entirely absent from the Breckland landscape for the last sixty years. The resource of early successional breck vegetation has aged, accumulating organic matter, nutrients and favouring closed sward vegetation.

Of the grass-heath resource for which we obtained information, 43% of the sheep grazed area was managed by low intensity grazing, 70% of the area extent had no or few rabbits and disturbance treatments covered less than 1% of the grass-heath extent. This is not compatible with conserving the priority assemblages that depend on this resource. Approaches to management should be revised, and best practice followed.

Recommendations for management of dry terrestrial habitats

- Large numbers of priority species require heavy and intense grazing, this should be implemented across large parts of most heathland sites.
- Presence of heather (*Calluna vulgaris*) should not be an obstacle to heavy grazing as retention of mature heather should not be an objective of management for priority species.
- Physical disturbance should be applied to a substantial part of all terrestrial sites to provide conditions required by large numbers of priority species.
- Physical disturbance is a key tool in mitigating deleterious effects of nitrogen deposition and eutrophication.
- Heterogeneity, with areas of lighter grazing, structurally diverse swards, and the juxtaposition of ungrazed elements (including ploughed or cultivated ungrazed margins within or alongside heath sites) all provide for additional species assemblages.
- Management should not be approached with the hope of keeping things from changing, rather management should be dynamic, episodic and disruptive as gradual recovery from grazing or disturbance provides conditions and structures not found on homogenously managed sites.
- Important assemblages that require physically disturbed ungrazed vegetation, including bare ground and ruderal plant communities, are best supported on arable field margins, through cultivated margin prescriptions, in the forest landscape, along lightly grazed margins of large grazed heathlands, or in brown-field sites.
- Large lightly grazed heathlands provide opportunities for recreation of breck arable and ruderal habitats through mechanical disturbance and cultivation.
- Brown field sites require mechanical management to create exposures of bare sand, gravel and chalk.
- Areas of uncertainty and recommendations for further research and survey identified.

Recommendations for management of wetlands: fen, pingos and meres

- Scrub and woodland should be largely removed from fen and wetland sites.
- A range of grazed and tall vegetation structures should be created.
- On large wetland complexes this may be achieved by flexible extensive grazing, while on smaller or wooded sites mechanical management may be required.

Strategic recommendations

Sites should no longer be considered in isolation, but management priorities should be considered that strategically integrate across multiple sites in the landscape.
Adjacent sites should be combined into larger contiguous integrated units.
Biodiversity resilience of sites will be enhanced by developing connectivity networks that are best achieved by:

- Buffering existing track-ways and track verges with cultivated margins through agri-environmental agreements in the arable landscape.

- Creating broad ruderal and disturbed highways for invertebrate and plant dispersal (by percolation) through the forest landscape.

The Challenges
Strategic challenges are identified, including

- The need to review the notified interest features for Sites of Special Scientific Interest.
- The need to revise condition assessment criteria for Common Standards Monitoring.
- Challenges in accepting uncertainty in management outcomes.
- The importance of agri-environment schemes in supporting key biodiversity in the arable landscape.
- Opportunities in the forested landscape.

Please provide feedback to help further develop this work:
This project is the first phase of an ongoing and live partnership, building resilient human networks and expertise. Throughout the BBA we have drawn on the best available evidence that we could collate. However, we recognise that understanding remains incomplete. Mapped distributions certainly have omissions. Broad assemblages are robust, but assignment of individual species to assemblages is provisional in some cases, as our understanding of the requirements of many species is currently incomplete.

We hope that through the publication of this report we can encourage more recorders and natural historians with knowledge that could benefit Breckland's biodiversity, to come forward and share their insights, so that the partnership can improve the growing body of evidence and knowledge on which effective conservation can be built.

Glossary

Acronyms

BBA: Breckland Biodiversity Audit
CPERC: Cambridgeshire & Peterborough Environmental Records Centre
FC: Forestry Commission
NNR: National Nature Reserve
NBIS: Norfolk Biodiversity Information Service
NBN: National Biodiversity Network
NCA: National Character Area
NE*:* Natural England
NWT: Norfolk Wildlife Trust
SAC: Special Areas of Conservation
SBRC: Suffolk Biological Records Centre
SPA: Special Protection Areas
SSSI: Site of Special Scientific Interest
SWT: Suffolk Wildlife Trust
UEA: University of East Anglia

Aestivation: hibernation or diapause during a hostile season (e.g. during cold winter or dry summer).
Assemblage: a collection of separate species that may co-occur.
Community: in plant ecology, attempts have been made to classify the underlying continuous variation of plant assemblages, that vary along complex ecological gradients (e.g. of nutrients, soil pH, grazing intensity, and climate) into distinct 'communities'. This can be a useful tool, but communities do not exist as clear entities, and local representations of a particular community will be idiosyncratic and varied.
Benthos: organisms living on or within the sediment of aquatic habitats.
Guild: different species that share common functional attributes in terms of life history, foraging or feeding strategy or habitat requirements.
Inquiline: is an animal that lives commensally in the nest, burrow, or dwelling place of an animal of another species. These are not parasites, because parasites are defined as having a deleterious effect on the host species, while inquilines do not.
Mere: a groundwater fed waterbody with a fluctuating water level due to a semi permeable base and lagged response to seasonal fluctuation in the underlying water table.
Periglacial: processes involving intense frost or permafrost in regions adjacent to ice sheets.
Pingo: an isolated pond or pool, often with a rampart of upheaved soil around the perimeter, caused by ice lens formation during periglacial conditions.
Psammophilous: species that has a specialised association with, or requirement for, sandy substrates particularly bare sand and windblown sand.
Rendzina: highly calcareous poorly formed soil formed from raw chalk, marl, limestone or calcareous drift**.**
Solifluction: soil movement, where waterlogged sediment flows slowly down-slope, over impermeable material. It occurs in periglacial environments where melting during the warm season leads to water saturation in the thawed surface material (active layer), that flows down-slope over impermeable deeper frozen (permafrost). When the "flow" is due to frost heave that creates undulating corrugation at right angles to the slope, then solifluction can result in striations or periglacial stripes.

Introduction

"Few of the lowland districts of England have more striking individual characteristics than the area known as Breckland."

W.G. Clarke, 1925

The Breckland Region

Breckland is a bio-geographical region of Eastern England, covering 1,019 km^2. The soils are characteristically sandy, very freely draining and nutrient-poor. The region has low rainfall, in common with much of East Anglia, while the climate is more semi-continental and experiences greater extremes of temperature. Plant and animal species more commonly associated with steppe or Mediterranean regions can be found in Breckland. This combination of drought-prone soil, low rainfall and cold winters has strongly influenced human land-use. As a result, this dynamic anthropogenic landscape has supported a distinctive and unique biodiversity unlike any other part of Britain.

Since the arrival of agriculturalists approximately six thousand years ago, the region has had a dynamic and changing history of land-use. This was historically characterised by large areas of extensively grazed dry vegetation, including grass or heather dominated heath, areas of low intensity agriculture and river valleys and fens. The farming of rabbits in large enclosed warrens from the early Middle Ages and intensifying through the 16^{th}-18^{th} centuries transformed parts of the landscape into mobile dune.

The Breckland region is often regarded as a 'heathland region', so a few words to clarify the various meanings of this term will be helpful. The term 'heath' can refer to a form of land-use, where livestock were grazed (often involving commoners' rights on land owned by an estate) across areas of low productivity vegetation growing on low fertility soils. In this sense, 'heath' is a place name that relates to a form of land-use. The term has been widely used in the classification of plant communities, where it most often relates to dwarf-shrub vegetation that includes Ericoid species (heathers) growing on acidic soils. In this sense, dry lowland heathland developed with grazing management on lowland mineral soils is distinct from either wet heath (in valley or raised mires) or 'moorland' heath, which developed in upland areas on organic soils in areas of higher rainfall. But confusingly, the terms has also been used by ecologists to describe the characteristic low nutrient grazed and disturbed processes that characterise these vegetation types, and thus grasslands lacking heather species but that are droughted, nutrient poor, disturbed and heavily grazed may be referred to as 'grass-heaths'. Throughout this report we refer to grass-heath and heathland interchangeably as describing vegetation, and 'heaths' as describing places in the landscape.

Since the scientific enquiry into natural history began, Breckland has long been recognised amongst entomologists and botanists as a place where distinctive biodiversity could be found. Early natural historians catalogued a range of distinct species that appeared to be restricted to this unusual region, and were rarely or never encountered elsewhere in Britain. Collectors and natural historians explored the warrens, heaths, track-ways and fallow arable fields of the region, making important discoveries. But the importance of this wide range of shifting and dynamic landscape elements

seems to have become lost from the consciousness of modern conservationists. More recently Breckland has been regarded as one of England's 'lowland heathland regions' (e.g. an area still supporting concentrations of lowland heathland, among a suite of regions that includes Dorset, the New Forest, the Weald, Surrey and Hampshire, and the Suffolk Sandlings). This perception of Breckland as a heathland region has permeated through priorities, objectives and approaches to conservation implementation. This has been further reinforced by designation of some internationally important features classified as 'heathland' due to the presence of heather *Calluna vulgaris* within the community, and this has not always led to management that is appropriate for the conservation of priority biodiversity.

Breckland was first named by W.G. Clarke, after the profusion of fallow 'brecks' (intakes from heathland that were converted to unintensive arable, often with long fallow rotations) that dominated much of the landscape in the late 1800s and early 1900s after the virtual abandonment of cereal farming. W. G. Clarke began describing the region's natural history, archaeology and landscape, in his contributions to the Transactions of the Norfolk and Norwich Naturalists Society, culminating in 1925 with his book "In Breckland Wilds". Clarke's account has become a defining vision of what Breckland once was – a landscape of rabbits, warrens, sand-dune and shingle, grazed heath and abandoned fields. However, it is important to recognise that the landscape Clarke described in 1890-1925 was just one snapshot-in-time, of a landscape undergoing a particular major transition, within a much longer history of upheaval and dynamic land-use change. Some aspects of this are explored in the section below.

Dynamic Changes in Breckland

The rapid arrival of warm, dry conditions after the last ice age, allowed raw chalk and sandy soils to be colonised by Mediterranean and steppe species. Although forest cover then developed, the combination of immature mineral soils, drought and large numbers of red deer *Cervus elaphus* along the fen margin (as indicated by archaeological remains) suggests forest cover in Breckland may have been fairly open. Breckland was settled and cleared by arriving farmers during the Neolithic, c. 6,000 years ago, and still retains post-glacial species requiring open conditions that have disappeared from most of lowland Britain. Subsequent forest clearance, shifting cultivation and stock grazing created more open habitats. A pattern of cereal cultivation and grazing continued through the Bronze Age, Iron Age and Romano-British periods, and after Saxon Estates were subsumed and redistributed by the arriving Normans, continued in varying forms until the late 1800s. In general, cereal cultivation was more prevalent in river valleys, with grazed commons and heaths on the drier plateaus and interfluves. However, all aspects of the land use were dynamic, and there have been changes and upheavals through time.

The type and intensity of domestic grazing have changed greatly through the centuries and in recent times. The mixed livestock flocks and herds that grazed during the Neolithic, Bronze Age, Iron Age and Romano-British periods included more cattle than in later periods, when the Medieval economy increasingly focused on sheep and wool production. Cattle would have imposed a different type of grazing to sheep. Sheep grazing declined from the 17th century (Postgate 1962). For example approximately 2,200 sheep grazed Lakenheath Warren in the 13th century; by the late 1940s only 600 occasionally grazed and these were withdrawn in 1956 (Crompton and Sheail 1975). Sheep flocks were already largely absent from the landscape later described by Clarke.

Inland Dunes

The 1km wide dune and blow-out at Lakenheath Warren, described by Alex Watt, was levelled during WWII.

A small fragment of this dune system remains at Wangford Warren, and other fixed dunes survive at Icklingham Plains and Foxhole Heath.

There is little mobile wind-blown accumulating sand in remaining systems, that are now fixed dune (lichen dune, grass swards or sand sedge *Carex arenaria* dominated vegetation).

Sheep and other livestock kept the nutrient status of heathlands low. Cropping of hides, milk, wool and dung transfer relocated nutrients in the system (Dean et al. 1975). Overnight folding of large sheep flocks onto arable land allowed their dung to fertilise the poorer soils increasing crop yields. The nutrients transferred from the sandy heaths to the arable were crucial to sustaining the fertility of cropped land (Newman 2002). Sheep were selectively bred to hold their dung until folded at night (Smith 1980). This practice depleted grass-heath soils and maintained the low nutrient conditions required by the heathland assemblages now valued so highly. Sheep herds were driven to-and-fro along track-ways; this would have dispersed plant seeds and propagules around the landscape.

Although rabbits may have been kept locally by the Romans, they presumably died out in early post-Roman times (Williamson 2007). Following their introduction to the UK by the Normans, rabbits were restricted to warrens (essentially enclosed rabbit farms) managed across increasingly large parts of the sandy uplands of Breckland from the 13th century through the middle and late medieval periods (Sheail 1971; Bailey 1988). It was only after the rise of game and sporting estates, which ruthlessly controlled predators that rabbits could spread and proliferate across the wider landscape (Sheail 1971); the ubiquitous distribution of rabbits described by Clarke was not representative of most of Breckland's history. It is also important to realise that the high densities of rabbits that so impressed early ecologists such as Ernest Farrow (Farrow 1915; 1917a; 1917b) and Alex Watt (Watt, 1936; 1937; 1938; 1940) were just a fraction of earlier intense levels of rabbit activity that would not be conceivable to modern ecologists (Crompton and Sheail 1975). For example, during 1855-1862 an average of 28,886 rabbits were harvested annually from Thetford Warren, at a sustainable cropping rate of 24 ha^{-1} yr^{-1} (Sheail 1972).

Cereal cultivation and fallows were key to Breckland

The Medieval open-field system and fold-course rotation produced large areas of fallow arable every year, ideal for populations of Breckland plants and insects that need disturbed ground and open conditions. It is likely that many species that are now rare and threatened in the modern landscape were once common in the cereal and fallow fields, rather than on the heath. Sheep were folded on uncropped fallows to improve the soil and after harvest were also folded on the rye and barley stubbles. Fallows were an intimate part of the open field rotation that included more frequently cropped infields, less intensively managed out-fields cultivated at intervals following long fallow periods (Postgate 1962; Bailey 1989) and later a third element, the 'brecks'. Brecks were intakes of heathland converted to arable and cultivated for a few years before being left fallow for a long period (Postgate 1973). Weedy fallows were widespread, for example in 1616, nearly two-thirds of the arable land of Elveden was cultivated, while at Wangford in 1625, outfields were cultivated only one year in three (Postgate 1962). The extent of cultivation versus fallow varied in response to economic demand.

The pattern of cereal cultivation and grazed heath has been dynamic, with episodes of increase and then decline. There have been losses and gains in the relative areas of cultivated cereal, biodiversity-rich fallows and grazed heath.

- At Grimes Graves and West Stow episodes of cultivation were followed by periods of abandonment, suggesting the location of Bronze Age and early Saxon farmsteads shifted location in the landscape, providing heterogeneity and variability.

- Following the Black Death of the mid 1300s, there is evidence that some arable was abandoned to heath (Bailey 1989).
- When grain prices collapsed in the 15th century as much as 70% of the demense arable could lie uncultivated in any one year (Bailey 1989).
- During the 17th to 19th centuries at Icklingham, the relative locations of frequently cultivated in-field and infrequently cultivated out-field at Icklingham shifted and changed (Postgate (1962).
- Brecks (ploughing of heathland for temporary fields) occurred during the 16th century, with references to 'breakes' 'breches' and 'brakes' (Postgate 1962).
- During the 18th and early 19th centuries, increased corn prices (e.g. during the Napoleonic Wars) led to widespread heathland reclamation and large areas of 'brake land' (Postgate 1973). However it is unlikely that these brecks were ploughed more often than once in ten years (Postgate 1973), suggesting a large increase in low nutrient fallows and broken ground.
- Sheail (1979) described 'shifting cultivation' in the 17th to 19th centuries whereby areas of heath were broken up and cultivated, offset by reversion of exhausted arable into the warren.

However, the common perception that all heathland in Breckland had experienced episodes of arable cultivation and was subject to 'shifting cultivation' throughout history is incorrect. The brecks and intakes of the 18th and 19th centuries were a more recent phenomena compared to the relative stability of heaths through the Middle Ages (Postgate 1962; 1973). According to Postgate (1962), little reclamation of heathland occurred in Breckland during the Middle Ages because of the opposition to "plowing the lords hethe '' that prevailed under manorial custom. Some Medieval heaths remained uncultivated up to the enclosures of the 1800s (Bailey 1989). Thus, although much of the existing grass-heath resource was created from brecks abandoned in the late 19th or early 20th century (e.g. Thetford Heath, much of STANTA), some parts of surviving heaths may be ancient and may not have been ploughed for at least 800 years.

The process of enclosure occurred more slowly and later in Breckland than elsewhere in East Anglia. Agricultural improvement then accelerated in the 18th and 19th centuries, peaking during 1800-1820, with enclosures, breaking up of ancient heaths, marling and soil improvement and conversion to arable on an unprecedented scale. The overall area of grass-heath declined from over two-thirds in the late 1600s, to approximately 30% by the 1830s (Sheail 1979). As part of the drive to crop the windswept mobile sands, charismatic pine shelter belts were planted during 1815-20 that still give the region a distinctive character.

However, results were patchy and some arable was abandoned from the early 1820s with the onset of agricultural recession, which further intensified through the later 19th and early 20th centuries with the collapse of grain and wool prices. From the late 19th century to the early 1900s, large areas of former arable, including recent intakes, were abandoned creating sandy fallow brecks, while rabbit farming or sporting becoming the main land-uses (Sheail 1979).

Between 1900 and 1934:

- the overall area of grass-heath and heath increased from 28,932 ha 31,922 ha.

However, the net increase of 2,990 ha masks even greater dynamic change during 1900-34:

- 7,872 ha of heath was lost to arable and afforestation.
- 10,862 ha of grass-heath were created from arable reversion (Farrell 1993).

Crucially, the economic depression that provided so many brecks throughout Breckland, also led to the loss of sheep grazing from the remaining heaths and so the landscape described by W.G. Clarke was primarily influenced by rabbits rather than livestock.

Recommendation:

- Further investigation of the long term patterns of land-use between heath and arable, linking land-use archaeology and ecology, will benefit understanding of habitat and species requirements.
- Relating the current and recent past distribution of speciality Breckland vascular plants to historical land-use will provide insights to past ecology.

Recent Landscape and Land-Use Change

The Land Utilisation Survey overseen by Dudley Stamp identified Breckland as an economically marginal region, with low rental values and large areas of fallow arable fields (Stamp 1938). Along with other marginal heathland regions, Breckland was therefore targeted for afforestation by the government. From 1922 heaths and sandy brecks were planted and converted to forest, primarily with pines and other conifers but also with stands of beech *Fagus sylvatica* and belts of other deciduous trees (Skipper and Williamson 1997). Although disrupted by military training during the Second World War, afforestation continued post-war and eventually one quarter of the region was planted. The resulting Thetford Forest is the largest lowland conifer forest in the UK (Eycott et al. 2006).

In parallel with afforestation, large agricultural estates realised that introduction of new rotations (involving lucerne, fodder crops and cattle), combined with newly available machinery, allowed conversion of even the sandiest and most unproductive acidic *Calluna*-dominated heaths to productive agriculture. With the twin pressures of afforestation and arable conversion, the remaining resource of fallow breck and heath rapidly diminished. From the mid-20th century, arable farming intensified. As elsewhere, the use of chemical fertilisers, pesticides, increase in winter sowing and consequent reduction in over-winter stubbles, have had a significant effect on the farmed landscape. However, it is notable that winter stubbles remain more prevalent in Breckland than in regions of clay soils. The development of modern irrigation systems, dependent on groundwater and river abstraction, has allowed the intensive cultivation of an array of high value vegetable and salad crops, whilst outdoor pigs and novel crops such as herbs and even tulips, have also joined the scene. Today, Breckland can be highly productive, with more variable cropping patterns than the adjacent claylands. Other than where agri-environment schemes have maintained specially managed areas, the fallow ‘breck’ has now completely disappeared from the landscape.

The area of grass-heath declined by 76% within the 20th century:

1900: 28,932 ha
1934: 31,922 ha
1950: 9,268 ha
1980: 4,529 ha [1]
1990s: c 7,000 ha [2]

[1] estimated by Farrell (1993)
[2] the Natural England Natural Area Profile estimate of grass-heath extent is 2,471 ha greater, as it also includes more recent reverted arable within STANTA in the estimate of the current resource.

Changes in Fen, Wetland and River Valley habitats

Fens were once extensive along the Breckland/Fenland boundary but have been almost entirely destroyed. Mosaics of species-rich fen meadow and wet grassland survive at Pashford Poors Fen and Lakenheath Poors Fen, for example, but these are small fragments of formerly extensive fen and wet grassland reclaimed prior to the 1940s. Reclamation of further areas on the fen edge occurred with the Great Ouse Flood Protection Scheme post-1950s (Rothera 1989). Remaining sites are detrimentally affected by adjacent drainage and are vulnerable to groundwater abstraction (Rothera 1998).

The spring-fed valley fens have been vulnerable to drainage on adjacent farmland, subsequent drying out and scrub invasion. Abandonment of traditional grazing, and/or cutting of reed, saw sedge and peat fuel during the 20th century led to willow and alder scrub invasion and a loss of wildlife value in remaining Breckland fens (Rothera 1989). Pingos, the relict peri-glacial waterbodies that hold important fen and invertebrate communities, occur at high densities within Breckland (Walmsley 2008), but have suffered loss through agricultural improvement and afforestation. The remaining pingo sites have also been subject to scrubbing up and succession to woodland, with resulting shading and organic mud accumulation from leaf litter as a result of a lack of grazing after the 1940s (Rothera 1998).

The rivers of Breckland and their adjacent wetlands have experienced substantial change and modification. Channel engineering works altered the course and profiles of rivers from the 17th Century through to the 1970s (Rothera 1998). Reclamation for agriculture and subsequent improvements led to a substantial loss of adjacent wetlands, such as wet grassland and fen, especially along the shallower valleys of the Wissey and the Lark (Rothera 1998). However, some river valley wetlands have survived, with concentrations of County Wildlife Sites on the Little Ouse downstream of Brandon and on the Lark near Cavenham, for example. However, these are often much altered, being drier, more fragmented and less species rich than a century ago. W G Clarke described redshank and snipe in nesting wet meadows, but these are now absent from Breckland as breeding species.

As with the spring-fed fens, the abandonment of traditional uses of riverside resources has led to the development of sallow car and wet woodland. The planting of poplar in Thetford Forest along the Little Ouse has altered the character of the riverside fenlands. However, as these plantations are abandoned and decay a rich mix of open fen, carr and standing dead wood is developing. A more intact series of riverside habitats has been preserved along the Wissey in STANTA.

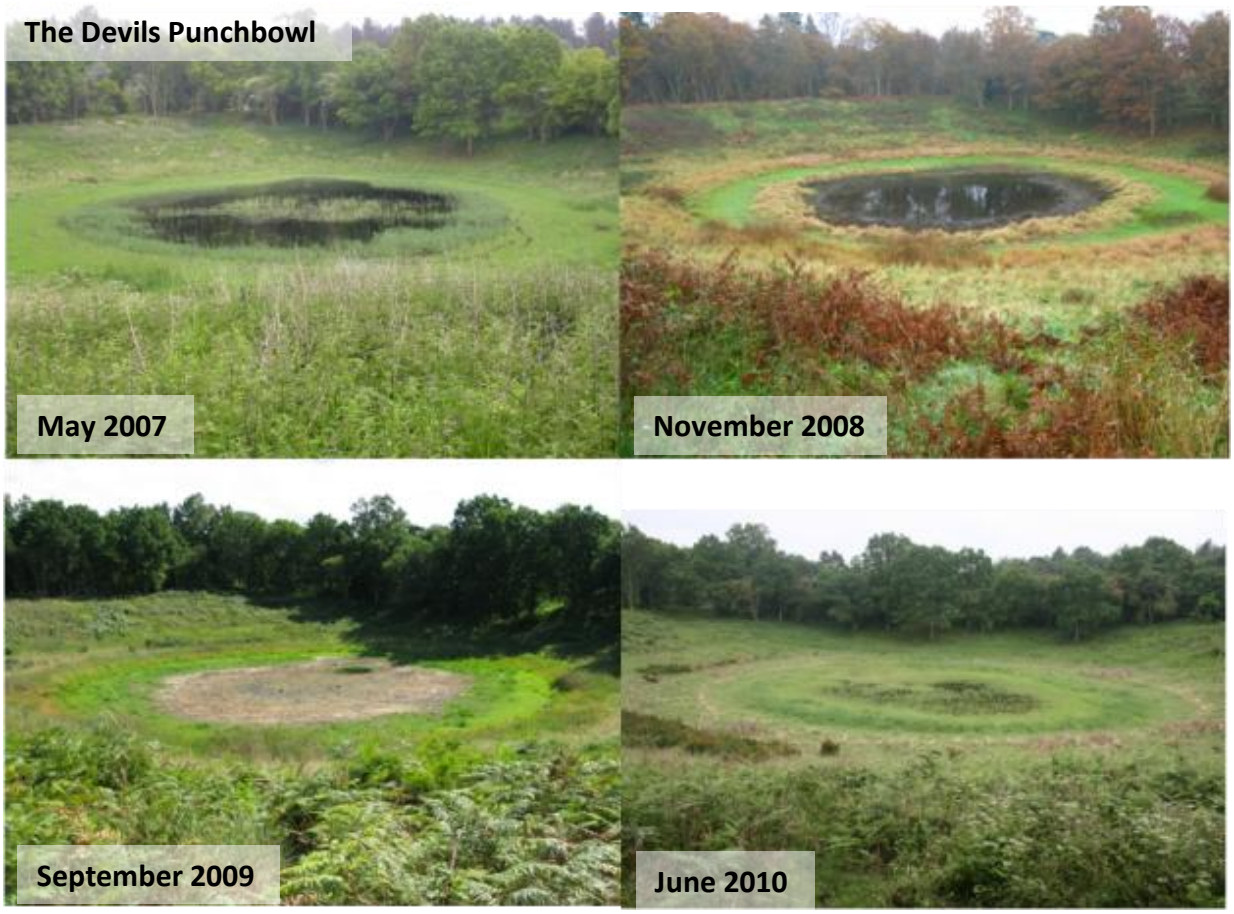
The damming of rivers has created areas of open water, such as Stanford Water on the Wissey and Thompson Water on a tributary of the Wissey, whilst modern gravel extraction has created new wetlands in place of more typical river valley habitats at Lackford, Lynford and south of Thetford.

Pingos

Pingos are ground water fed pools created from the thawing of peri-glacial ice-lenses.

Pingo sites are a key feature of Breckland and support important communities of aquatic invertebrates including Heteroptera and Coleoptera.

Breckland Meres



Breckland Meres are ground-water fed fluctuating water bodies, with percolation of ground-water through a semi-permeable base lagging behind groundwater recharge from winter rainfall. Successive flooding and draw-down results in concentric zoning of vegetation. Pictured: The Devils Punchbowl in four successive years © N. Armour-Chelu (2007-09) & T. Pankhurst 2010

Grazed meres support rare and distinctive species associated with re-flooding of droughted sediments, such as the two-spined seed shrimp *Cypris bispinosa*, a Mediteranean species that occurs episodically in some Breckland Meres.

Breckland Conservation and the Need for this Audit

The afforestation of Breckland and the loss of heathland was decried in the mid 1930s by the Norfolk Naturalists Trust and notable figures such as the biologist E.J. Salisbury and geographer L.D. Stamp, who campaigned to preserve some of the wild landscape to protect its character and biodiversity. Their bold vision for a connected network spanning from STANTA in the north in a broad sweep of landscape joining remaining heaths in the east and south of Breckland (Sheail 1979) was never realised. However, a number of key sites were secured for conservation in perpetuity, beginning with the acquisition of East Wretham Heath by the Norfolk Naturalists Trust (now Norfolk Wildlife Trust) in 1939, closely followed by Weeting Heath and Thetford Heath (purchased for the Norfolk Wildlife Trust by the philanthropist and conservationist Christopher Cadbury), in 1942 and 1949 respectively. Supported by a legislative framework, nature conservation (the National Parks and Access to the Countryside Act 1949) came into being, the Nature Conservancy and its successor agencies (the Nature Conservancy Council, English Nature and most recently Natural England) designated a suite of key sites and secured their protection (see Table 4).

The national and international importance of Breckland has been recognised by the designation of four National Nature Reserves (NNR) and 55 Sites of Special Scientific Interest (SSSI) that cover 40% of the land area. Of these more than 30 are heaths or contain a substantial heathland element. The designation of many of these sites in the 1950s and 1960s coincided with a period of rapid and profound ecological change on most heathland sites.

The loss of livestock grazing, a consequence of the dominance in the farming economy of arable cropping, elevated the importance of rabbits in grazing the vegetation and preventing succession. The selective grazing and small-scale scraping and disturbance created by rabbits were crucial in controlling both the plant species composition and the physical structure of the vegetation and thus the range of micro-habitats available for invertebrates and plants (Farrow 1917a; Watt 1957; 1960; 1962; 1981a; 1981b; Rodwell 1992). Following the introduction of myxomatosis to the UK in 1953 and the translocation and release of infected animals by farmers seeking to control rabbits in the agricultural landscape, the rabbit populations had collapsed by 1955. The effects on both vegetation and invertebrates were immediate and profound. Many heaths became grassy, overgrown and subject to scrub and pine invasion (e.g. Marrs Hicks and Fuller 1986) and it is likely that some species and population extinctions can be directly attributed to these. In addition, the harvesting of heath products such as gorse, bracken and heather had also ceased during the early 20th century, allowing further invasive change to occur (Crompton and Sheail 1975; Rothera 1998).

Conservation efforts have been successful in restoring grazing management regimes to the majority of heathland SSSIs. At some sites rabbit populations rapidly recovered (e.g. Weeting Heath NNR); however, the destruction of rabbit populations on some key heathland sites following their recovery hindered conservation interests. STANTA has been sheep grazed since before the 1970s, while at some privately managed sites sheep grazing was introduced during the 1970s (e.g. Thetford Heath NNR). Establishment of grazing regimes was greatly helped by the introduction of agri-environment support mechanisms. In 1988 the Breckland Environmentally Sensitive Area (ESA) scheme was established, providing area payments to landowners to graze heathland, combined with capital payments for grazing infrastructure such as fencing and control of scrub and bracken. The ESA scheme was closed to new applications in 2004 and has been followed by the introduction of Environmental Stewardship (ES) in 2005, providing a similar range of incentives with generally

enhanced payment rates. Under the Breckland ESA, all the major heathland areas have been fenced, grazed and managed (Perkin and Norden 2007).

However, at some key sites such as Lakenheath Warren, the eventual restoration of grazing only occurred after a period without grazing that spanned many decades. During this time dense grassland, bracken, scrub and woodland cover dominated, with resulting effects on soil conditions. Grazing, at least by livestock, is still absent from some heathland SSSIs, including Barnham Cross Common, Maidscross Hill and, perhaps unsurprisingly, Thetford Golf Course.

Heathland restoration has been further helped by initiatives such as English Nature's Tomorrow's Heathland Heritage programme (2000-2005, with support from the Heritage Lottery Fund, HLF). A significant project was the creation of 300ha of predominantly grass-heath within Thetford Forest, a project which continues now as the Brecks Heaths Project, a partnership of NWT, FC and NE. Norfolk Wildlife Trust's own HLF-funded project, Securing the Future, supported habitat restoration on the Trust's heathland and wetland nature reserves in Breckland.

However, the period of vegetation succession that most sites experienced prior to the restoration of grazing regimes had important consequences, as follows:

- In respect of local populations of species requiring open conditions or bare ground, it is not clear what has been lost during the period when heaths were unmanaged and developed closed vegetation.
- It is not clear how readily scarce invertebrates have been able to re-colonise sites following the restoration of management.
- Accumulation of organic matter into upper layers of soil may have persistent and long-lasting effects on nutrient availability, vegetation composition, plant communities, rates of succession and the rapidity with which vegetation and grass mats recover and close following minor disturbance.

The importance of physical disturbance to grass-heath species was recognised by ecologists such as Alex Watt. At a small number of SSSIs, soil disturbance was initiated in 1960 following myxomatosis (Dolman and Sutherland 1992), but primarily to provide nesting opportunities for stone curlew, and also as firebreaks, rather than as part of a wider understanding of ecological management. After the recovery of rabbit populations at Weeting and Thetford Heaths, for instance, rotovation treatments were discontinued, and the existence of these managed plots was largely forgotten. Examination of the vegetation developed on these previously rotovated plots in the late 1980s, combined with monitoring cultivation treatments in a replicated blocked experiment, confirmed the importance of physical disturbance to maintaining the open, lichen-rich conditions on which many characteristic species depend (Dolman and Sutherland 1991; 1992; 1994). Subsequent conservation management at some key sites has included practices such as rotovation and turf stripping. However, across most sites, the area of physical disturbance treatment has remained minimal, with sheep grazing (and occasionally cattle or ponies) considered the key tool for conservation.

Internationally important habitats within Breckland have been designated with the Breckland SAC (Special Area of Conservation; see Conservation Resource section). Designation in 2000 of the Breckland SPA (Special Protection Area; see Conservation Resource section) for populations of breeding stone curlew *Burhinus oedicnemus*, woodlark *Lullula arborea* and nightjar *Caprimulgus europaeus* coincided with the designation of the Breckland Farmland SSSI and the Breckland Forest

SSSI. The Breckland Forest SSSI citation also notes important vascular plant and invertebrate assemblages.

Conservation success includes the reversal of decline in the Breckland SPA population of stone curlew with a doubling of the Breckland population and the BAP species target, to contribute 125 breeding pairs by 2000 and 180 by 2010, was met and surpassed ahead of schedule with 230 pairs in 2009 (Tim Cowan *pers. comm.*).

However, this has largely been achieved by labour intensive intervention on arable land, including nest location and protection through effective liaison with farmers and land managers. This is not sustainable in the long term and restoration of suitable conditions across semi-natural grass-heaths to support a larger proportion of the population, together with initiatives to increase the area of safe nesting habitat on arable land, is a high priority by both the RSPB and Natural England.

The technical challenges of the large scale restoration and management of Breckland's wetlands (especially pingo sites) are great, but within the last 15 years new techniques have facilitated extensive restoration works at Norfolk Wildlife Trust's Thompson Common. Similar work has also recently been undertaken at Cranberry Rough, Hockham, clearing carr to re-establish fen alongside wet woodland, with the introduction of an extensive grazing regime encompassing this and adjacent pingos. Pingo restoration work has also been undertaken on the STANTA and on Foulden Common, and an increasing number of pingo sites (both SSSI and County Wildlife Sites) are now being managed under Environmental Stewardship. Under the Breckland ESA scheme over 2000 ha of river valley grassland and associated wetland habitats have been managed under sympathetic management regimes, and a further 320 ha re-created from arable land. Some of this has only modest value for nature conservation (with the landscape value of these grasslands sometimes the main rationale), but opportunities exist under Environmental Stewardship to enhance and extend this (with increased payments and improved targeting), with benefits for wetland plants, invertebrates and birds.

The extinct pool frog *Rana lessonae* (a Breckland specialist, extinct in the UK since the 1990s) has been reintroduced to one pingo site. Early indications to date are that this has been successful, forming a self-sustaining population without need for reinforcement.

Current concerns for Breckland's Biodiversity

Despite conservation successes, there are major concerns.

In developing the Breckland Natural Area profile, Stephen Rothera produced the most comprehensive collation and synthesis to date of information on the species present within Breckland (Rothera 1989). Although the numbers of RDB, BAP and Breckland speciality species associated with each habitat were given, and examples listed, the numbers identified can now be seen to be incomplete and out-dated following revision of the BAP species lists in 2007. The Natural Area profile did not aim to provide guidance on the ecological requirements or conservation management of priority species. The need remains, so that evidence based prescriptions can be formulated and delivered.

Most crucially, land managers lacked a comprehensive evidence base on which conservation prescriptions and management could be based. Particular issues were the following:

- There was insufficient knowledge of what species occur in Breckland.
- The ecological requirements and management techniques to sustain most Breckland conservation priority species were not readily available to conservation advisers or land managers.
- Objectives and priorities for conservation management were incomplete and often poorly defined.

A workshop to take stock of progress and challenges in conservation in Breckland (Davy 1995) identified the need to:

- Analyse habitat requirements, trends and distribution of key biodiversity.
- Identify which species are indicators of Breckland.
- Determine how the management of one species affects others.
- Look at the habitat requirements of key species.
- Assess the present status of rare plants and animals in Breckland.

Fifteen years later progress on most of these priorities has been very limited. Notably, the workshop recognised the strong potential for an approach based on collating and pooling the valuable knowledge available but scattered among practitioners and local experts:

> "no shortage of volunteers with good knowledge but that there is a great need for them to be properly co-ordinated"
> "need to co-ordinate, but also for people to send their data in".

In 2007 the Suffolk and Norfolk Biodiversity Partnerships brought together nearly 40 participants to review progress for conservation in Breckland (Perkin and Norden 2007). For grass-heaths, the workshop noted that:

- Broken turf grasslands continue to decline.
- Heaths are much "grassier" than they used to be.
- There has been insufficient research and monitoring.

Also highlighted at the workshop was the plight of specialist Breckland species, both plants and invertebrates, which require cultivated and ungrazed situations. The uncropped wildlife strips (cultivated arable margins), established under the Breckland ESA, were suggested as an important mechanism for managing these species, but it was noted that research and survey in this area had been limited (B. Nichols, *pers. comm.*).

The workshop (Perkin and Norden 2007) recommend that strategic action include:

- Greater sharing of information and a more coordinated and prioritised approach to conservation action in the Brecks.
- The preparation of a Brecks management plan and Brecks BAP as an integral component of the proposed management plan.
- An initial assessment of the presence or absence in the Brecks of the new priority BAP species and habitats included in the revised national BAP list.
- A detailed planning and feasibility study on the creation of an ecological network in the Brecks, to build on the ecological networks studies undertaken in Norfolk and Suffolk.

The Breckland Biodiversity Audit has set out to address many of these needs and to provide an understanding of the priority species in Breckland, their requirements, and strategic approaches to management for their conservation.

Aims of the audit

The Breckland Biodiversity Audit was commissioned and guided by a wide partnership of organisations that included the Biodiversity Partnerships of Norfolk and Suffolk, the Brecks Partnership, the Forestry Commission, Natural England and Plantlife. It seeks to provide a robust evidence base to guide actions to secure Breckland's biodiversity for the future.

The aims of the Breckland Biodiversity Audit may be summarised as three key elements: What, Where and How.

1) **What** is the biodiversity in Breckland?
   The audit:
   - Collated and examined available evidence to understand what species are present in Breckland.
   - Objectively defined the suite of Breckland conservation priority species.
   - Where possible, assessed the recent or current status of priority species, although the evidence base for this was expected to be highly incomplete.

2) **Where** is this biodiversity?

   In order to support strategic biodiversity delivery at a landscape scale, we undertook to:
   - Map the density of BAP species across the region
   - Map the density of range restricted regional specialists
   - Map assemblages requiring particular ecological conditions and processes, in order to identify hotspots and spatial priorities for different groups
   - Assess the quality of evidence and gaps in the knowledge base, for both species distributions and status, and provide recommendations for further survey requirements.

3) What does the priority biodiversity require? (**How** can it be conserved?)

A key objective of the Breckland Biodiversity Audit was to provide land managers and conservation advisers with guidance as to how to enhance and sustain the important biodiversity. Effective management is best achieved by providing prescriptions based on sound evidence rather than on myth, hearsay, received wisdom or dogma. The novel approach taken here was to identify multi-species assemblages and associated flagship invertebrate and plant species, requiring similar ecological processes and conditions (here-after referred to as 'assemblages' or 'guilds'). This has the aim of integrating prescriptions for multiple species into habitat-based approaches, but through an evidence-based approach rooted in an understanding of the ecological requirements of individual species.

The steps taken in this process were to:

- Collate and objectively analyse documentary evidence and expert knowledge for numerous Breckland conservation priority species from across a wide range of taxonomic groups.
- Compile management experience and relate this to the ecological requirements of assemblages.
- Provide explicit management guidance for each of the different groups of species.
- Identify gaps in relation to the evidence base, in terms of understanding distributions, requirements, and responses to management.
- And thus to provide recommendations for research and experimental work required to support the evidence base for management.

The Breckland bio-geographic region: climate, soil, vegetation and regional limits

The unique and distinctive character of the Breckland bio-geographical region results from the interplay between its characteristically low nutrient, free-draining soils and its slightly drier climate relative to most of southern England, plus the influence of both of these on human land-use and vegetation.

The Breckland National Character Area (NCA) [1] covers just 1019 km^2, just of the land area of the UK. It lies in a gap in the chalk escarpment between Newmarket to the south and Swaffham to the north (Figure 1). The peat and silt Fens border Breckland to the west and the clayland plateau of the East Anglia Plains lies to the north-east, east and south. Breckland drains westward via three main rivers, the Little Ouse, Wissey and Lark, into the fens. The river valley floodplains are flanked by gravel terraces. The interfluves between these, consists of gently undulating high ground mostly of 20 – 50 meters altitude, dissected by broad dry valleys.

Regional boundaries

The boundaries of Breckland are not clearly defined. The transition from the Breckland sands to the peats and silt fen soils at the edge of the Fens can be fairly abrupt. However, elsewhere the Breckland landscape gradually gives way to rolling chalk farmland to the south and a gradual transition into less extreme soils and land use to the north and east. For this reason, different authorities have offered various definitions of the extent and limits of the region. Throughout this study we adopt the latest of these, the Breckland National Character Area, which coincides with the earlier Natural Area (NA) as defined by Natural England. The Natural Area was primarily defined by the mapped extent of sandy soil-series, characteristic of Breckland (Figure 3) and thus has a clear ecological basis. In contrast, the boundaries of the earlier Breckland ESA were influenced by easily mapped boundaries, such as roads and rivers. Whilst almost all of the ESA is encompassed within the NCA, there are some discrepancies between the boundaries, particularly to the north and the west (Figure 2). A handful of Sites of Special Scientific Interest (SSSI) are fully excluded by one or both definitions of Breckland (Appendix 1). For example, pingos at East Harling Common and wetland at Castle Acre Common are included within the NCA but not the ESA. Six hectares of Thompson Water, Carr and Common fall outside the ESA boundary and small parts of the Breckland Farmland SSSI (notified in 2000, under the 1981 Act for the internationally important population of stone curlew *Burhinus oedicnemus* as a prelude to proposing the Breckland Special Protection Area) lie outside both boundary systems. Lakenheath Poors Fen, comprising damp calcareous grassland, neutral grassland and fen meadow, is regarded as a transitional site between Breckland sands and the Fens basin (Rothera, 1998). It is important as a remaining fragment of a previously extensive tract of similar habitat lost to arable cultivation. However, the site is not included in either the NCA or the ESA. However, it is important to recognise that that the boundaries of the NCAs are not precise and that many of the boundaries should be considered as broad zones of transition.

[1] Under a Natural England initiative, England has been divided into 159 areas with similar landscape character, which are called National Character Areas (NCAs); previously known as Joint Character Areas (JCAs). The NCAs are a widely recognised national spatial framework, used for a range of applications.

Climate

Breckland has long been known for a climate that is less oceanic than of the rest of the UK. Breckland is drier, colder in winter and has more days with air frosts in all seasons than south-eastern and central southern England (Table 1). Breckland also has lower minimum temperatures in all seasons and a greater number of frosts in all seasons compared to both Cambridge and to East Anglia. Breckland, however, is not drier than Cambridge or the wider East Anglian region (Table 1).

Table 1. Climate in south-eastern and central southern England, East Anglia, Cambridge and Breckland (Santon Downham) for the period of 1979-2008.

	Winter	Spring	Summer	Autumn	Annual
			SE & CS England		
Mean annual total rainfall (mm)	217.4	165.5	164.0	236.0	784.4
Mean minimum daily temperature (°C)	1.8	4.9	11.5	7.2	
Mean maximum daily temperature (°C)	7.8	13.4	21.1	14.7	
Mean number of days of air frost per season	30	10	0	7	46
			East Anglia		
Mean annual total rainfall (mm)	149.5	131.8	161.3	172.6	612.5
Mean minimum daily temperature (°C)	1.1	4.2	11.0	6.6	
Mean maximum daily temperature (°C)	6.8	13.0	20.8	14.2	
Mean number of days of air frost per season	30	10	0	6	45
			Cambridge		
Mean annual total rainfall (mm)	130.1	132.3	146.8	161.8	571.1
Mean minimum daily temperature (°C)	1.6	4.8	11.5	7.4	
Mean maximum daily temperature (°C)	7.5	13.5	21.6	14.8	
Mean number of days of air frost per season	28	8	0	5	42
			Breckland (Santon Downham)		
Mean annual total rainfall (mm)	158.6	149.4	176.6	179.0	663.7
Mean minimum daily temperature (°C)	0.4	3.2	9.9	5.4	
Mean maximum daily temperature (°C)	7.6	13.6	21.3	14.8	
Mean number of days of air frost per season	40	22	1	15	78

Source of data: Cambridge http://www.metoffice.gov.uk/climate/uk/stationdata; SE & CS England and East Anglia http://www.metoffice.gov.uk/climate/uk/datasets; Breckland http://badc.nerc.ac.uk/home/index.html).

Geology, hydrology, soils and vegetation

The bedrock lying beneath Breckland is cretaceous chalk. This is overlain by chalk-sand 'drift' and in some places, by chalky 'boulder clay', most likely deposited by extensive ice sheets during the penultimate glaciation some 350,000 – 130,000 years ago. The drift comprises fractured lumps of chalk, set in a mixture of chalk and sand. The clay content is generally less than 5%, but can be locally higher particularly in the east of Breckland (Figure 3; Corbett, 1973). During the subsequent interglacial, the drift was weathered and leached, and then during the last glaciation was reorganised by peri-glacial frost heave in the prevailing tundra conditions. This resulted in stripes or

polygons of alternating calcareous ridges and deeper more acidic sand. Surface layers of wind-blown sand have also been deposited. The resulting soils are extremely complex and varied.

The predominant soil types are sandy highly drained and drought prone and low in mineral clay or organic content and thus potentially very infertile and low in nutrients.

Calcareous sandy soils and even shallower chalky rendzinas derived from the chalk-sand drift, cover 37% of the Breckland National Character Area (Table 2). These tend to occur on slopes where the overlying weathered material has been removed by solifluction. Deeper, well-drained and leached soils that range from less calcareous to highly acidic, cover a further 41% of Breckland. These tend to occur on plateaus and range from sand over gravel, stony sand or strongly acidic podzols. Gravel deposits cover some high level plateaus, up to 7 metres in depth, and other gravels occur in valley terraces and valley head deposits. Localised areas of loamy soils occur in the peripheral areas of Breckland (Figure 3) but are less droughty and nutrient poor, with dry loams, and damp loams and clay soils, covering 5% and 4% of Breckland respectively.

Where vegetation is grazed and not annually cultivated, a range of grass-heath vegetation develops on these sandy soils. Different plant communities are recognised on the chalky or on the acidic sands. The relationship between soil type and the species composition of a spectrum of grass-heath vegetation, from lichen rich vegetation on raw chalk soil through chalk turf to acidiphilous grassland, was initially described by Alex Watt (1940). These grassland types were later re-classified as part of the National Vegetation Classification (Rodwell, 1991; 1992) (see Table 3).

However, although the extremes may be distinct, the species composition of these plant assemblages merges and intergrades along a gradient of pH and soil development from rendzinas to podzols. While some management units may be dominated by one or other type of grassland, these assemblages can also occur in intimate and complex mosaics at many sites. This range of calcareous grassland, acidiphilous grasslands and lowland heath assemblages all share common ecological characteristics, they are:

- droughted, stress tolerant vegetation.
- developed on dry mineral sands that are low in nutrients, particularly nitrogen (Davy and Bishop 1984).

For this reason they are all treated as variants of “grass-heath” vegetation (following Watt 1940; Dolman and Sutherland 1992; Rothera 1998). For the purposes of this audit, and particular in making management recommendations, we most often generalise across these acidic and calcareous vegetation types.

Wetlands, fens, fluctuating water bodies and pingos

Elsewhere in the landscape, where drainage is impeded, gleys and peats have formed, covering 12% and 1.4% of the Breckland National Character Area respectively (Table 2). At the periphery of floodplains, or in the lower reaches of dry valleys adjacent to the fens, seasonal water tables can lead to impeded drainage and the development of gley soils formed under anaerobic conditions. On the lowest ground where the water table is permanently at or near the surface, the sands and gravels are covered by anaerobic peaty and humose gleys. Gleys can support mesic vegetation

influenced by seasonal water tables and damp grassland, while undrained intact peat can support fen communities.

In the headwaters and tributaries of the Little Ouse, Lark, Wissey and Thet spring-fed valley-head fens have developed on chalky nutrient poor water that percolates upward through thin peat layers (Rothera 1989). Fen exists in a number of sites including at Great Cressingham Fen, Thompson Common and Gooderstone Fen in Norfolk and Market Weston Fen in Suffolk which also has saw sedge *Cladium mariscus*, as does Hopton Fen nearby. Fen with saw sedge *Cladium mariscus* also exists at Talent's Fen on Foulden Common and at Swangey Fen on the edge of the National Character Area.

Organic peat occurs over most of the river valley floodplains, reaching 2-3 metres depth in the centre of larger valleys, but is generally drained and humified to a eutrophic state (Corbett, 1973). Little of the valley fen resource remains, though areas do exist along the River Little Ouse between Thetford, Brandon and Weeting and in fragments elsewhere.

Peats have also formed locally in meres (Corbett 1973) – fluctuating ground-water fed water bodies on the plateaus, all restricted to the Norfolk Breckland. These unusual hydro-geological features are fed by base-rich groundwater with no in-flow or out-flow streams and exhibit concentric zones of different vegetation due to fluctuation in the water table. Importantly, they are thought to be naturally self sustaining, not silting up or filling in, as vegetation is killed off by drying and re-flooding (Rothera 1989). There are five principal meres which are recognised as true fluctuating ground-water fed meres, these are: Langmere, and Ringmere (both at East Wretham Heath), Fowlmere, Home Mere (in STANTA at Thorpe Great Heath) and the Devil's Punchbowl. There are 3 other meres within STANTA which demonstrate some characteristics of fluctuating meres - Smoker's Hole, West Mere and West Tofts Mere. Of these, Smoker's Hole is the most like the principal five, the other two are less typical, West Mere may have with underlying impermeable strata, whilst West Tofts is spring-fed), but which nevertheless exhibit a response to high water tables in the surrounding chalk/sands. The identification of remaining meres is less certain but essentially comprises a series of hollows around the East Wretham/Roudham area, which clearly have the same form as the principal meres but that hold water only occasionally when the water table is particularly high. There are at least seven of these on East Wretham Heath and a further 8 through the Roudham Forest block to the east of East Wretham Heath (B. Nichols *pers. comm.*). Some water bodies near Larling have also been suggested to exhibit fluctuating mere characteristics (Watson, 1974). A number of other waterbodies exist that are rain-fed and lack the characteristic species of fluctuating meres.

Pingo systems, created by ice lenses during tundra conditions c20, 000 years ago, comprise complexes of pools. Within one system, different pools may vary in the extent to which they are ground water fed, their pH, whether water levels fluctuate and in their vegetation. This provides complex range of ecological conditions. Surviving systems occur at Thompson Common, Foulden Common, East Harling Common, Great Hockham (Hills and Holes), Breckles Heath and Frosts Common and within STANTA (Rothera 1989; Walmsley 2008).

The floristic diversity and interest of the pingo systems arises from variations in substrate, hydrology, water pH and the resulting habitat mosaic (Walmsley 2008). Where water levels within the hollows fluctuate, vegetation may be unable to establish for long periods and bare mud on the draw-down zones can provide opportunities for species that need low levels of competition. High

quality calcareous fen communities may develop in peat-filled basins fed by calcareous springs, or ponds which drain down to damp mud during the summer months (Walmsley 2008).

The exceptional invertebrate fauna, which includes numerous RDB species as well as Breckland specialities, is attributed to the stability of these habitats over very long periods, as well as the large diversity in habitats (Foster 1993; Lambley, 2005). Foster (1993) observed that: 'the remnants of early postglacial biota' probably persist because they are often still fed by the same groundwater source that created them. Snail-killing flies are an outstanding feature at many pingo sites, particularly Thompson Common, which supports a large proportion of the national fauna (Walmsley 2008).

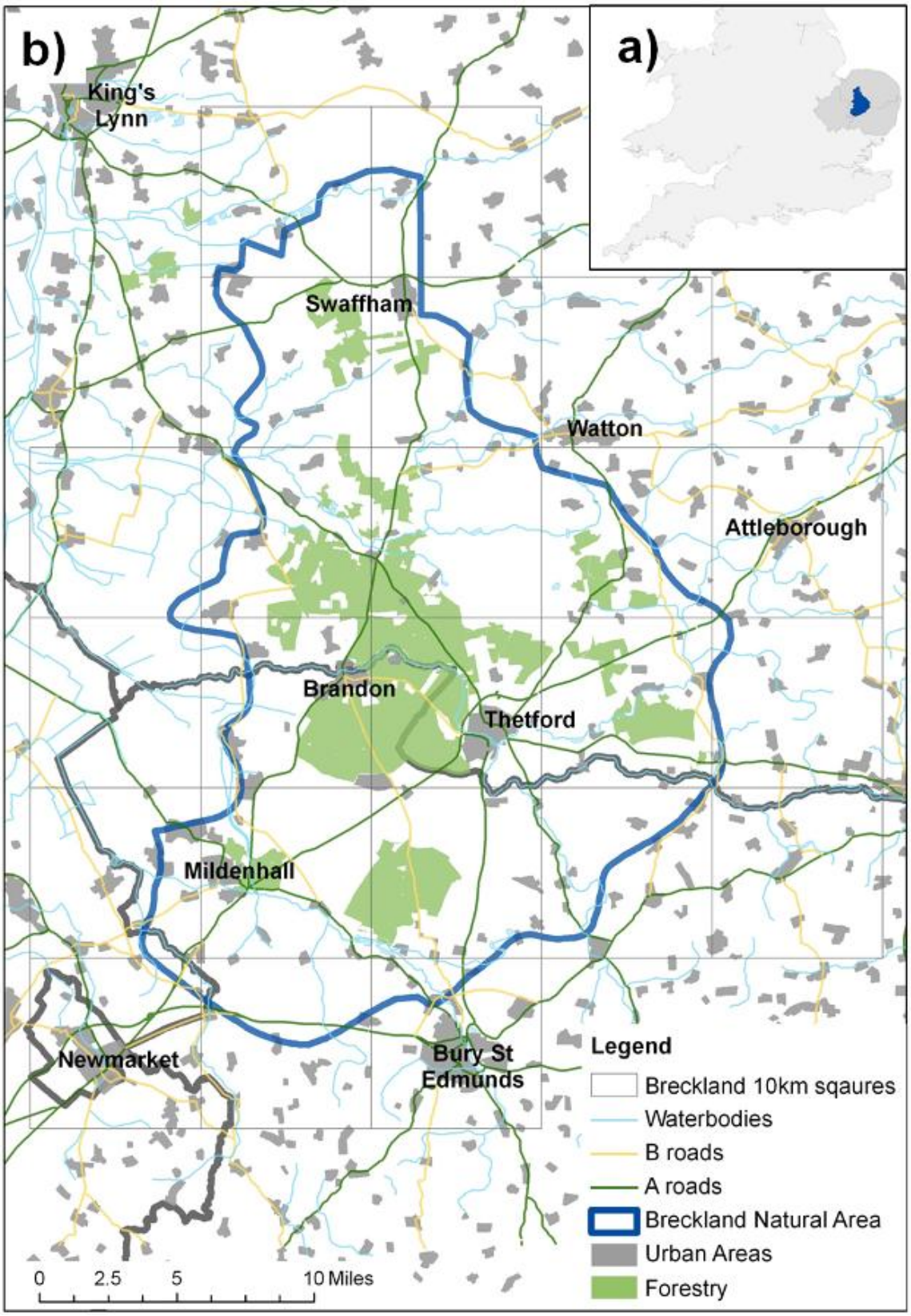


Figure 1. a) Map showing the location of Breckland within England and within the counties of Norfolk, Suffolk and Cambridgeshire, b) Location and boundary of the Breckland National Character Area (NCA), showing urban centres, major roads and forest cover

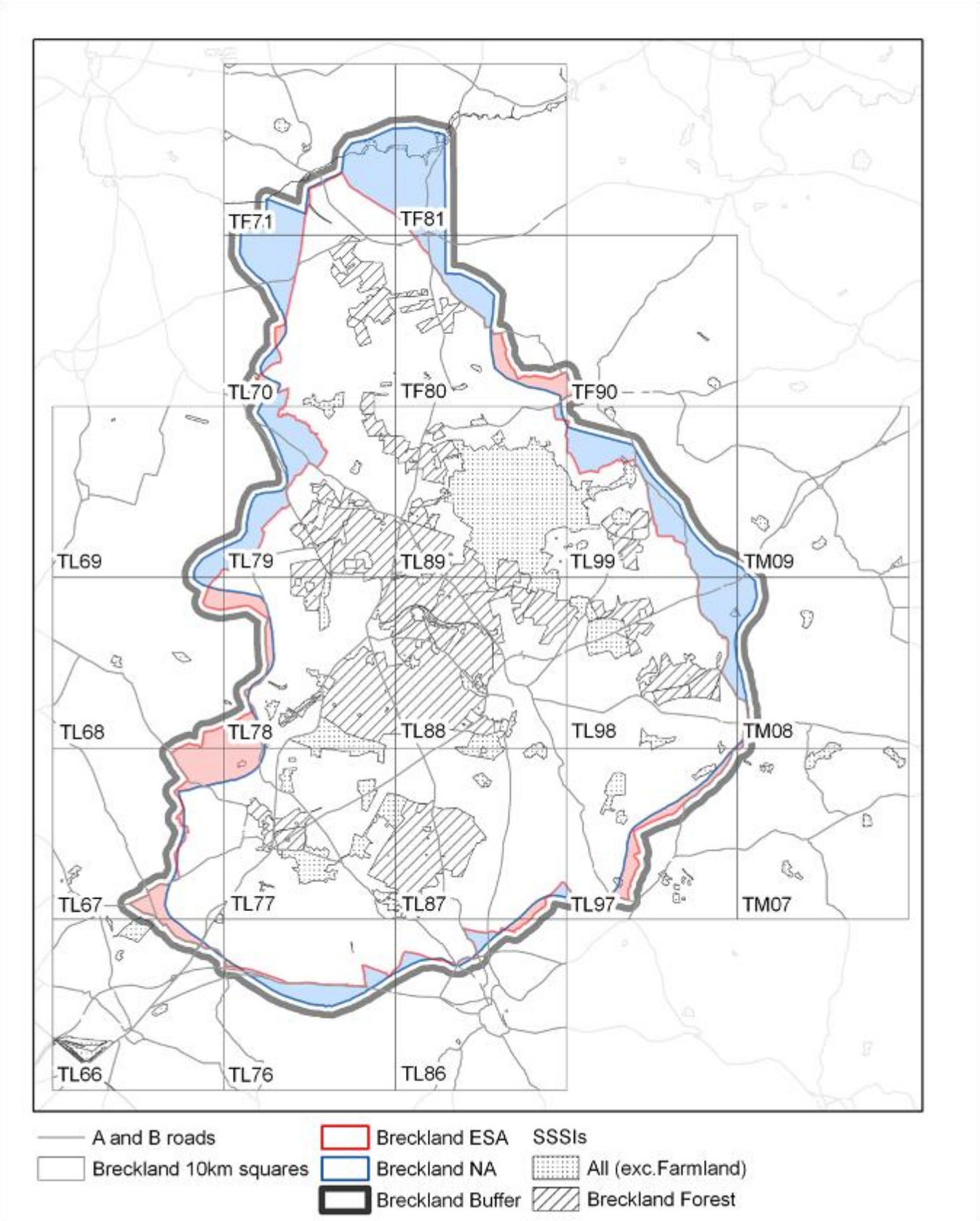


Figure 2. The extent of Breckland, showing the limits of the Breckland National Character Area and Breckland Environmentally Sensitive Area overlain on Ordnance Survey 10km squares. The Breckland buffer is the widest extent of the combined area of the NCA and ESA, buffered by 1 km, and was used for selection of the Breckland 10 km squares

Table 2. Soils occurring within the Breckland Natural Character Area (Figure 3) showing the area and percentage of the NCA covered by aggregate types. Soil series and horizon data obtained under licence from NATMAP, National Soil Resources Institute, Cranfield University, with soil classification also informed by Corbett (1973)

Major Soil Group	Soil Series	Description	Area (km^2)	Area km^2 (%)
Calcareous soils	Newmarket 1 & 2	Dry chalky Rendzina	252.3	376.3 (37 %)
	Methwold	Deep well drained chalky sand	124.0	
Well drained sandy soils (non-calcareous to acidic)	Worlington	Deep well drained, acidic sand or stony sand	268.8	415.5 (41 %)
	Newport 2, 3 & 4	Deep well drained coarse sand	146.7	
Dry loamy soils	Swaffham Prior & Moulton	Well drained chalky loam	46.1	48.6 (4.8 %)
	Reach	Shallow humose chalky loam	2.0	
	Barrow & Melford	Dry loamy sandy-clay	0.5	
Damp loamy or clay soils	Burlingham 1 & 3	Damp deep loam	14.4	39.8 (3.9 %)
	Ollerton	Damp deep sandy loam	9.0	
	Ashley	Damp deep loam to clay	15.9	
	Hanslope	Damp deep calcareous clay	0.5	
Gleys: seasonally wet poorly drained organic or clay soils	Isleham 2	Poorly drained seasonally wet gleyed deep humose sand	107.4	122.6 (12 %)
	Thames	Poorly drained seasonally wet gleyed deep calcareous clay	1.0	
	Wickham 2	Seasonally wet humose silty clay	5.4	
	Beccles 1 & 2	Seasonally wet deep loamy clay	8.8	
Fen peat	Adventurers 1 & 2	Fen peat, mostly drained and oxidised	14.6	14.6 (1.4%)
Open Water			1.7	1.7
		Total area:	1019	

Table 3. Grass-heath vegetation in Breckland classified in relation to the National Vegetation Classification (Rodwell, 1991; 1992), also showing closely related grassland communities

Chalk grassland in slightly mesic/temperate sites	
CG2 *Festuca ovina-Avenula pratensis* grassland	Short-grazed, species-rich calcareous grassland characteristic of free-draining calcareous soils with temperate (relatively warm and dry) lowland climate. Compared to xeric oligotrophic CG7 (below), CG2 is a widespread community of lowland grazed chalk grassland (e.g. North and South Downs, Chilterns to Lincolnshire and Yorkshire Wolds).
Calcareous Grass-heath (Watt's grasslands A and B)	
CG7 *Festuca ovina-Hieracium pilosella-Thymus praecox / pulegoides* grassland	Chalk grassland characteristic of thin stony very free-draining and highly oligotrophic calcareous soils developed in more continental climatic conditions, with heavy grazing and occasional disturbance.
CG7a *Koeleria macrantha* sub-community	Grassier and herb rich sub-community
CG7b *Cladonia* spp. sub-community	*Cladonia*-rich calcareous grass-heath characteristic of Breckland, found elsewhere in UK at Porton Down in Salisbury Plain (*Avenula pratensis* can increase in dominance in absence of grazing).
CG7c *Ditrichum flexicaule-Diploschistes scruposus* sub-community	Rare community confined to Breckland, with crustose lichens on firm calcareous substrate, especially on exhausted arable soils, rabbit warrens, turf stripped areas or mounds of chalk rubble
CG7d *Fragaria vesca-Erigeron acer* sub-community	Grassier grass-heath that can occur on abandoned arable, *Festuca rubra* may replace *F. ovina*.
CG7e *Medicago lupulina – Rumex acetosa* sub-community	Grassier sub-community
Acidiphilous Grassland (Watt's grasslands D-G)	
U1 *Festuca ovina-Agrostis capillaris-Rumex acetosella* grassland	
U1b typical sub-community	Associated with lighter grazing
U1a *Cornicularia aculeata-Cladonia arbuscula* sub-community	Pioneer or established lichen heath sub-community, on recently colonised ground, also associated with heavier grazing; community considered by Rodwell as largely restricted to Breckland within UK
U1c *Erodium cicutarium-Teesdalia nudicaulis* sub-community	Winter annual sub-community, associated with surface disturbance; community considered by Rodwell as largely restricted to Breckland within UK and contains characteristic steppe species including Breckland specialists
U1d *Anthoxanthum odoratum-Lotus corniculatus* sub-community	Transitional towards calcareous CG7 grass-heath
U1e *Galium saxatile – Potentilla erecta* sub-community	Occurs on more mesic soils; transitional to U2a *Deschampsia flexuosa* grassland
Fixed dune communities	
SD8 *Festuca rubra-Galium verum* fixed dune grassland	Fixed dune grassland, on windblown sand or former arable
SD10 *Carex arenaria* dune community	*Carex arenaria* (sand sedge) dominated vegetation on stabilised blown sand
SD12 *Carex arenaria - Festuca ovina - Agrostis capillaris* dune grassland	Mossy fixed dune grassland
Transitions to dwarf-shrub heathland	
H1 *Calluna vulgaris - Festuca ovina* heath	Intergrades with U1 grassland depending on intensity of grazing and disturbance history
Transitions to Deschampsia dominated grassland depending on nutrient status and management	
U2a *Deschampsia flexuosa* grassland*; Festuca ovina-Agrostis capillaris* sub-community	Not described by Watt, may be occurring increasingly in Breckland as a result of nitrogen enrichment and organic matter accumulation

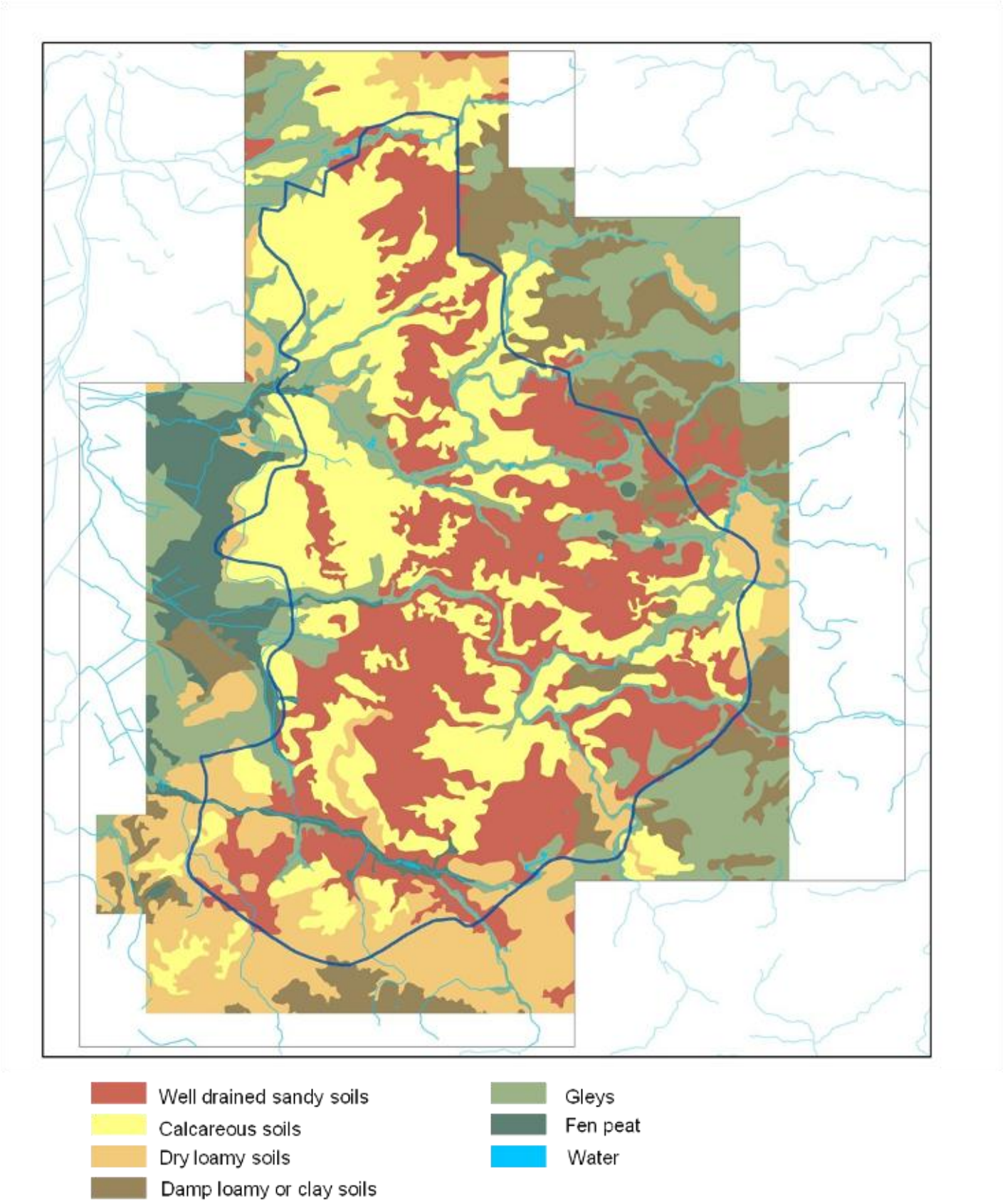


Figure 3. Distribution of soil types in the Breckland Natural Character Area and surrounding region. Soil series and horizon data obtained under licence from NATMAP, National Soil Resources Institute, Cranfield University.

The Conservation Resource: Designated Areas

Internationally Important Features: The SAC and SPA

The Breckland Special Area of Conservation (SAC) totalling 7,548 ha is designated under the EC Habitats/Species Directive for the following features:

Features of grass-heath and heather heath habitats:

- Inland dunes with open *Corynephorus* and *Agrostis* grasslands.
- European dry heaths.
- Semi-natural dry grasslands and scrubland on calcareous substrates (*Festuco-Brometalia*).
- Natural eutrophic lakes with Magnopotamion or Hydrocharition-type vegetation (the fluctuating meres).

Other qualifying features included in the Breckland SAC, but which are not the primary reason for selection:

- Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (Alno-Padion, Alnion incanae, Salicion albae).
- Great Crested Newt *Triturus cristatus.*

Rex Graham Reserve SSSI is a SAC in its own right, as an important orchid site within calcareous grassland (*Festuco-Brometalia*).

A number of wetland and fen SSSIs within Breckland are also of international importance:

- Foulden Common, Great Cressingham Fen and Thompson Common contribute to the Norfolk Valley Fens Special Area of Conservation for their calcium rich spring fed vegetation (e.g. M13) and transitions to reed-swamp and other fen and wet grassland types. The SAC is also listed for the presence of the Desmoulin's whorl snail *Vertigo moulinsiana*, for example at Thompson Common.
- Market Weston and Hopton Fens are part of the Waveney and Little Ouse Valley Fens Special Area of Conservation for their calcareous fen with saw sedge *Cladium mariscus*, for purple moor-grass meadow vegetation on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*) and EC Habitats and Species Directive-Annex II species: narrow-mouthed whorl snail *Vertigo angustior*, and Desmoulin's snail *V. moulinsiana.*

The Breckland Special Protection Area (SPA), the EC Directive on the conservation of wild birds (79/409/EEC) (see: http://www.jncc.gov.uk/default.aspx?page=2016), is designated for qualifying breeding populations of woodlark *Lullula arborea*, nightjar *Caprimulgus europaeus* and stone curlew *Burhinus oedicnemus.* Recent population sizes of these species are given below:

	Qualifying population	Recent population estimate (year)
Woodlark *Lullula arborea*	430	241[1] (2009)
Nightjar *Caprimulgus europaeus*	415	349 (2004) 248 (2010)
Stone Curlew *Burhinus oedicnemus*	115	230 (2009)

[1] Woodlark numbers relate to numbers of singing males, not breeding pairs, and exclude additional birds nesting on heathland outside of the Forestry Commission estate.

Sites of Special Scientific Interest (SSSIs)

Fifty five SSSIs are located in the Breckland NCA, with a further 31 in the periphery (within the 23 10 km squares of the Breckland region (Table 4, Figure 4). These SSSIs include sites also designated as Special Protected Areas (SPAs), Special Areas for Conservation (SACs) and National Nature Reserves (NNRs). Approximately 40% of the Breckland NCA is designated as SSSI. This is a very high level of designation compared to other bio-geographic areas, for example 5% of the South Downs National Character Area and only 2% of the Fens National Character Area are designated as SSSIs.

Three sites dominate the total designated area, Breckland Forest (18,079 ha), Breckland Farmland (13,335 ha) and Stanford Training Area (STANTA) (4,681 ha).

- The **Breckland Farmland** was designated for internationally significant breeding population of stone curlew. However within the arable area there is also known, and potential, plant and invertebrate interest, including populations of species largely or entirely restricted to Breckland.

- **Breckland Forest** (comprising the majority of Thetford Forest together with some other land) is designated for populations of woodlark and nightjar that contribute to the Breckland Special Protection Area, but nationally important assemblages of rare plants and invertebrates are also important interest features of the SSSI. The large extent of the Breckland Forest with its unimproved soils and varied mosaic of semi-natural habitats, together mixed plantations interspersed by a network of open space, make this an extremely valuable landscape of high nature conservation value.

- **STANTA** is an extensive landscape comprising a mosaic of ancient heaths (>170 years old) and a range of grass-heaths, the last of which were reverted after 1932 (Sheail 1979). There are also with areas of plantation and wetland. Although historically supporting substantial populations of stone curlew, much of the grass-heath is now only lightly grazed, and even the youngest of these have now been accumulating organic matter and nutrients for over 68 years (since the establishment of the training area in 1942). In 1968 a minimum of 13 pairs of stone curlew, and a likely total of 16 – 18 pairs, were breeding on sheep grazed breck or heath in STANTA; in 1980 there was evidence of 22 pairs across 18 sites (Green and Bowden 1987), but in 2008 there was only one pair and in 2009 only 3 pairs (RSPB data, supplied by NE), representing an almost complete collapse.

All other SSSIs are less than 600 ha in size, with the smallest being London Road Industrial Estate, Brandon (0.11 ha).

Virtually all substantial areas of unimproved Breckland grass-heath or heathland that had escaped conversion to arable by the late 1950s are now designated and protected as SSSIs. In addition further SSSIs have been notified for their wetland or woodland biodiversity or habitats. Among these, the pingo sites are particularly notable in a Breckland context.

National Nature Reserves (NNR)

There are four National Nature Reserves in Breckland. Cavenham Heath (204ha) and Brettenham Heath (233ha) are both managed by Natural England, while Weeting Heath (137ha) and Thetford Heath (98ha) are managed by Norfolk Wildlife Trust.

County Wildlife Sites (CWS)

There are 583 County Wildlife Sites in the Breckland area of interest, 383 of which are in Norfolk, 174 in Suffolk and 25 in Cambridgeshire (Figure 4). Thetford Forest Park and The Kings Forest combined comprise 44% (5937 ha) of the total area designated as CWS (13,566 hectares), although these overlap the Breckland Forest SSSI. The smallest CWS, Chiswick Avenue, is 53 m^2 and designated for its Sand Catchfly population. Approximately 50% of the total area of CWS is now designated as SSSI, encompassing all or part of 164 sites.

Roadside Nature Reserves (RNR)

There are forty-eight Roadside Nature Reserves (RNRs) in the Breckland 10 km squares (Table 4). The largest RNR (2.06 ha) is along the A1065 at Lakenheath, designated for its Breckland flora, including field wormwood. The smallest (53.5 m^2) in Mildenhall is designated for its sand catchfly population.

Table 4. Interest features of the Sites of Special Scientific Interest (SSSIs) in the selected 23 10 km squares encompassing Breckland. Sites in grey lie within the Breckland NCA. Interest features are those features from the citation that are recognised by the Natural England database (ENSIS). * denotes Schedule 8 moss, rather than a Schedule 8 plant

		Feature of Designation														
Site Name	Area (ha)	Grassland	Heath	Woodland	Wetland	Flowing Waters	Standing waters	Geological	Vascular plants	Invertebrates	RDB plant / Sch 8 plant	Nationally rare invert spp	Agg. of breeding birds	Agg. of non-breeding birds	Mammals	Amphibians
Bangrove Wood	18.3			X												
Barnham Heath	76.5	X			X								X			
Barnhamcross Common	67.3	X							X							
Berner's Heath, Icklingham	233.5	X	X													
Black Ditches, Cavenham	1.7	X									X					
Blo' Norton and Thelnetham Fen	21.1				X											
Boughton Fen	15.8				X											
Brackland Rough	10.7			X												
Breckland Farmland	13,393												X			
Breckland Forest	18,079							X	X	X			X		X	
Bridgham & Brettenham Heaths	446.0	X	X										X			
Bugg's Hole, Thelnetham	4.0				X											
Burgate Wood	29.8			X												
Castle Acre Common	17.7				X											
Cavenham-Icklingham Heaths	398.8	X	X	X	X				X	X			X	X		
Cherry Hill & the Gallops, Barton Mills	10.1	X		X					X							
Chippenham Fen and Snailwell Poor's Fen	155.6	X		X	X		X			X	X		X			
Cranberry Rough, Hockham	81.4			X	X			X	X							
Cranwich Camp	12.6	X							X	X	X					
Deadman's Grave, Icklingham	126.3	X							X				X	X		
Devil's Dyke	39.8	X		X					X							
Didlington Park Lakes	25.9						X						X			
East Harling Common	14.9	X			X					X						
East Walton and Adcock's Common	62.5	X		X	X			X		X	X*	X				
East Wretham Heath	141.1	X					X									
Elm Road Field, Thetford	5.0	X							X							
Eriswell Low Warren	6.6	X							X							
Fakenham Wood, Euston & Sapiston Great Grove	201.1			X												
Field Barn Heaths, Hilborough	18.7	X														
Foulden Common	136.8	X		X	X					X						
Foxhole Heath, Eriswell	84.5	X	X						X				X	X		
Gooderstone Warren	22.0	X														
Great Cressingham Fen	13.7	X			X											

Site Name	Area (ha)	Grassland	Heath	Woodland	Wetland	Flowing Waters	Standing waters	Geological	Vascular plants	Invertebrates	RDB plant / Sch 8 plant	Nationally rare invert spp	Agg. of breeding birds	Agg. of non-breeding birds	Mammals	Amphibians
Grime's Graves	64.9	X	X					X							X	
Hilgay Heronry	1.8												X			
Hookswell Meadows, Gt Cressingham	16.1	X		X	X											
Hopton Fen	15.2				X											
Horringer Court Caves	3.8														X	
How Hill Track	3.3								X							
Kenninghall and Banham Fen with Quidenham Mere	48.4				X		X									
Knettishall Heath	91.2	X	X													
Lackford Lakes	106.1				X					X			X	X		
Lakenheath Poors Fen	5.2				X											
Lakenheath Warren	570.6	X							X				X			
Little Heath, Barnham	45.7	X											X			
London Road Industrial Estate, Brandon	0.1										X					
Lordswell Field, Eriswell	3.1	X									X					
Maidscross Hill, Lakenheath	45.2	X							X		X					
Middle Harling Fen	12.7	X			X											
Narborough Railway Embankment	7.8	X								X						
New Buckenham Common	21.0	X														
Newmarket Heath	297.3	X							X		X					
Old Bodney Camp	32.2	X										X				
Old Buckenham Fen	34.5			X	X											
Pashford Poors Fen, Lakenheath	12.2	X		X	X		X			X						
Potter's Carr	6.3			X												
RAF Lakenheath	115.5	X							X	X	X					
Redgrave and Lopham Fen	127.1									X		X				
Red Lodge Heath	20.8								X	X		X				
Rex Graham Reserve	2.7										X					
River Nar	212.4					X										
Scoulton Mere	34.2			X	X				X		X					
Shaker's Lane	0.5											X				
Shippea Hill	27.6							X								
Snailwell Meadow	15.2				X						X					
Soham Wet Horse Fen	33.8	X			X											
Stallode Wash	34.1								X		X		X			
Stanford Training Area (STANTA)	4597.0	X	X	X	X		X	X	X	X			X	X	X	
Stanton Woods	66.1			X												
Swangey Fen	48.6			X	X											

Site Name	Area (ha)	Grassland	Heath	Woodland	Wetland	Flowing Waters	Standing waters	Geological	Vascular plants	Invertebrates	RDB plant / Sch 8 plant	Nationally rare invert spp	Agg. of breeding birds	Agg. of non-breeding birds	Mammals	Amphibians
The Brinks, Northwold	16.3	X														
The Glen Chalk Caves	1.6														X	
Thetford Golf Course & Marsh	119.6	X	X	X	X											
Thetford Heaths	269.4	X	X					X	X		X		X			
Thompson Water, Carr & Common	156.0	X		X	X				X	X			X			X
Wangford Warren & Carr	65.6	X														
Wayland Wood	31.8			X												
Weather & Horn Heaths, Eriswell	130.8	X	X													
Weeting Heath	140.8	X							X		X		X			
Westhall Wood and Meadow	43.1	X		X												
West Stow Heath	42.6	X	X	X					X							
Weston Fen	49.6			X	X		X									
Wilde Street Meadow, Mildenhall	10.9	X														
Wortham Ling	53.2	X	X													
Wretham Park Meres	27.5						X						X			
Wretton	20.6							X								

Table 5. The 32 Breckland Sites of Special Scientific Interest containing grass-heath. A number of sites dominated by other habitats are not included, despite containing minor areas of dry grass-heath. Dry grassland and heathland National Vegetation Communities (NVC) are given for each site. Note that NVC features listed relate to those known at the time of notification and are not necessarily a complete account of what is currently present (Source: Natural England). Although the notified feature may be "CG7abde", pooling of these sub-communities into a single aggregate feature does not imply all are present on a site. Neither CG7d or CG7e are known to occur in Breckland (Rodwell 1992), as confirmed by the 1992 Norfolk and Suffolk Chalk Grassland survey commissioned by Natural England

Site of Special Scientific Interest containing grass-heath resource	Area (ha)	Calcicolous grasslands CG	Shingle, strandline and sand-dune communities SD	Calcifugous grasslands U	Dwarf-shrub heath H	Mesotrophic grasslands MG	Notified dry grassland and heathland NVC communities
Barnham Heath	76.5	X		X			CG7abde, U1bcdf, U4, U4/20
Barnhamcross Common	67.3	X	X	X			CG6, SD10, U1bcdf
Berners Heath, Icklingham	233.5	X	X	X	X		CG7abde, SD8, U1bcdf, H1
Black Ditches, Cavenham	1.7	X					CG2
Bridgham & Brettenham Heaths	446	X	X	X	X		CG7abde, U1abdf, U1e, SD8,
Cavenham-Icklingham Heaths	398.8		X	X	X		SD11, U1bcdf, H1
Cherry Hill & The Gallops, Barton	10.1	X					CG6
Cranwich Camp	12.6	X					CG7abde
Deadmans Grave, Icklingham	126.3	X		X			CG7abde, U1bcdf
East Harling Common	14.9	X					CG2, CG6
East Wretham Heath	141.1	X	X	X			CG7abde, SD8, U1bcdf
Elm Road Field, Thetford	5	X					CG6
Eriswell Low Warren	6.6	X		X			CG7abde, U1bcdf
Field Barn Heaths, Hilborough	18.7	X					CG2
Foulden Common	136.8	X					CG2, CG6
Foxhole Heath, Eriswell	84.5	X		X	X		CG7abde, CG7c, U1a, U1bcdf,
Gooderstone Warren	22	X	X	X			CG2, SD10, U1bcdf, H1
Grimes Graves	64.9	X	X	X	X		CG7abde, SD8, U1e, H1
Knettishall Heath	91.2	X		X	X		CG7abde, U1bcdf, H1
Lakenheath Warren	570.6	X	X	X			CG5, CG7abde, CG7c, SD10, SD11. U1a. U1bcdf. U4
Little Heath, Barnham	45.7	X		X			CG7abde, CG7c, U1a, U1bcdf
Lordswell Field, Eriswell	3.1	X		X			CG7abde, U1a, U1bcdf
Maidscross Hill, Lakenheath	45.2	X	X	X			CG7abde, SD11, U1bcdf
Narborough Railway Embankment	7.8	X					CG2, CG7abde
Old Bodney Camp	32.2	X	X	X			CG7abde, SD8, SD12, U1bcdf
RAF Lakenheath	115.5	X		X			CG7abde, U1bcdf
Stanford Training Area (STANTA)	4597	X	X	X	X	X	CG2, CG6, CG7abde, SD8, U1bcdf, U1e, H1, H9, MG5
Thetford Golf Course & Marsh	119.6	X		X	X		CG2, CG7abde, U1bcdf, H1
Thetford Heaths	269.4	X		X	X		CG7abde, CG7c, U1a, U1bcdf,
Thompson Water, Carr & Common	156	X	X	X			CG2, SD10, U1bcdf
Wangford Warren & Carr	65.6	X		X			CG7c, U1a, U1bcdf
Weather & Horn Heaths, Eriswell	130.8			X	X		U1bcdf, H1
Weeting Heath	140.8	X		X			CG7abde, CG7c, U1e
West Stow Heath	42.6	X		X	X		CG7abde, U1bcdf, H1

Environmentally Sensitive Area (ESA)

The Breckland Environmentally Sensitive Area was designated in 1988, covering 94,535ha (Figure 2), it is one of 22 such areas in England. The scheme, now administered by Natural England, has several objectives, including the maintenance and enhancement of the nature conservation value of heathland, river valley grasslands and arable land. The scheme provides incentives to landowners through area payments against standard prescriptions to meet environmental objectives, together with capital payments to support specific projects, for example, the re-introduction of grazing and restoration of heathland vegetation. In addition to grant aiding management of heaths and river valley grasslands, the scheme established uncropped wildlife strips (cultivated margins) on arable land, one of only two ESAs in the country to do so, as well promoting conservation headlands (unsprayed areas of cereals) and incentives to maintain over-wintered stubbles. To date still it is the only national statutory designation to have been conferred on Breckland. Under the agri-environment scheme which replaces it, Environmental Stewardship, Breckland currently remains one of Natural England's priorities for targeting funding.

Important Plant Areas (IPAs)

The Breckland Important Plant Area (IPA) has been defined and championed by Plantlife to assist in targeting protection of vascular plant, bryophyte, lichen and algal species. The IPA comprises three layers (Figure 6); a Core Layer that indicates the key areas of botanical interest and is based on existing statutory protection network boundaries (SSSIs); a Zone of Opportunity Layer that provides a wide boundary, indicating an area with potential for restoration to support key features in the future; the third layer comprises those tetrads identifying the Criterion A species (Globally and European threatened plants and other threatened endemics or near endemics) (*pers. comm.* Pankhurst, Plantlife).

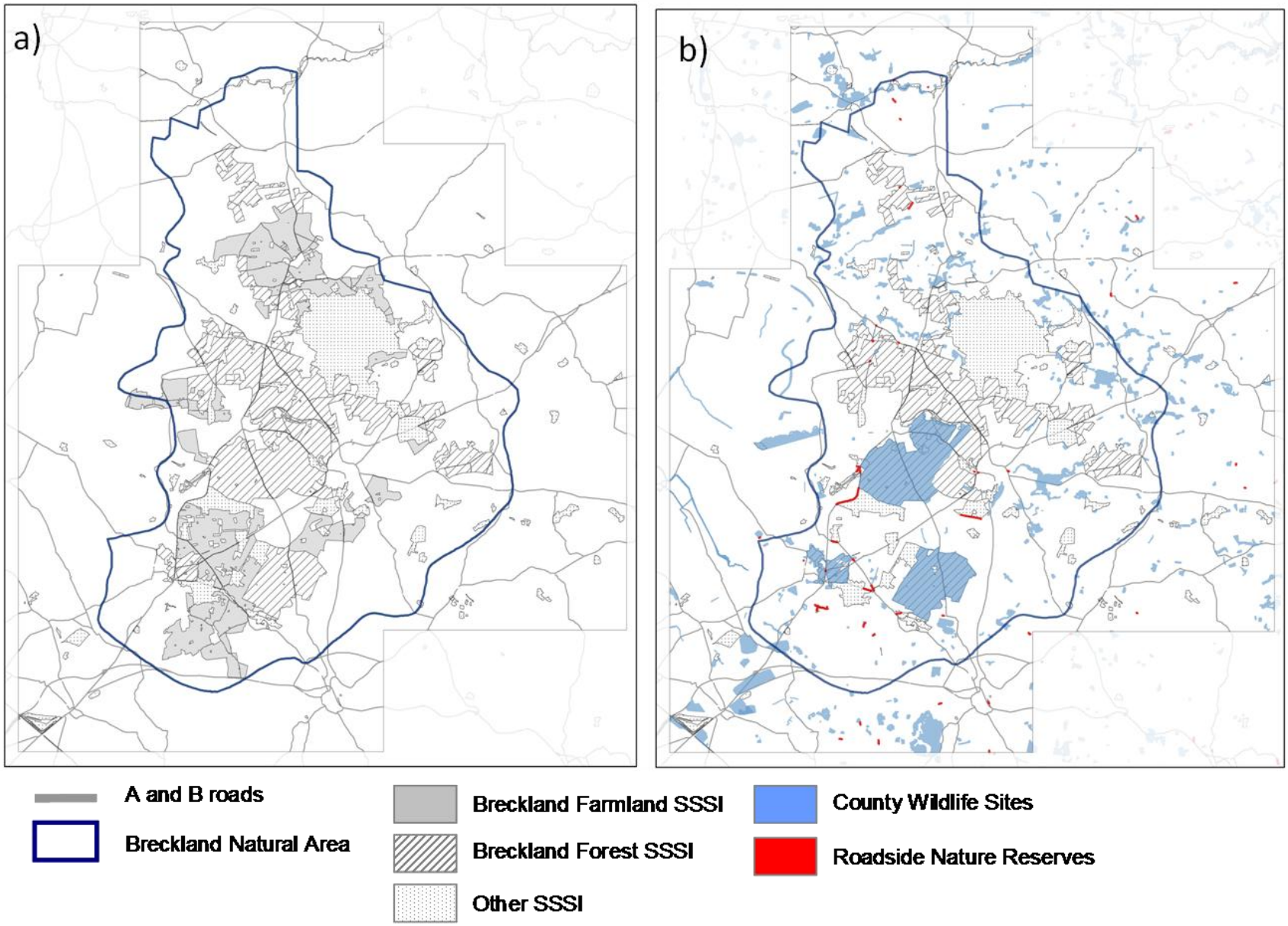


Figure 4. Location of designated sites within the Breckland National Character Area and the 23 10 km Ordnance Survey grid squares: a) Sites of Special Scientific Interest (SSSI); b) County Wildlife Sites (CWS) and Roadside Nature Reserves (RNR

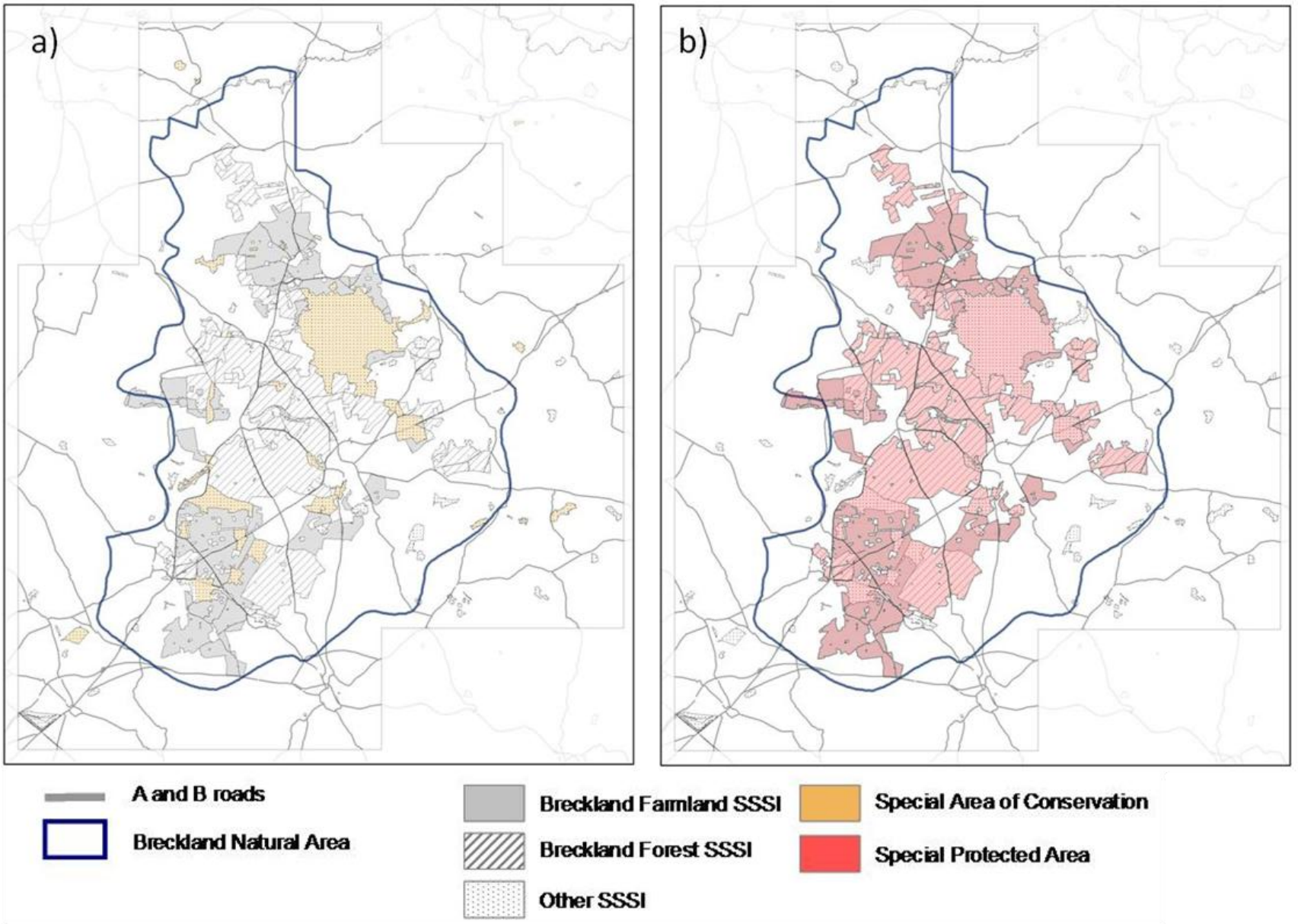


Figure 5. Location of designated sites within the Breckland National Character Area and the 23 10 km Ordnance Survey grid squares: a) Special Area for Conservation (SAC); b) Special Protected Area (SPA)

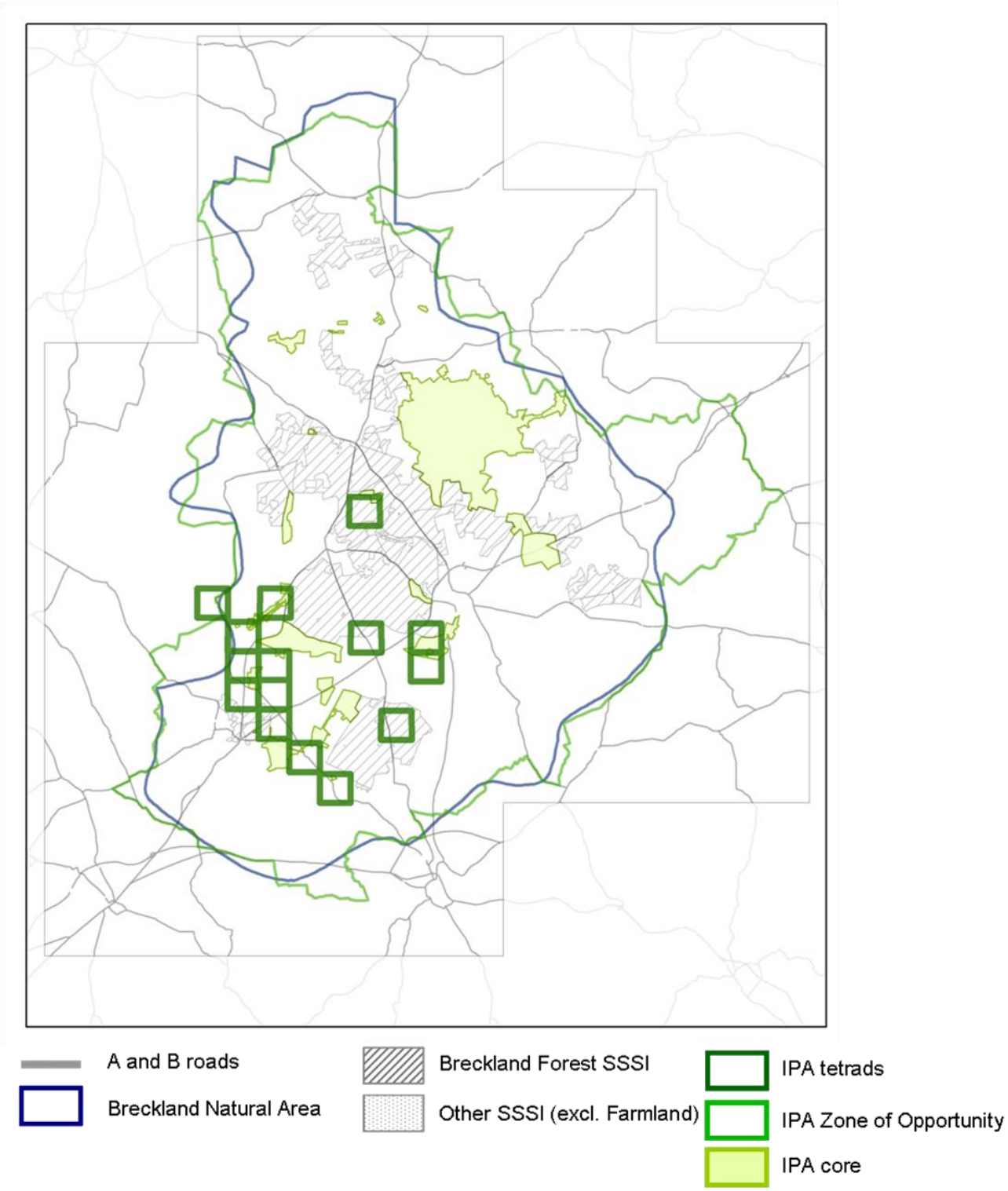


Figure 6. Location of Plantlife's Important Plant Areas (IPA), within the Breckland National Character Area and the 23 10 km Ordnance Survey grid squares

Breckland Biodiversity Audit: Methodology

Analysing Long-Term Trends in Weather

Weather data were collated and analysed in order to:

- Quantify and contrast the Breckland climate to that of East Anglia and Southern England (see Climate section).
- Analyse the extent and magnitude of any change in weather during recent decades.
- Consider qualitatively the potential consequences for Breckland biodiversity.

For both rainfall and temperature analyses, seasons (each of three months duration) were defined as follows:

Spring:	March - May
Summer:	June - August
Autumn:	September - November
Winter:	December - February

Daily precipitation (total mm) and daily minimum and maximum temperature (°C) data were obtained from the British Atmospheric Data Centre (BADC) (http://badc.nerc.ac.uk/home/index.html). Forty six weather stations were located in the Breckland region. However, data coverage was intermittent and no single station covered the whole of the previous century.

Individual stations that provided the longest and most consistent run of data for temperature, and separately for rainfall, were selected. In order to fill in gaps in the data time series recorded at these primary references stations, records from other subsidiary stations were also used. The relationship between the subsidiary station and reference station was first established using linear regression for all days with overlapping mutual records, and then this equation was used to predict values missing from the reference station. Full details are provided in Supplementary Materials in the Appendix.

Elveden Hall was used as the primary station for rainfall data, with Santon Downham and Thetford Water Works selected as subsidiary stations. Santon Downham, Grimes Grave and Santon Downham were used as primary stations, with Honington used for subsidiary data. The locations of all weather stations used are shown in Figure 7.

Analyses of trends through time

The relationship between total rainfall (mm) per season, and mean daily minimum and mean daily maximum temperatures per season over time (across years) was examined by relating weather to year using linear regression (with normal error). Whether the numbers of drought events, numbers of extreme rainfall events and number air frost days per season had changed through time was examine by modelling weather against year, using general linear models with Poisson error terms (to account for the discrete count data with small range and non-normal error). Significance of trends through time were examined using Wald Chi square tests.

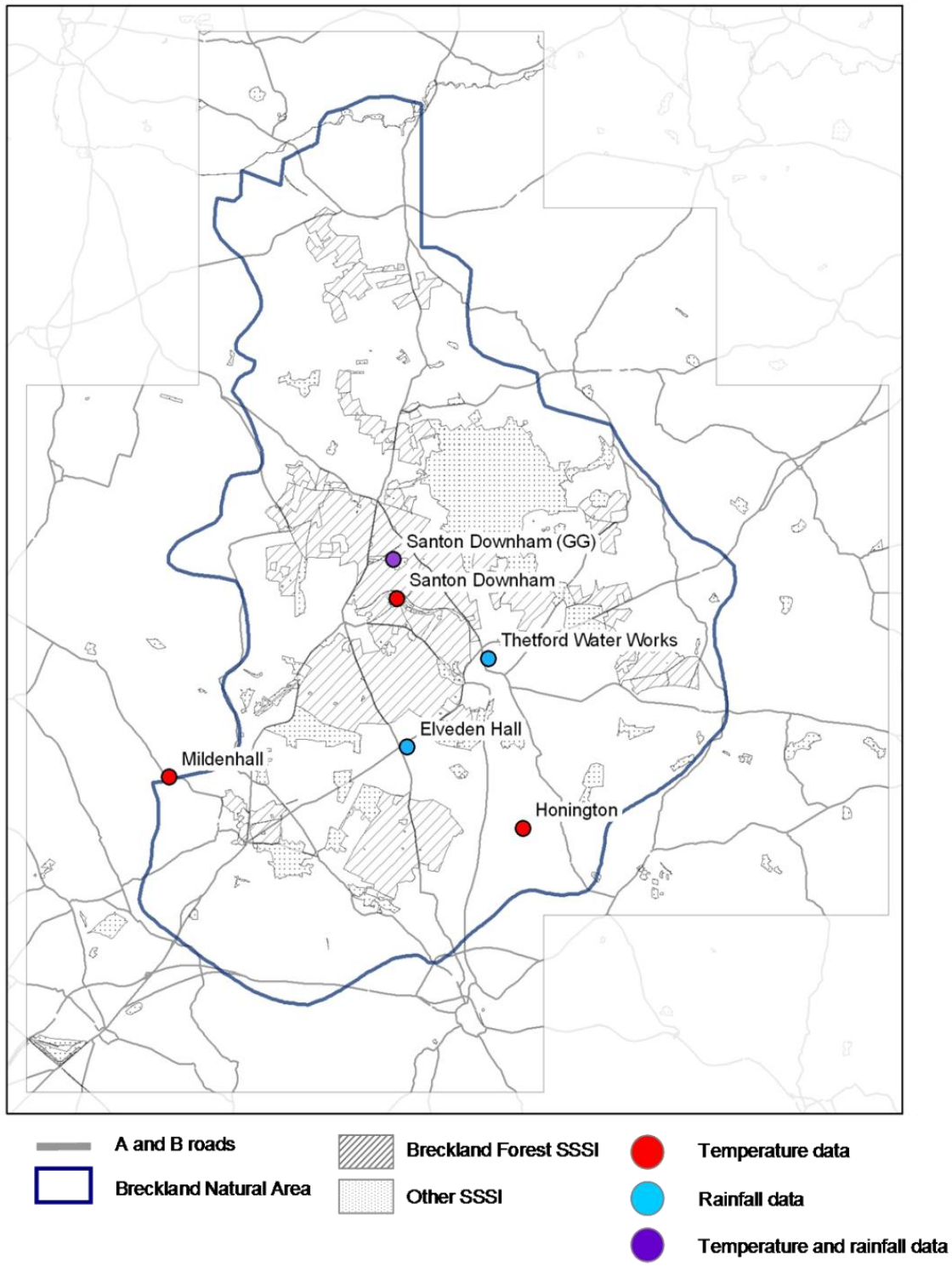


Figure 7. Locations of stations in Breckland from which weather data were sourced

Defining the Area of Species Record Capture

It was felt important to capture the full extent of characteristic species when collating records. Data extraction and mapping, therefore, considers a slightly larger area than that of the NCA. This wider area encompasses the largest area classified as Breckland by either the National Character Area (1019 km^2) or the Breckland Environmentally Sensitive Area (945 km^2) and adds a 1km buffer to this as a safety margin. Species observations (records) were collated from all available sources for each of the 23 10 km grid squares that lay within or included part of the combined and buffered (1 km) National Character Area and Environmentally Sensitive Area (Figure 2).

The collation of records, from 23 10km squares resulted in the inclusion of records from sites generally considered to lie outside of Breckland, for example Redgrave and Lopham Fens. The compilation of data from 10 km squares was important for a number of reasons:

- Several datasets were only available as units of 10 km grid squares.
- Some records were only available at 10 km resolution.
- Collation, and subsequent mapping, of records from the wider area would allow questioning of the suitability of the Breckland National Character Area as a definitive area for the region's important specialists.

This is referred to subsequently as the Breckland "region", to distinguish it from the Breckland NCA or any other boundary.

Collation and Sources of Species Records

Species data were imported and managed using the software Recorder 6 (www.jncc.gov.uk/page-4592).

Sources of Species Records

Key data sources included: Local Records Centres of Norfolk, Suffolk and Cambridgeshire, the National Biodiversity Network gateway, Invertebrate Site Register, County Natural History and Recording Societies and the Breckland Rare Plant Database. These are discussed in turn below and a full list of data sources, including the number of records provided, is given in Table 12.

<u>Local Records Centres (LRC)</u>

The three local biological records centres in the selected area; the Norfolk Biodiversity Information Service (NBIS), Suffolk Biological Records Centre (SBRC) and Cambridgeshire & Peterborough Environmental Records Centre (CPERC) provided all species data available for the 23 selected 10 km grid squares. These Local Record Centres actively collect data from local recorders and recording schemes and where possible from national recording schemes. They also provide information to the NBN Gateway.

<u>National Biodiversity Network (NBN)</u>

Records were sourced from the National Biodiversity Network (NBN). NBN is a national database that holds records from 493 organisations, including county recording schemes and natural history and taxonomy groups. Access to data was granted by 38 of 44 organisations holding records in the 23 Breckland grid squares (Table 12). Access was not provided to the Dipterists Forum Recording

Scheme for Stilt & Stalk Flies, Dragonfly records from the British Dragonfly Society's Dragonfly Recording Network for the period between 1992 and 2009, Fungal Records Database of Britain and Irelandand the Threatened Bryophyte Database. Whilst access to these databases would certainly have improved our understanding of the occurrence and distribution of species in these groups, other databases, such as those from LRCs, include records for these groups. In addition, we also had access to the British Dragonfly Society's former Dragonfly Recording Network prior to 1992.

Invertebrate Site Register (ISR)

Data obtained from the NBN included all available records from the Invertebrate Site Register (ISR). The ISR was established by English Nature to identify, document and evaluate sites of importance for the conservation of terrestrial and freshwater invertebrates in Great Britain. The national database holds records from 1900 to 2005, with the majority of observations made in the late 1980s. ISR data for the Breckland square TF80 were not available.

County Natural History and Recording Societies

A large number of county recording societies, such as Norfolk Bryology Group, provide data to the relevant Local Recording Centre and these would have reached the BBA via the LRCs.

Both the Norfolk and Suffolk branches of Butterfly Conservation provided all of their records for the Breckland grid squares. The Suffolk Moth Group provided all records from the area, with the exception of a small number that were confidential; it is not known for which species confidential records exist. This is an unfortunate omission because the confidential records may include information on priority species of importance to the audit. The Norfolk Moth Group provided their entire Norfolk database to NBIS, from whom we obtained the Breckland records. The Freshwater Invertebrate Survey of Suffolk, the British Plant Gall Society and the British Arachnological Society provided records directly to the BBA. Records from all these organisations were not duplicated in other databases, with the exception of a small number of records passed on to multiple organisations by individual recorders.

Breckland Rare Plant Database (BRPD)

A number of vascular plant species known to be largely or entirely restricted to the Breckland region had long been a focus of interest among botanists and conservationists. During the mid 1970s Gigi Crompton, of the Cambridge University Botanic Garden, collated all known historic records for selected rare vascular species in Breckland (Table 6) (Compton, 1977). Historic and known extant sites were visited and populations recorded in detailed field surveys during 1975-77. The resulting survey data, arranged by focal species, were collated separately for Norfolk and Suffolk and archived with the Nature Conservation Council offices in Norwich and Bury St Edmunds.

In Suffolk, populations of 31 focal species were systematically surveyed from 1991 and onwards by Yvonne and David Leonard, with many populations receiving annual survey. Gillian Beckett was commissioned by English Nature to collate available records for 23 rare plant species in the Norfolk Breckland, including 12 species not surveyed by Gigi Crompton, and to survey known and lost sites during 1992 (Beckett, 1993). A small number of species and sites were selected to receive follow-on work, conducted in 1993-4 (Beckett, 1995) and in subsequent years (Gibbons, 2000). However, many sites and species lacked any consistent or systematic survey coverage in the last 15 years. Data collated during this period and deposited with English Nature included records for smooth rupturewort *Herniaria glabra* sites surveyed by Jean Gaffney through the 1980s and 1990s.

For a subset of rare plants entirely or largely restricted to Breckland (including field mugwort *Artemisia campestris,* spiked speedwell *Veronica spicata,* Spanish catchfly *Silene otities,* grape hyacinth *Muscari neglectum,* perennial knawel *Scleranthus perenni*s ssp. *prostratus,* proliferous pink *Petrorhagia prolifera* and fingered speedwell *Veronica triphyllos*), it is likely that all existing populations have been located and identified. For a further selection of species (e.g. Breckland thyme *Thymus serpyllum, Herniaria glabra,* Breckland speedwell *Veronica praecox,* purple-stemmed cats-tail *Phleum phleoides*), our understanding of distribution is good but thought to be incomplete. For a further group of species (e.g. burr medic *Medicago minima,* fine-leaved sandwort *Minuartia hybrida,* lucerne *Medicago sativa* ssp. *falcata*, dense silkybent *Apera interrupta*) specific surveys have not been conducted, although records of these species were made during monitoring of focal species, and records under-represent their distribution.

Breckland Rare Plant Survey data had not been entered into any electronic database previously and were not fully captured within the LRCs of either Suffolk or Norfolk. Data for 11 Breckland speciality plants covered by Gigi Crompton's surveys in 1975-7 were collated by P. Dolman (Dolman and Sutherland 1992). The audit updated and greatly expanded this database. Records for 28 rare Breckland plant species (Table 6) were compiled to create the Breckland Rare Plant Database (BRPD), collated in April 2010 by Helen Jobson, a University of East Anglia student working with Plantlife. Suffolk Rare Plant Survey records were obtained from the Natural England office in Bury St Edmunds and Norfolk Rare Plant Survey records were obtained from the Natural England office in Norwich. For each of the focal species that had received species-specific survey visits, every dated survey record was captured. In addition, any incidental records of additional rare plants (e.g. *Phleum phleoides,* sand catchfly *Silene conica*, *Apera interupta, Medicago minima, Medicago sativa* ssp. *falcata*) noted during surveys of focal populations, were also compiled in the electronic database. Further vascular plant records were obtained from the Conservation Room at STANTA, Gillian Beckett's electronic files and Plantlife records for tower mustard *Arabis glabra* and red-tipped cudweed *Filago lutescens*.

Table 6. Rare vascular plant species for which records were collated into the Breckland Rare Plant Database (BRPD). Key surveys generating records are shown: Y indicates populations systematically surveyed; (Y) indicates lower priority and casual survey; associated records – species not subject to survey for which records were extracted from surveys of focal species

	Crompton (1975-77)	Beckett (Norfolk only, 1992)	Beckett (1993-4)	Leonard (Suffolk only, 1991-2009)	Associated records
Alyssum alyssoides	Y	Y		Y	
Apera interrupta					Y
Arabis glabra		Y		Y	Y
Artemisia campestris	Y	Y		Y	
Carex ericetorum		Y			Y
Corynephorus canescens				Y	
Dianthus deltoides		Y		Y	Y
Festuca longifolia			Y	Y	Y
Filago lutescens				Y	
Galium parisiense		Y			Y
Herniaria glabra	Y	Y	Y	Y	
Hypochaeris glabra					Y
Hypochaeris maculata				Y	
Medicago minima		(Y)		Y	Y
Medicago sativa ssp. *falcata*				Y	Y
Minuartia hybrida					Y
Muscari neglectum				Y	
Petrorhagia prolifera		Y			
Phleum phleoides	Y	Y		Y	Y
Scleranthus annuus					Y
Scleranthus perennis ssp. *prostratus*				Y	
Silene conica		Y		Y	Y
Silene otites	Y	Y	Y	Y	
Thymus serpyllum	Y	Y	Y	Y	Y
Veronica praecox	Y	Y		Y	
Veronica spicata ssp. *spicata*	Y	Y		Y	
Veronica triphyllos	Y	Y		Y	
Veronica verna	Y	Y		Y	Y

Other Datasets, Reports and Records from Individuals

Detailed annual plant, invertebrate and vertebrate biodiversity surveys of the Elveden site have been commissioned by Center Parcs since 1990. All data from the 1990-2009 surveys were obtained by the BBA.

Invertebrate records collected by Mark Telfer and Brian Eversham between 1993 and 1994 from a number of grass-heaths, including Lakenheath Warren and road verge sites (Telfer and Eversham 1995). All records were obtained by the BBA.

All records were also obtained from the report "Invertebrates of Red Lodge Heath in relation to other sites in the Breckland National Character Area: Aculeate Hymenoptera and Coleoptera" (Harvey, 2004). These included species recorded during the survey of Red Lodge Heath and records collated by Peter Harvey from other sources.

34,369 records were obtained from the ADAS report to MAFF "Biological Monitoring of Arable Field Margins in the Breckland ESA, 1989-1996" (ADAS 1997). However, 32,177 were only identified to family or genus level and contained few priority invertebrate records.

The BBA also obtained unique species records found in letters, personal communication and reports stored in the offices of Forestry Commission, SBRC, Natural England (Bury St Edmunds and Norwich), STANTA, NBIS, Suffolk and Norfolk Wildlife Trusts. Generally these undigitised records were pre-1990 and many are thought to have been captured by the ISR and therefore be duplicates. However, the paper records obtained by the BBA provide, in contrast to those in the ISR, site and recorder names and more precise grid references. A sub-set of approximately half of the relevant Breckland County Wildlife Site files held by NWT were examined for records. Very few unique records of Breckland conservation priority species were obtained and further examination of site files at SWT was therefore not considered useful for the purpose of collating species records. However, these files contain valuable information on plant assemblages and site habitat conditions.

Unpublished theses and dissertations (Ph.D., MSc. and BSc.) from the University of East Anglia and Anglia Ruskin University were assessed for additional species records. Few contained records of priority or Breckland specialist species. However, useful records for arachnidae were obtained from Sastre (2003), and carabid records from Lin (2005) and Bertoncelj (2010). Records were also obtained from current students, Scott Pedley, Chris Jones and Ben Christie.

Thirty-two species recorders and taxonomic experts provided additional and previously un-captured records. Individuals providing large numbers of records are indicated in Table 12.

Duplicate Records

Records from NBIS, SBRC and CPBRC did not contain large numbers of records also duplicated in the ISR or NBN. However, a number of records passed on to multiple organisations by individual recorders will have resulted in duplicate records. Datasets obtained from NBN frequently included multiple entries of the same record. Most of the multiple records had NBN observation keys (codes) and could be removed. However, records from the ISR and the former Dragonfly Recording Scheme did not have observation keys and duplicates could not be removed.

As analysis considers only the overall representation of each species in each 1 km x 1 km square, retained duplicate and multiple records are not considered a problem; therefore duplicates were not filtered further as this would have been excessively time consuming.

Record coverage and completeness

Due to the confidentiality of a number of mammal records, particularly those relating to badgers, the BBA database is incomplete in relation to mammals. Mammal species were therefore, included in the list of conservation priority species, but were not included in the mapping of priority species.

Avian species records passed to the Local Records Centres, often via county bird reports, provide incomplete, idiosyncratic coverage compared to the systematic monitoring data conducted by the British Trust for Ornithology (BTO) with funding from the Joint Nature Conservancy Council (JNCC). Bird species for which records were collated are included in the list of conservation priority species, but due to poor coverage of records, they are not included in the mapping of priority species. It is recommended that subsequent analysis should be conducted using BTO Breeding Bird Survey (BBS) and Atlas data to identify those bird species for which the region supports nationally important populations or wintering numbers.

Recommendation

- BTO be commissioned to analyse Atlas data, BBS data and other survey coverage from Breckland, in relation to East Anglia and lowland England, to identify which species have regionally or nationally important populations.

Species historic to Breckland

Where possible conservation priority species whose presence in Breckland is now only historic (i.e. locally extirpated or nationally extinct) were identified, using extinct statuses (Red Data Book Extinct), local knowledge, information from taxonomic experts and the Natural England publication Lost Life: England's lost and threatened species (Brown et al. 2010).

Data quality and resolution

A species record is defined as an observation of one species, in one place and at given time.Mandatory and preferred fields for collated species records were:

Identification to species level

In addition to the 32,177 records from ADAS, a further 3525 records were received that were not identified to species level. These records were obtained from a range of sources, including Local Records Centres, ISR and national recording schemes.

Grid reference

29,096 records (3.5%) were received from locations outside of the 23 Breckland 10 km grid squares. These included records supplied with incorrect grid references and valid records from outside the selected Breckland area.

Most collated records had grid references resolved to a minimum of 1 km. However, 33,877 records (4.1%) were only resolved to 10 km. Species from these records were included in species and priority lists, but were not considered when mapping to a 1 km resolution.

151,138 observations, primarily of flowering plants, were recorded as tetrads. For mapping at a 1 km resolution it was assumed that the observed species was found in all four 1 km squares that made up the tetrad, i.e. a single tetrad observation was converted to four single 1 km records. This will over-represent the true distribution of some scarcer species and artificially smooth species distributions. However, this is offset by the fact that many SSSI sites straddle a number of 1 km squares but species records are often placed on a hypothetical centre point.

Observation date

There were 904 records without an observation date or that had large date ranges that spanned either side of the selected cut-off date of 1980 (see Data Mapping section for further details). These were included in species and priority lists but were removed prior to 1 km mapping of priorities.

Species recorder

A species recorder and/or determiner were unavailable for approximately 20% of records, many obtained from the ISR. This prevented the validation of some uncertain species records.

Species lists and validation

The total number of species and total species list were collated from all the valid records. From this, all species with a national or international conservation status were identified to create a list of Breckland conservation priority species (see below for more information regarding designations).

Local Records Centres receive validated species records from county recorders. In addition, records received from other recorders are passed to county recorders for validation. This validation is the foundation of how local record centres work and ensures the data are fit for purpose. However, this process is not completely failsafe. It was therefore important to validate the priority list of species, and to filter inaccurate or infeasible records. The first draft of the Breckland conservation priority species list was shown to species experts at the Species and Habitat Workshop held at UEA on 5th October 2009, with separate lists examined for all groups of taxa. Later iterations of the Breckland conservation priority species list were further validated by circulation to a number of experts who were asked to comment on any records that they considered suspect, or to provide additional species that they knew to occur.

Following validation, forty-seven species were removed having been identified as not occurring in the Breckland area, as being incorrect identifications, were considered to be garden escapes, recently introduced or deliberately planted species (Table 7).

Eleven species were identified by experts as occurring in Breckland and being of importance (priority or Breckland specialists), but for which there were no records available. These species were included in the priority lists.

Table 7. Species for which records were excluded, showing the source and reasons for exclusion

* a number of other species are recorded in Breckland as accidentals or vagrants and with no regular or passing residence are not of management concern in Breckland

Group	Species	Source of validation	Reason for exclusion
Conifer	*Pinus sylvestris*	BBA	Widely planted, native status uncertain
Flowering plant	*Buxus sempervirens*	BBA	Widely planted as game cover
Flowering plant	*Calamagrostis scotica*	Ian Simper	Most likely misidentification
Flowering plant	*Centaurea calcitrapa*	Ian Simper	Not native to Breckland
Flowering plant	*Clinopodium menthifolium*	Ian Simper	Not native to Breckland
Flowering plant	*Colchicum autumnale*	Neal Armour-Chelu	Not native to Breckland, gardened species
Flowering plant	*Meconopsis cambrica*	Ian Simper	Not native to Breckland
Flowering plant	*Melittis melissophyllum*	Ian Simper	Not native to Breckland, gardened species
Flowering plant	*Polemonium caeruleum*	Ian Simper	Not native to Breckland, gardened species
Flowering plant	*Saxifraga hypnoides*	Ian Simper	Not native to Breckland, gardened species
Flowering plant	*Teucrium chamaedrys*	Ian Simper	Not native to Breckland, gardened species
Crustacean	*Palinurus elephas*	BBA	Marine species
Arachnid	*Callilepis nocturna*	Paul Lee	Most likely misidentification
Arachnid	*Talavera petrensis*	Paul Lee	Most likely misidentification
Coleoptera	*Melanotus punctolineatus*	Duncan Sivell	Spurious record
Diptera	*Cheilosia carbonaria*	Ivan Perry	Most likely misidentification
Diptera	*Cheilosia mutabilis*	Ivan Perry	Rejected during validation
Diptera	*Dorylomorpha haemorrhoidalis*	Ivan Perry	Most likely misidentification
Diptera	*Erioptera meigeni*	Ivan Perry	Most likely misidentification
Diptera	*Fannia umbratica*	Ivan Perry	Rejected – Scottish species
Diptera	*Gimnomera tarsea*	Ivan Perry	Rejected during validation
Diptera	*Graphogaster brunnescens*	Ivan Perry	Most likely misidentification
Diptera	*Hilaria psedochorica*	Ivan Perry	Most likely misidentification
Diptera	*Meiosimyza laeta*	Ivan Perry	Most likely misidentification
Diptera	*Melangyna guttata*	Ivan Perry	Rejected during validation
Diptera	*Melieria picta*	Ivan Perry	Most likely misidentification
Diptera	*Orellia falcate*	Ivan Perry	Rejected during validation
Diptera	*Paroxyna producta*	Ivan Perry	Rejected during validation
Diptera	*Pegohylemyia apiciseta*	Ivan Perry	Most likely misidentification
Diptera	*Platyceirus podagratus*	Ivan Perry	Most likely misidentification
Diptera	*Ramonda prunaria*	Ivan Perry	Rejected during validation
Diptera	*Renocera striata*	Ivan Perry	Most likely misidentification
Diptera	*Rhadiurgus variabilis*	Ivan Perry	Most likely misidentification
Diptera	*Tabanus glaucopis*	Ivan Perry	Rejected during validation
Diptera	*Tipula holoptera*	Ivan Perry	Rejected during validation
Diptera	*Tipula pseudovariipennis*	Ivan Perry	Rejected during validation
Heteroptera	*Adelphocoris seticornis*	Bernard Nau	Rejected during validation
Heteroptera	*Anthocoris viscid*	Bernard Nau	Rejected during validation
Heteroptera	*Halticus saltator*	Bernard Nau	Rejected during validation
Heteroptera	*Micronecta minutissima*	Bernard Nau	Rejected during validation
Heteroptera	*Myrmedobia coleoptrata*	Bernard Nau	Rejected during validation
Heteroptera	*Rhopalus (Rhopalus) rufus*	Bernard Nau	Rejected during validation
Lepidoptera	*Idaea dilutaria*	BBA (Norfolk Moths)	Most likely a misidentification
Reptile	*Lacerta agilis*	Neal Armour-Chelu	Outside historically validated species range

Breckland Conservation Priority Species: Criteria

Current conservation statuses (see: http://www.jncc.gov.uk/page-1773) for all designated taxa were obtained from the JNCC's Conservation Designations for UK Taxa (http://www.jncc.gov.uk/page-3408; latest update accessed on 27/07/10).

This list of designations included:

- Species listed on the Red Lists, based on IUCN criteria, as Extinct, Extinct in the wild, Critically Endangered, Vulnerable, Rare, Near threatened and Data deficient, but excluding species of Least concern (Table 8).
- Species listed on Red Lists not based on IUCN criteria, including Nationally Rare and Scarce statuses (Table 9). Older species reviews have used Notable A and B statuses defined, for example, as Notable A, nationally scarce and occurring in 30 or fewer 10 km squares and Notable B, occurring in 31-100 of the UK 10km squares by Hyman and Parsons (1992) in a review of Carabids. Species with these designations were considered Breckland conservation priority species where these categories were included in the JNCC's Conservation Designations for UK Taxa.
- Biodiversity Action Plan Priority Lists (hereafter referred to as BAP species).
- Species listed European Directives.
- Species listed the Schedules of the Wildlife & Countryside Act 1981.

However, the JNCC list is incomplete and was found to not include a number of spider species designated as Notable A or B (Scott Pedley, *pers. comm.*). The priority list for spiders was supplemented with information from the Provisional Atlas of British Spiders (Harvey, Nellist and Telfer 2002). The Orthoptera priority list was also supplemented with the Atlas of Grasshoppers, Crickets and Allied Insects in Britain (Haes and Harding 1997). Additional designations for the families Acalpytrate and Calyptrate families are available in unpublished reviews provided by Ivan Perry.

For the purposes of analysis, the following groups were considered to be Breckland Conservation Priorities:

- **BAP – all Biodiversity Action Plan priority species as in the revised 2007 list.**
- **Rare species – those designated on the Red Lists (Global and UK lists, but not those listed as Least concern), those with Nationally Rare and Nationally Scarce statuses, Notable A and B species and Red List birds (Amber List birds were excluded, due to their moderate threat level).**
- **Species known or considered to be Breckland Specialists (see below for methodology and definition).**

Note: Bird and mammal species were included in the list of Breckland conservation priority species, but were excluded from mapping (see Record Completeness and Coverage section for more details)

Many species had more than one designation and full details for all Breckland conservation priority species recorded are given in an Appendix.

Table 8. Descriptions of Red Data Book species conservation designations based on IUCN criteria (Source http://www.jncc.gov.uk/page-3425)

Designation	Description
Extinct	Taxa which are no longer known to exist in the wild after repeated searches of their localities and other known likely places.
Extinct in the wild	Taxon only known to survive in cultivation, in captivity or as a naturalised population (or populations) well outside the past range.
Critically Endangered	Taxon is facing an extremely high risk of extinction in the wild in the immediate future, as defined by any of the IUCN criteria A to E.
Endangered	Best available evidence indicates that taxon meets any of the IUCN criteria A to E for Endangered and it is therefore considered to be facing a very high risk of extinction in the wild.
Vulnerable	Best available evidence indicates that taxon meets any of the IUCN criteria A to E for Vulnerable and it is therefore considered to be facing a high risk of extinction in the wild.
Rare	Taxa with small populations that are not at present Endangered or Vulnerable, but are at risk. In GB, this is interpreted as species which exist in fifteen or fewer 10km squares. This category is not in the 1994 or 2001 criteria, but still applicable to lists that have not been reviewed since 1994.
Data Deficient	Inadequate information is available to make a direct, or indirect, assessment of the risk of extinction based on its distribution and/or population status. Listing of taxa in this category indicates that more information is required and acknowledges the possibility that future research will show that a threatened category is appropriate.
Near Threatened	A taxon is Near Threatened when it has been evaluated against the criteria but does not qualify for Critically Endangered, Endangered or Vulnerable now (or Lower risk-conservation dependant in the pre 1994 criteria), but is close to qualifying for or is likely to qualify for a threatened category in the near future. In GB, this category includes species which occur in 15 or fewer hectads but do not qualify as Critically Endangered, Endangered or Vulnerable.
Least Concern	A taxon is Least Concern when it has been evaluated against the criteria and does not qualify for Critically Endangered, Endangered, Vulnerable, Near Threatened (or Lower Risk - conservation dependant, or Nationally Scarce in Britain). Widespread and abundant taxa are included in this category.

Table 9. Descriptions of species conservation designations not based on IUCN criteria (Source http://www.jncc.gov.uk/page-3425 and http://www.bto.org/psob/index.htm#the_criteria)

Designation	Description
Nationally Rare	Occurring in 15 or fewer hectads in Great Britain. Excludes rare species qualifying under the main IUCN criteria.
Nationally Scarce	Occurring in 16-100 hectads in Great Britain. Excludes rare species qualifying under the main IUCN criteria.
Bird population status: Red	Species that are Globally Threatened (IUCN criteria)
	A severe decline in the UK between 1800 and 1995, without substantial recent recovery (Historic Decline).
	Severe decline in the UK breeding population size, of more than 50%, over 25 years or since 1969 (Breeding Population Decline)
	Severe decline in the UK non-breeding population size, of more than 50%, over 25 years or the longer-term (Non-breeding Population Decline)
	Severe decline of more than 50% in the UK range, as measured by number of 10 km squares occupied by breeding birds, over 25 years or the longer-term (Breeding Range Decline)
Bird population status: Amber	Species categorised as a Species of European Conservation Concern
	Red listed for Historical Decline in a previous review but with substantial recent recovery (more than doubled in the last 25 years) (Historical Decline – Recovery)
	Moderate decline in the UK breeding population size, of more than 25%, over 25 years or since 1969 (Breeding Population Decline)
	Moderate decline in the UK non-breeding population size, of more than 25%, over 25 years or the longer-term (Non-breeding Population Decline)
	Moderate decline of more than 25% in the UK range, as measured by number of 10 km squares occupied by breeding birds, over 25 years or the longer-term (Breeding Range Decline)
	UK breeding population of less than 300 pairs (BR), or non-breeding population of less than 900 individuals (WR). (BR and WR Rarity)
	At least 50% of the UK breeding (BL) or non-breeding (WL) population found in 10 or fewer sites (BL and WL Localisation)
	At least 20% of the European breeding (BI) or non-breeding (WI) population found in the UK (BI and WI International Importance)

Treatment of Sub-species

All designated sub-species are given in the list of priorities in an Appendix. However, the accuracy of identification of some sub-species was doubtful, such as the presence of the Scottish species *Lycaena phlaeas subsp. hibernica*. In addition, a number of older records may have been made prior to the confirmation of the sub-species. *Scleranthus perennis* ssp. *prostratus* and *Veronica spicata* ssp. *spicata* are sub-species naturally restricted to Breckland within the UK and, although other sub-species occur elsewhere in the UK, those do not occur naturally in Breckland. However, a number of records for both species were only recorded to species resolution, without sub-species being explicitly stated.

If the sub-species was designated but the parent species was not (e.g. *Helianthemum oelandicum* subsp. *incanum* - Status: Nationally Scarce; *Bromus hordeaceus* subsp. *thominei* - Status: Nationally Scarce), the parent and the sub-species were considered separately in all analysis and presentation. Where both the main and the sub-species were designated, records for the two were combined and the higher designation was assigned (e.g. *Monotropa hypopitys* – RDB: Endangered, BAP; subsp. *hypophegea* – RDB: Endangered, Status: NS, BAP; *Eurhynchium pulchellum* - Status: Nationally Scarce, BAP; var. *diversifolium* – RDB: Endangered).

Viola tricolor subsp. *curtisii* is a coastal sub-species occurring inland in Breckland but is not designated, whilst the subsp. *tricolor* and the parent species are both designated as RDB. In this case the sub-species *Viola tricolor* subsp. *curtisii* was considered separately from the parent species or other sub-species.

Breckland Specialist Species: Criteria

Selection of Breckland Specialists

The importance of Breckland for regional endemics and specialists was established by identifying species whose distribution range or population size:

- Is entirely restricted to the Breckland region.
- Is largely restricted to the Breckland region.
- Have a primary stronghold in the Breckland region.
- Have a secondary stronghold in Breckland.
- Species with a mainly coastal distribution and not found inland apart from within Breckland, were also considered as a separate class of regional specialist as these also contribute to the distinctive biological character of the region.

Definitions of restricted status and strongholds are given in Table 10. Note: As described earlier, the Breckland region was defined as the 23 10 km squares that make up the National Character Area.

Initial identification of Breckland specialists was conducted by a preliminary study of all statements in Recorder 6 database. These statements include information from the Invertebrate Site Register and a number of Red Data Books and species atlases (Table 11). Species for which “Breckland” or the “East Anglian Brecks” was stated as important were selected and formed the draft list of Breckland specialists.

This list was refined in consultation with specialists and experts at the Species and Habitat Workshop and subsequently by contacting approximately a further 60 species experts. In total, the population or distribution status of 744 species was evaluated in relation to their uniqueness to Breckland.

For some taxonomic groups accurate information regarding UK distributions and populations sizes are available and were used to classify Breckland specialist status. Sizes of breeding bird populations were used to select Breckland specialist birds according to the criteria in Table 10. Atlases of UK population distributions for flowering plants and spiders were available and these included the number of UK 10 km grid squares in which a species has been recorded (Hill et al. 2004, British Arachnological Society records (P. Harvey *pers. comm.*). For other groups, such as

carabids, odonata, orthoptera and earwings, atlases were also available but with distributions only available to the BBA as maps. For these groups the number of 10 km Breckland squares with records was related to the estimated total number of UK 10 km squares from the atlas maps.

Distribution maps available via NBN are not considered to be accurate for most species, because the databases are incomplete and include doubtful or inaccurate records. However, for many groups, NBN maps are the current best knowledge of the distribution of species and were used to classify Breckland specialist status. NBN maps were used to make an initial visual assessment of the number of 10 km squares in which a species had been recorded in the UK. Species occurring in approximately 100 or more 10 km squares in the UK were not considered further; since the lower criteria for a Breckland specialist was 25% of UK 10 km squares and there were 23 10 km squares in the Breckland region. For species judged to occur in fewer than 100 10km squares in the UK, the number of squares were counted and the percentage of those occurring in Breckland was calculated. The species were then assigned to the appropriate specialist category.

A number of species have been recorded only one or two times in the UK, including once in Breckland. These species have therefore, been assigned Breckland specialist status. However, for some of these species, it is likely that a combination of genuine scarcity, under-recording and difficulty in identification has resulted in very few records. Further examination of the Breckland specialist status of species is needed as and when new records come to light.

The final provisional list of Breckland specialists was further validated by a number of recorders with expertise in differing taxonomic groups and by representatives from Plantlife and Buglife.

Table 10. Criteria used to identify and categorise species distinctive to, or characteristic, of Breckland – Breckland specialist species

Specialist definition	Percentage of species distributions or population sizes (birds only)	Example species
Entirely Restricted	100% of 10 km squares in which a species have been recorded are within the Breckland 10km squares	*Cypris bispinosa* (crustacean) *Thymus serpyllum* (flowering plant)
Largely Restricted	≥80% of 10 km squares in which a species have been recorded are within the Breckland 10km squares	*Herniaria glabra* (flowering plant) *Meioneta fuscipalpa* (araneae)
Primary Stronghold	≥50% of 10 km squares in which a species have been recorded are, or ≥50% of breeding population occur, within the Breckland 10km squares	Stone curlew *Burhinus oedicnemus* (e.g. 2004: 63% of total UK numbers) *Harpalus froelichii* (coleoptera) *Medicago sativa* (flowering plant)
Secondary Stronghold	≥25% of 10 km squares in which a species have been recorded are, or ≥25% of breeding population occur, within the Breckland 10km squares	*Medicago minima* (flowering plant) *Cerceris quinquefasciata* (hymenoptera) Woodlark *Lullula arborea* (c25% of UK population)
Coastal Species	Mainly coastal in distribution, but of note when inland	*Cteniopus sulphurous* (coleoptera) *Corynephorus canescens* (flowering plant)

Collating and Synthesising Species Ecological Requirements

Rationale for the Approach

Having identified the full suite of Breckland conservation priority species, the next objective was to provide management guidance for these. A key aim of the BBA was to facilitate management for groups of species with shared requirements, rather than presenting land managers and conservation advisers with a multitude of species-specific management prescriptions that assume, but have not demonstrated, their relevance to a wider assemblage of 'fellow travellers'. Another important aim was to move away from focusing on distinct and mutually exclusive habitats.Instead, we sought to provide broad management prescriptions to benefit groups of species, cutting across taxonomic divisions and land-use distinctions such as arable, forest and heathland. A key stage in the work was to classify species into guilds or assemblages that have shared requirements in terms of ecological processes and structures and thus have common responses to management.

Selection of Habitat and Ecological Process Categories

An initial list of 24 broad habitats, micro-habitats, ecological structures and management actions were compiled. The classification of broad habitats was initially based on land-cover habitat classes in the Land Cover Map (LCM2000). However, these were refined to emphasise more detailed subdivisions relevant to Breckland biota, for example, broadleaved woodland and coniferous woodland were retained as broad categories, while shingle was considered as a separate habitat even though this is subsumed in a broad coastal habitat class in the LCM. Important micro-habitats, structures and ecological processes were provisionally identified by the BBA commissioning group. The provisional list of broad habitats, micro-habitats, structures and ecological processes subsequently underwent significant editing by species experts. It was initially presented to taxonomic experts during the Species Workshop and substantial refinements were obtained. The resulting revised list of process and structures was then circulated for further scrutiny, and comments, input and validation was received by at least one expert from all major taxonomic groups in order to ensure cross-taxa validity.

The final validated list of criteria to classify ecological requirements of species included 103 habitats, structures and ecological process requirements. This list is given in an Appendix. These included:

- 27 broad habitat classifications, for example, fluctuating waterbodies, shingle, lowland heath, arable, brownfield, deciduous woodland, fen, mature fen carr;
- 48 micro-habitats and structures each of which can occur across a number of broad habitats, e.g. deadwood, short grass, broken turf, bare ground;
- 28 ecological processes – dynamic actions that create or modify habitat micro-habitat structure and suitability, e.g. positive or negative responses to intensive grazing, physical disturbance, nutrient enrichment, biomass removal, poaching, silting up of water bodies.

For each of the Breckland conservation priority species (BAP, RDB or Notable and Breckland specialists), autecological requirements were assessed against the full list of habitats, structures

and processes. Requirements for broad habitat classes, microhabitats or structures and ecological processes were each assessed on a scale where:

- +3 – an essential condition or process, or a primary habitat
- +2 – an important condition, process or habitat
- +1 – of minor benefit or importance
- 0 – known to have no effect
- -1 – minor detrimental effect
- -2 – major detrimental effect
- -3 – having a destructive or damaging effect
- -? – may have a negative effect
- +? – may have a positive effect
- n/a – not relevant
- Blank cells – no information

Sources of Ecological Information

The BBA team compiled habitat, structure and process information for all Breckland conservation priority species from a wide range of published and documentary sources (Table 11). Twelve species and taxonomic experts were able to give considerable time to fully compile and classify habitat, structure and process understanding for all Breckland conservation priority species within their taxonomic areas of expertise. This autecological information was subsequently validated by experts in a range of taxonomic groups.

The largest source of readily available ecological information was the species accounts stored within Recorder 6. This information includes species accounts originally developed within the Invertebrate Site Register, various Red Data Book accounts and checklists and reviews of taxonomic groups (Table 11) These Recorder 6 accounts generally provided a good basis for understanding the autecological requirements of most species. In addition, a large number of other sources of information were obtained, including species accounts in atlases, taxonomic reviews and specialist journal publications (Table 11). These were all used to complete the habitat and process matrix for respective taxonomic groups. However, no information was obtained for approximately 5% of Breckland conservation priority species, many of which were Diptera species represented by only a handful of national records, with little or no ecological understanding yet available.

The completed habitat matrix was used to assess the relative importance for priority species of each of the broad habitats, with sand, chalk and gravel pits combined, plus the micro-habitats dung, mammal burrows, carrion, detritus/leaf litter and deadwood. All habitat associations of +2 and +3 were selected for priority species. The total number of Breckland conservation priority species, the number of BAP designated species, the number species unique to a single habitat, the number of Breckland specialist species and the number of those that have a mainly coastal distribution were calculated for each habitat.

Table 11. Published, documentary and expert sources used to assess the ecological requirements of Breckland conservation priority species

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Guild Analysis

A number of habitat and process categories were rarely completed or the information available was not sufficiently detailed to allow them to be accurately completed. For example, it was rarely possible to differentiate between a requirement for standing versus fallen deadwood and these were combined prior to guild analysis. It was also not possible to differentiate between differing kinds of dung and therefore, livestock and rabbit dung were combined into one dung category. The distinction between a species requiring unsprayed or uncropped field margins was not possible with the information available and these were combined together as cultivated, arable margins.

Using the habitat matrix, completed for 2149 Breckland conservation priority species, habitats and processes with values of +2, +3, -2 and -3 were selected and used to create a list keywords (usually between three and six words) for each species. These were then used to group species with identical keywords to form initial guilds of species with the same requirement. This allowed the immediate identification of a number of important guilds:

1) Species for which our information indicated a requirement only for one of the following: woodland, open woodland, veteran trees, wetland, standing water or running water. These were assigned to a guild of the appropriate name, e.g. woodland. Generally, these were species for which current ecological knowledge is limited.
2) Species that had one essential requirement e.g. dung or deadwood, but that are not ecotone specific.
3) Species that occur in a range of ecotones were assigned as such, e.g. open and woodland ecotone and open, woodland, wetland ecotone.

The remaining species (approximately 86% of the total number) were classified into one of six broad ecotones; open, open with scrub, open woodland, woodland, wetland, wet woodland. Within these broad ecotones the requirements of species for disturbance and grazing was assessed and guilds were formulated based on these options.

Guilds were formulated independently of normal habitat associations (e.g. dune, brownfield etc.). However, information on ecological structures and micro-habitat requirements were used to inform guilds. For example, species of arable or brownfield habitats but that were not recorded from any habitats likely to experience grazing, i.e. not recorded from lowland heathland, calcareous grassland or sand dune, unless otherwise known, were taken to have a requirement for disturbance in the absence of grazing. They were therefore, assigned to a disturbance-no/light grazing guild. Similarly, species that occur in grassland were taken to require some intensity of grazing.

Detailed and specific information on species requirements for grazing and disturbance was available for almost no species. However, it was possible to assess the needs and tolerances of many species in relation to high and low levels of grazing and disturbance. Where there was uncertainty regarding responses to important ecological processes such as grazing or disturbance, then species were retained within a general guild for their key habitat type.

Species assigned to standing water and running water guilds are mostly aquatic or semi-aquatic for all or part of their lifecycle. Species assigned to the littoral guild may be either largely aquatic or terrestrial but occupy similar habitats, often related to fluctuating water bodies. Species requiring plant stems, seeds or flower-heads were assigned to guilds without or with limited grazing.

The keywords of individual species were subjectively assessed and the species placed into the appropriate guild. Where there was uncertainty in the placement of a species into a guild, information regarding the species was referred to. Species were placed into guilds objectively, irrespective of taxonomic group.

The guild assignment of a sub-set of species was validated by referring back to the original Recorder statements and other information resources. Further validation was carried out by a number of experts, with expertise in a range of taxonomic groups.

In addition to the 5% Breckland conservation priority species for which there was insufficient information to complete the habitat and ecological requirement matrix, a further 92 species could not be assigned to a guild, due to the paucity of ecological information for the species or uncertainty of requirements. The initial stages of the classification of guilds demonstrated that 5 large mammals and 149 bird species could not be placed effectively in the same guilds as plants and invertebrates using this method of guild analysis. This was because, in general, the habitat requirements of bird and mammal species occur at larger scales than those of most plant and invertebrate species.

Current Conservation Management

Site Management Questionnaire

In order to understand the current and historic management of SSSI sites, a questionnaire was sent to SSSI site managers requesting information about:

- Grazing regime – livestock type, stock density/number, time of grazing.
- Rabbit grazing – rabbit numbers, rabbit management.
- Vegetation structure – average sward height, coverage of bare ground, coverage of heather.
- Physical disturbance treatments – type of disturbance, frequency.
- Vegetation management – type of vegetation management, frequency of management.
- Current and historical status of Breckland birds.
- Challenges to management.

Site managers were requested to complete a separate questionnaire for all compartments within a site.

Site Management Workshop

The purpose of the Site Management Workshop, held on 29th October 2009, was to bring site managers and conservation advisors together with species experts and natural historians, to discuss the effectiveness of management practices for groups of species with different ecological requirements. Further information regarding the meeting can be found in an Appendix.

The specific questions for the workshop were:

1) Does the management currently carried out work?
2) What are the practicalities, the evidence of effectiveness and the costs of management techniques, to produce the required conditions?
3) What are the constraints to successful conservation (practical, costs, knowledge)?
4) Are there examples of sites available for monitoring where innovative management has been implemented?
5) What monitoring is most useful managers to implement within constraints?
6) What further experimental work is required to better inform management?

Arable Management Workshop

An Arable Management Workshop was held in order to inform approaches for managing and enhancing arable land in Breckland, especially for its characteristic species. A range of advisers, ecologists and species specialists attended the meeting on 22nd February 2010. Further information regarding the workshop can be found in an Appendix.

The main objectives of the workshop were to:

- Review knowledge about where species are located and what management they require.
- Examine the effects of different field margin management – what species benefit; what vegetation results and what influences these outcomes.
- Develop prescriptions for arable options (such as cultivated margins, conservation headlands, fallow plots, low input cereals) to enhance conditions for rare, scarce and declining species.

Data Mapping and Analysis

<u>Mapping at 1 km resolution</u>
All maps of records and species are presented by 1 km squares, rather than by sites of conservation management. This was because it was important to include areas outside SSSI and other designated sites, such as Roadside Nature Reserves, in order to assess their value in the context of the wider landscape, and to identify additional un-designated sites of biodiversity importance.

In addition, individual sites have been given many different variations in name and effectively collating species records from a site is difficult. Furthermore, a number of data sources were only available at 1 km resolution (or less in the case of tetrads).

<u>Selection of cut-off date for species mapping</u>
Maps of the total number of records, the total number of taxonomic groups and the total number of species in each 1 km square included records from all years.

When mapping the distribution of Breckland conservation priority species, Breckland specialists and guilds a cut-off date for records of 1980 was used, i.e. only records made during or after 1980 were

used. This was in order to ensure that the maps of priority species showed relatively current and relevant distributions.

This date was chosen in consultation with experts at the Species Workshop. It coincides with the securing of additional grass-heath resource and increasing conservation management on the heaths. Furthermore, the cumulative number of records of priority species increases considerably after this date (Figure 8).

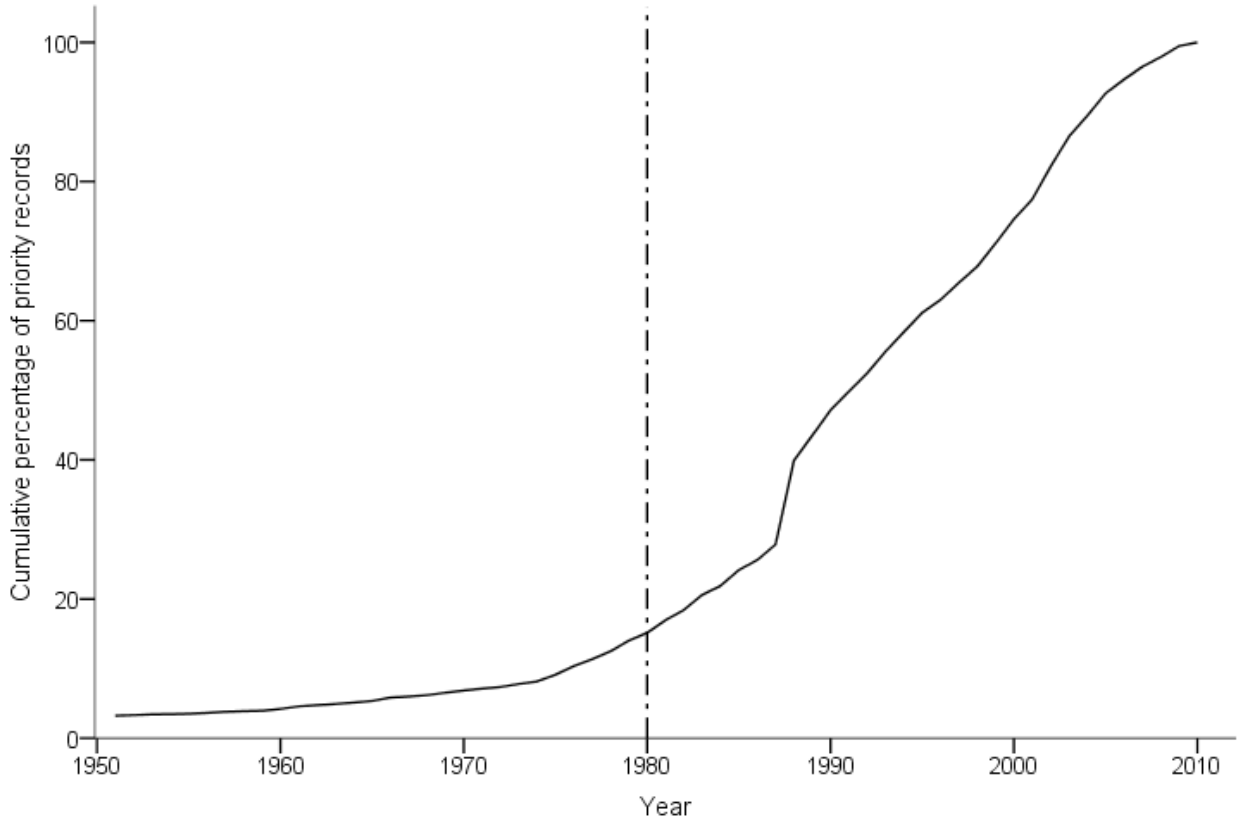


Figure 8. Cumulative percentage of records of conservation priority species, showing the cut-off of 1980 used for mapping

Findings of the Breckland Biodiversity Audit

Records and coverage

Number of records

830,747 records were obtained (1,219,373 records including ungrouped tetrads, Table 12). This represents huge effort in biological recording and submission of records to recording schemes and databases. Twenty percent of records obtained were observations from the five years from 2003-2008. This is due to an increase in both recording effort and digitisation of records.

Records were obtained from 55 taxonomic groups (Table 13). The largest numbers of records were of flowering plants and moths – 30% and 22% of records respectively (percentages calculated prior to ungrouping of tetrads). Large numbers of records were also obtained for birds, Coleoptera, butterflies and Diptera (Table 13). Seventeen of the 20 most commonly recorded individual species were butterflies, including over 4,000 records of small white (*Pieris rapae*). Also in the top 20 most recorded species were roe deer, brown hare and the moth, large yellow underwing (*Noctua pronuba*).

There was considerable discrepancy in the recording effort for different groups compared to the number of species in that group. For example 64,114 butterfly records were obtained (Table 13) compared to the 59 species occurring in the UK (www.ukbutterflies.co.uk), but in contrast 5,598 records were obtained for Hemiptera compared to approximately 2,000 species in the UK (www.britishbugs.org.uk). It is therefore, important to note that understanding of the distribution of some taxonomic groups is more relatively good (e.g. butterflies, plants), while other taxa, often the more “difficult” groups, are under-recorded and distributions very poorly understood.

At a national scale there is likely to be under-recording of some difficult taxonomic groups. Furthermore, there may be under-recording of neglected micro-habitats (e.g. interstices of shingle, litter layers) and this may make particular assemblages look nationally rare.

Sources of records

The largest proportion of records (65%) was obtained from the Local Records Centres (LRCs) (NBIS, SBRC and CPBRC) (Figure 9, Table 12). A further 11% of records were obtained from 38 recording schemes (Table 12), accessed via the National Biodiversity Network. These national recording schemes do not systematically share their records with the local Biological Records Centres and would not be routinely accessed by LRCs when responding to development control enquiries. Many of these schemes consider taxonomically challenging and under-recorded groups.

Combined, the LRCs and NBN provided 76% of all records and these are sources that are largely accessible, subject to permissions being granted by individual recording schemes and Biological Records Centres. The remaining 24% of records were from sources not in the public domain. This included 16% of records from national organisations, such as Norfolk and Suffolk branches of Butterfly Conservation (Table 12). Whilst records were readily provided to us by these organisations, the lack of full integration of biological records and a single point access reduces

understanding of species distributions and may hinder conservation effort. There is a move towards improving this and both Norfolk and Suffolk Moth Group records were very recently integrated into the LRCs. This initiative was partly catalysed by this project.

Through the work of this audit an additional 67,573 records were captured which were not previously available within county or national databases. Of these, 56,826 were obtained from paper records or databases maintained by agencies such as Natural England, ADAS and the Forestry Commission. Some of these included key data sets for taxonomically important groups, including surveys of under-recorded landscape elements, such as the Breckland Rare Plant Survey and high quality invertebrate surveys of Roadside Nature Reserves.

Recommendations:

- Continue further integration of national and county recording schemes into centralised databases, such as NBN or the local Biological Records Centres.
- Continue digitalisation of paper records, particularly those within reports.
- Create and implement further mechanisms to transfer information and records between regional offices of FC and NE, and the county wildlife Trusts, and local Records Centres

It should be emphasised that, with the exception of a small proportion of records from commissioned surveys, almost all records collated in this audit were originally generated by the efforts of amateur natural historians. A notable and impressive feature is that the large majority of these public generated records were already within recording organisations, whether via national or county schemes. Of the 95 individual recorders that we contacted, 29 responded with records that had not already been incorporated into recording schemes, generating a further 10,747 records. It is likely that a large proportion of these would ultimately have reached either NBN or the local Biological Records Centres. However, a small number of current records created and held by specialist amateur taxonomists have not been submitted to any recording organisation and therefore cannot be used for conservation efforts. In some instances, this includes records collected by diverse individuals and passed to a county recorder who is not prepared to make these data available to the local Biological Records Centre. This is an unfortunate culture, though thankfully not widespread. In addition, a larger number of older and undigitised records have not been captured and remain in notebooks. The digitisation of historic records will provide greater understanding of species distributions and requirements.

Recommendations:

- Encourage further survey and recording effort of under-represented groups, particularly true bugs (hemiptera), flies (diptera) and non-carabid coleopteran (beetles), and regionally important under-recorded groups such as freshwater aquatic invertebrates and spiders.
- Consider ways to aid digitisation of historic records.

Recording Effort and Coverage

There were 15 1 km grid squares for which no records were obtained, with the majority being located on the southern edge of Newmarket (Figure 10). The mean number of records per 1 km grid square was very high, 515 ± 948 (± SD, range 0-16219).

The SSSIs were generally well recorded, with large numbers of individual records from a wide range of taxa (Figure 10, Figure 11). Within the National Character Area, East Wretham Heath, Thompson Common and Knettishall Heath SSSIs and outside the NCA, Redgrave and Lopham Fens SSSI, have been subject to extensive recording (Figure 10, Figure 11). In contrast, Breckland Farmland SSSI generally had low levels of recording and effort within Breckland Forest SSSI was very patchy, with high recording effort focussed in a small number of sites. These tended to be easily accessible areas, such as car parks, paths and road verges.

Recording effort was generally lower outside of the Breckland National Character Area, particularly to the west. Newmarket Heath and Shippea Hill SSSIs were particularly poorly recorded (Figure 10).

There were a number of non-SSSI recording hotspots (1 km squares) scattered throughout the study area. The records of most of these recording hotspots were dominated by moths, and we believe these are the locations of regular moth traps. For example, in a hotspot at Great Ellingham there were 7812 records, of which 97% were of moths and were made by one recorder. In contrast, one location near Carbrooke (TF9401) has been subjected to very high levels of recording from a very wide range of taxonomic groups (Figure 10 and 11) and we understand this square to include the back garden of a taxonomic expert.

Recommendation:

- Encourage recording of multiple taxa in under-recorded areas, particularly within the Breckland Forest and Farmland SSSIs

Table 12. Sources of all species records obtained by the Breckland Biodiversity Audit

Source of data		No. of records
County Records Centres		
CPBRC		19,924
SBRC		218,823
NBIS		300,506
	Total:	**539,253**
National Databases – obtained via NBN		
Invertebrate Site Register		**42,943**
National Recording Schemes – obtained via NBN		
Aquatic Heteroptera Recording Scheme		493
Atomariinae and Ptiliidae Recording Scheme		219
Brachycera (Diptera) records from Britain and Ireland to 1990		464
Bees, Wasps, Ants Recording Scheme (BWARS)		2278
Cantharoidea and Buprestoidea Recording Scheme		360
Cerambycidae Dataset		179
Ciidae (Coleoptera) records from Britain and Ireland to 2004		20
Coccinellidae Data		142
Collembola Recording Scheme		16
Colony Count Survey (bat)		278
Cranefly records for Britain to 2007		687
Dixidae (Diptera) records from Britain and Ireland to 1988		29
Field Notebook Records of Dr Francis Rose 1950s to 1990s		978
Flea (Siphonaptera) Recording Scheme		248
Former Dragonfly Recording Scheme (up to 1992)		3706
Hoverfly Recording Scheme		4779
Hypogean Crustacea recording scheme		7
Isopoda (Interim dataset)		790
Millipede (Diplopoda) records for Britain and Ireland to 2005		908
Mosquito Recording Scheme		44
Muscidae (Diptera) records from Britain and Ireland to 1985		40
National Pond Monitoring Network		471
National Trichoptera (Caddisfly) Recording Scheme		52
Neuroptera Recording Scheme		366
Noctule, Serotine and Pipistrelle Field Survey		44
Opiliones (Harvestman) Dataset		305
Orthoptera Recording Scheme		1074
Outdoor Psocoptera (barkfly) records for Britain & Ireland (1850 -)		24
Reptiles and Amphibians Dataset		443
Seed and Leaf Beetle Recording Scheme		2338
Sepsidae (Diptera) records from Britain and Ireland to 1985		341
Suffolk Orthoptera Data		43
Ticks distribution for the British Isles		168
UK Ladybird Survey		958
Bryophyte data for Great Britain from the British – Bryological Society		16770
Welsh Invertebrate Database		1221
Fungal Records Database of Britain and Ireland (Mycological Society)		9586
	Total:	**50,869**
National Recording Schemes – obtained directly		
British Arachnological Society		12482
British Plant Gall Society Records		1786

Butterfly Conservation (Suffolk)		17750
Butterly Conservation (Norfolk)		28052
Elveden Center Parcs		19166
Suffolk Freshwater Invertebrates Database		3258
Suffolk Moth Group		47,554
	Total:	**130,048**
Reports and paper records		
ADAS Arable Margin Report		34372
Breckland Rare Plant Database		5851
Forestry Commission		2294
Natural England Bury Office		550
NBIS paper records		1518
Norfolk and Suffolk Wildlife Trusts		80
Norfolk County Council (RNRs)		142
Red Lodge Data		3260
SBRC paper records		506
STANTA, West Tofts Office		435
Telfer and Eversham Report		632
Other organisations/Reports		7186
	Total:	**56,826**
Individual Recorders		
Ben Christie (Spiders)		130
Doreen Wells (Ants)		1210
Francis Farrow (Mayflies)		47
Garth Foster (Water beetles)		321
Geoff Nobes (Range of invertebrates)		599
Ian Rabarts (Diptera)		225
Ivan Perry (Diptera)		207
Jerry Bowdrey (Beetles)		45
Mark Telfer (Beetles)		203
Micheal Chinnery (Range of invertebrates)		200
Nicholas Gibbons (Amphibians and Reptiles)		46
Peter Hodge (Beetles)		161
Chris Jones (Lepidoptera)		2997
Peter Lambley (Lichens)		204
Phil Withers (Diptera)		716
Rex Hancy (Galls)		84
Robin Stevenson (Bryophytes)		81
Scott Pedley (Spiders)		630
Tim Strudwick (Hymenoptera)		79
Other individuals		2692
	Total:	**10,747**
	Total number of records obtained:	**830,747**
	Total number of usable records*:	**1,219,373**

Table 13. Number of records received for each taxonomic group

These records are the total number of useable records, i.e. including additional records from the scaling up of tetrads, but excluding records from outside the area and those not identified to species level.

Group of species	No. of records	Group of species	No. of records
Bacteria	1	Springtail (Collembola)	54
Fungoid	35	Booklouse (Psocoptera)	53
Fungus	21421	Cockroach (Dictyoptera)	8
Slime Mould	741	Earwig (Dermaptera)	353
Lichen	3643	Flea (Siphonaptera)	269
Alga	30	Orthopteran	4013
Diatom	37	True bug (Hemiptera)	5598
Stonewort	248	Beetle (Coleoptera)	82786
Liverwort	1803	Alderfly (Megaloptera)	55
Moss	18989	Caddis fly (Trichoptera)	304
Clubmoss	3	Lacewing (Neuroptera)	405
Horsetail	2546	Mayfly (Ephemeroptera)	459
Fern	5701	Scorpion fly (Mecoptera)	31
Conifer	4975	Snakefly (Raphidioptera)	18
Flowering Plant	614306	Stonefly (Plecoptera)	16
Coelenterate (Cnidarian)	24	Hymenopteran	21823
Roundworm (Nematoda)	1	True fly (Diptera)	31993
Rotifer	29	Dragonfly (Odonata)	7931
Flatworm (Turbellaria)	78	Butterfly (Lepidoptera)	64114
Bryozoan	13	Moth (Lepidoptera)	173983
Annelid	324	Jawless Fish (Agnatha)	41
Mollusc	8137	Bony Fish (Actinopterygii)	2624
Centipede (Chilopoda)	379	Amphibian	1936
Millipede (Diplopoda)	1438	Reptile	960
Crustacean	2639	Bird	88143
False Scorpion (Pseudoscorpiones)	43	Mammal	20373
Acarine (Acari)	701		
Spider (Araneae)	22012	**Total number of records**	**1,219,373**
Harvestman (Opiliones)	733		

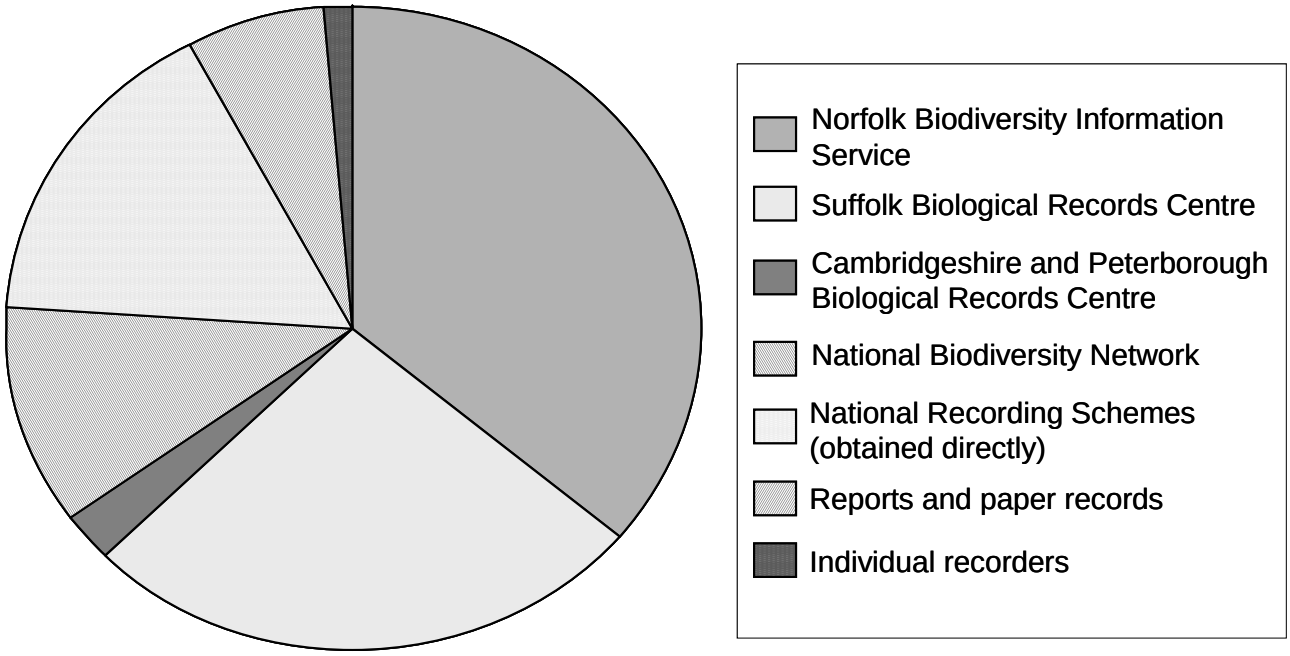


Figure 9. Sources of species records obtained by the Breckland Biodiversity Audit. Total number of records obtained was 830,747 and full breakdown of sources is given in Table 12

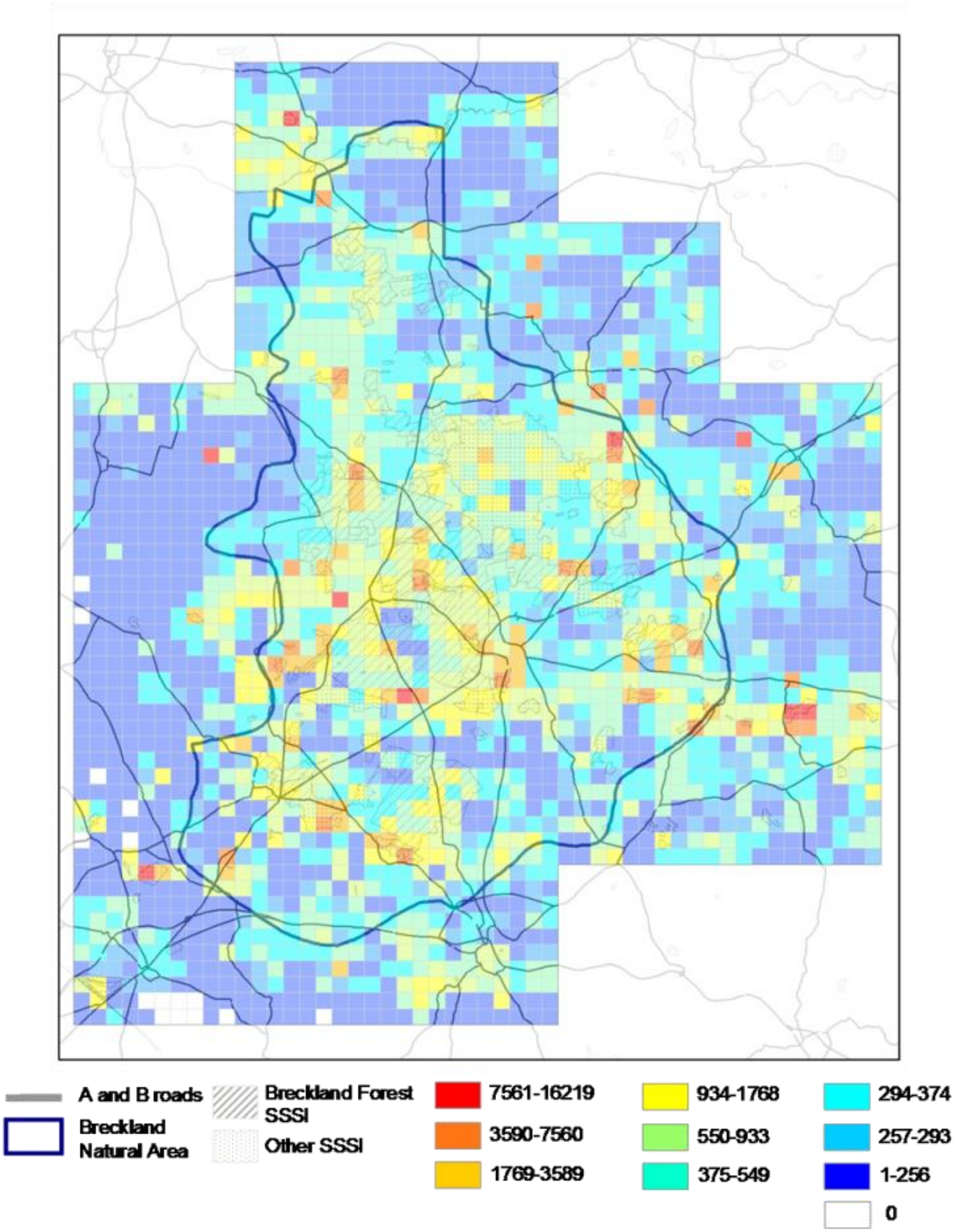


Figure 10. Number of records obtained in each 1 km grid square in the Breckland study area. Class breaks in the number of species records were selected by geometric interval

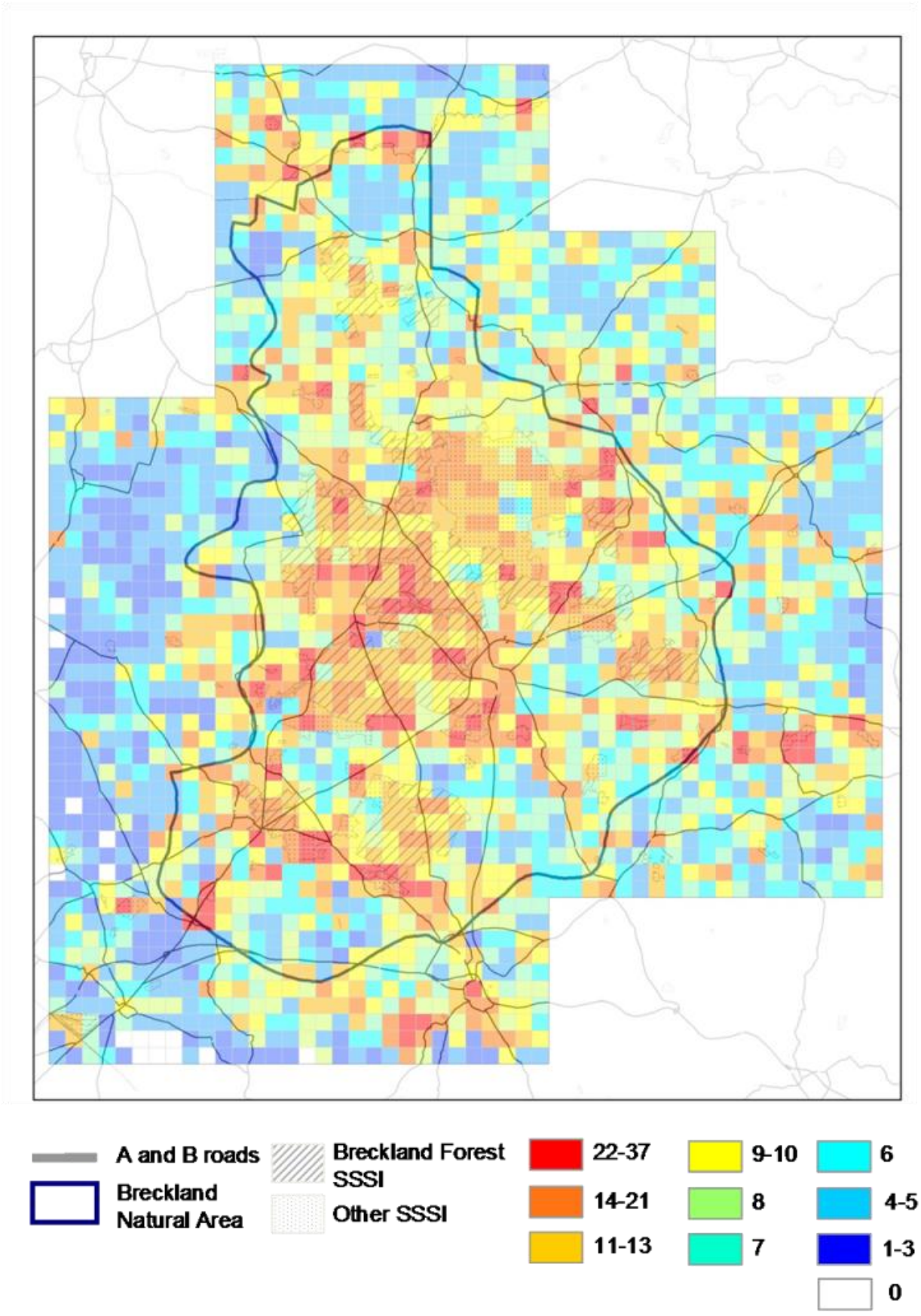


Figure 11. Number of taxonomic groups for which records were obtained, in each 1 km grid square in the Breckland study area. Full list of taxonomic groups is given in Table 2. Class breaks in the number of taxonomic groups were selected by geometric interval

The Biodiversity Importance of Breckland

Many more species occur in Breckland than anyone thought

- 12,845 species from 55 taxonomic groups have been recorded in the Breckland region (Table 13, Table 14).

This total included 2,420 Diptera species, 2,251 Coleoptera species and 1,538 species of moth (Table 14). Less species-rich groups, not listed individually in Table 14, included 72 Acari, 38 lacewing (Neuroptera) and 18 mayfly (Ephemeroptera) species.

Breckland is much more important to UK biodiversity than previously thought, with more than 2,000 conservation priority species

26% of UK species with a conservation status occurr in the area.

2149 Breckland Conservation Priority species were identified including:

- 634 Red Data Book species, plus 43 Red List birds.
- 317 Biodiversity Action Plan species.
- 1,317 Nationally Rare, Scarce and Notable (A & B) species.
- 162 Breckland specialist species.

2,149 Breckland Conservation Priority species (inc. birds, mammals and coastal specialist species, Table 14), of which 1,972 were non-vertebrate organisms. The largest taxonomic groups of conservation priority species were Coleoptera (693 species) and Diptera (490 species) (Table 14).

The UK biodiversity interest of Breckland is remarkably high, particularly in the context of the small total area of the region, with 26% of all UK conservation priority species in only 0.9% of the UK area (Table 15).

317 BAP species occur in the wider Breckland area (the 23 10 km squares), representing 27.5% of all UK BAP species. Moths, flowering plants and vertebrates comprised 68% of BAP species (Table 14).

In addition, 16% (612 species) of all UK RDB species and 27% of National Rare/Scarce and Nationally Notable (A & B) species occur in Breckland.

Three Global RDB species have been recorded in the Breckland region; the European eel *Anguilla anguilla*, lesser white fronted goose *Anser erythropus* and white-clawed crayfish *Austropotamobius pallipes*.

There were 634 Red Data Book species (plus 43 Red List birds) (Table 14). This contrasts markedly with other estimates of the biodiversity importance of Breckland, for example 173 RDB vascular plant and invertebrate species were recognised to occur in Breckland by Rothera (1998). The

difference is partly attributable to a more comprehensive treatment of habitats that were not considered fully in the Natural Area Profile, but also reflects the BBA's more exhaustive compilation of records from national regional and previously uncollated sources. The largest taxonomic groups of RDB species were Diptera (165 species), Coleoptera (151 species) and flowering plants (146 species). There were also significant numbers of moths and Hymenoptera (Table 14).

1,317 Nationally Rare, Scarce and Notable (A & B) species have been recorded. In contrast to BAP species, 65% of the Nationally Rare, Scarce and Notable (A & B) species were Diptera and Coleoptera. Hymenoptera, mosses and spiders comprised a further 13% of species (Figure 12).

More than 160 species are restricted or have major strongholds in Breckland

These comprise:

- 21 species that are entirely restricted to the Breckland region.
- 8 species that are largely restricted to the Breckland region.
- 43 species whose primary stronghold is in the Breckland region.
- 90 species whose secondary stronghold is in Breckland region.

A further 27 species are only found inland in Breckland and are otherwise restricted to the coast.

Subsequently in this report, we refer to Breckland Specialists to mean the full 189 species that are either restricted, have a primary or secondary stronghold, or are coastal rarely occurring elsewhere inland.

189 species were identified as Breckland specialists, of which 162 are inland species concentrated to some extent in Breckland and 27 are coastal species. This is many more than were previously recognised. For example, Rothera (1998) noted 25 vascular plants and invertebrates that he considered to be Breckland specialist. This Audit has greatly expanded on this number by carefully considering all taxonomic groups and incorporating the expertise of large numbers of taxonomists. Furthermore this study has examined species from all habitats to consider whether they may be regional endemics, in addition to those classically considered "Breckland habitats", such as heavily rabbit-grazed grass-heath, waysides, meres and pingos. Thus, we are able to recognise 29 species entirely or largely restricted to Breckland and a further 43 that have their primary stronghold in the region. The future for these 72 species in the UK will depend crucially on conservation action taken in Breckland.

Table 14. Number of species within taxonomic groups for which records were obtained. The number of priority species includes RDB (UK and Global), Notable/A/B, Status: NR/NS, BAP, Bird: Red, Bird: Amber and Breckland specialists (species that are restricted to or have a stronghold in Breckland). Coastal Breckland Specialists are also listed. Note: many species have multiple designations. Species with doubtful records are excluded.

	Total no. of species	No. of priority species (excl. Bird: Amber)	No. of RDB species	No. of Notable A/B and Status: NS/ NR species	No. of BAP species	No. of Breck specialists (inc. coastal)
Fungi	1613	6	-	-	6	-
Lichen	270	47	15	44	9	2 (2)
Stonewort	17	11	6	5	5	-
Liverwort	70	7	1	7	1	-
Moss	303	51	10	50	7	1 (1)
Clubmoss	2	1	1	1	1	-
Fern	29	4	1	4	1	-
Conifer	33	1	-	-	1	-
Flowering Plant	1650	208	146	140	64	20 (22)
Bryozoan	1	1	1	-	1	-
Mollusc	131	11	9	-	9	0 (1)
Crustacean	74	3	1	-	1	2 (2)
False Scorpion (Pseudoscorpiones)	8	1	1	-	-	-
Spider (Araneae)	388	61	8	49[1]	8	7 (9)
Cockroach (Dictyoptera)	1	1	-	1[1]	-	-
Earwig (Dermaptera)	3	1	-	1[1]	-	-
Orthopteran	19	4	-	4 [1]	-	0 (1)
True bug (Hemiptera)	487	55	13	41	1	7 (7)
Beetle (Coleoptera)	2251	693	151	535	21	68 (79)
Caddis fly (Trichoptera)	59	5	4	1	-	-
Stonefly (Plecoptera)	4	2	-	2	-	-
Hymenoptera	564	115	37	73	11	7(12)
True fly (Diptera)	2420	490	165 [2]	323 [2]	4	27(30)
Dragonfly (Odonata)	30	4	4			
Butterfly (Lepidoptera)	48	17	17	-	14	-
Moth (Lepidoptera)	1538	172	41	36	94	19 (21)
Fish (Agnatha and Actinopterygii)	33	6	1	-	6	-
Amphibian	7	4	-	-	4	-
Reptile	4	4	-	-	4	-
Bird	275	149 (48)	44	-	30	2 (2)
Mammal	48	14	-	-	14	-
Other	265	-	-	-	-	-
	12,945	2,149	677	1,317	317	162 (189)

[1] Additional Notable A & B species were identified from Atlases
[2] Additional RDB and Notable A & B species were indicated by I. Perry

There were Breckland specialist species from 11 taxonomic groups. The largest number of specialist species were Coleoptera, but there were also large numbers of Diptera, flowering plants and moths, and smaller numbers of Hymenoptera, Araneae and Hemiptera (Table 14). A full list of Breckland specialist species is given in an Appendix.

The level of regional endemism was very high, with 21 species being entirely restricted in the UK to the Breckland region. 66% of these were beetles and flowering plants (Figure 13).

27 species were found to only occur inland in Breckland whilst otherwise having a coastal distribution; this number is likely to be an underestimate. Species with conservation status were the starting point for the identification of Breckland specialists. However, species that are relatively common on the coast tend not to have a conservation status. Furthermore, whilst experts were very good at identifying regional specialists, many did not necessarily consider coastal species to be important in a Breckland context or were less familiar with their distributions.

Recommendations:

- Further investigation is needed to understand the distributions of coastal Breckland specialists and to fully quantify the number of species that have their only inland population in Breckland.
- Work is needed to understand the importance of inland populations and the potential as refuges of primarily coastal species. This may be increasingly important in context of sea level rise and threats to coastal habitats.

Table 15. Total number of species, number of Red Data Book (RDB), Rare / Scarce / Notable and BAP species in the UK and in the 23 10 km Breckland grid squares. Figures in parentheses include additional notified species (listed in Atlases and indicated by I. Perry) that were not included in the JNCC list; these were not considered when presenting the percentage of notified species represented in Breckland

		Breckland[1]	UK[2]	% of UK compared to Breckland
	Area (km^2)	2300 (1019)	244,820	0.9 (0.4) %
No. species recorded	UK RDB	612 (613)	3814	16.0 %
	Notable, Rare and Scarce[3]	1238 (1317)	4561	27.1 %
	BAP	317	1150	27.5 %
	Bird: Red	43	61	70.5 %
	Global RDB	3	69	4.3 %
	Bird: Amber	106	126	84.1 %
	Total number of designated species	**2020 (2120)**	**7757**	**26.0%**

[1] Breckland species totals exclude sub-species and species considered to be doubtful records, but includes species now considered extinct (see Methodology for more details).
[2] Species from JNCC designation list of taxon designations (http://www.jncc.gov.uk/page-3408; updated 27/07/2010). This list also includes marine species and includes designations for subspecies; therefore the proportion of Breckland species in comparison with UK terrestrial species is an underestimate.
[3] Notable / A / B and Status: NS / NR – excluding marine species.

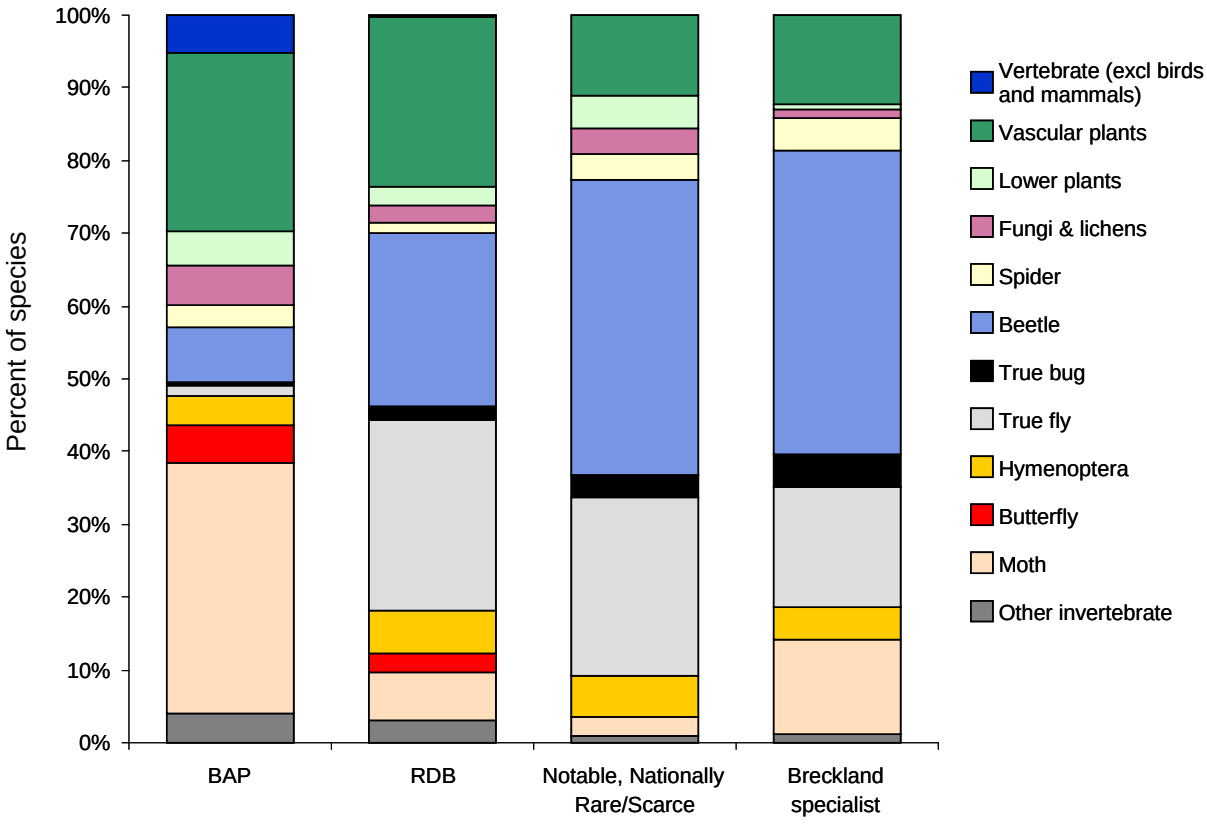


Figure 12. Proportion of Breckland specialists (excluding coastal specialists) and species with conservation designations from different taxonomic groups

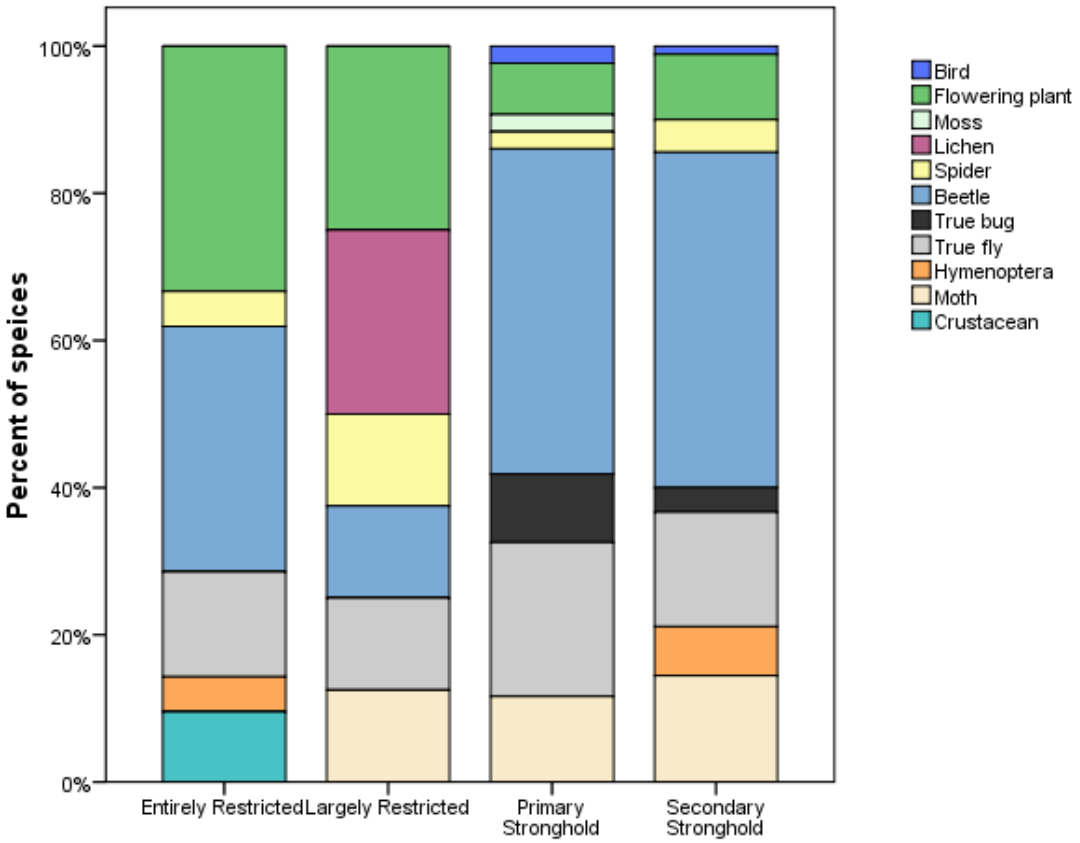


Figure 13. Proportion of Breckland specialist species from different taxonomic groups. For definitions of Breckland specialist categories see Methodology section.

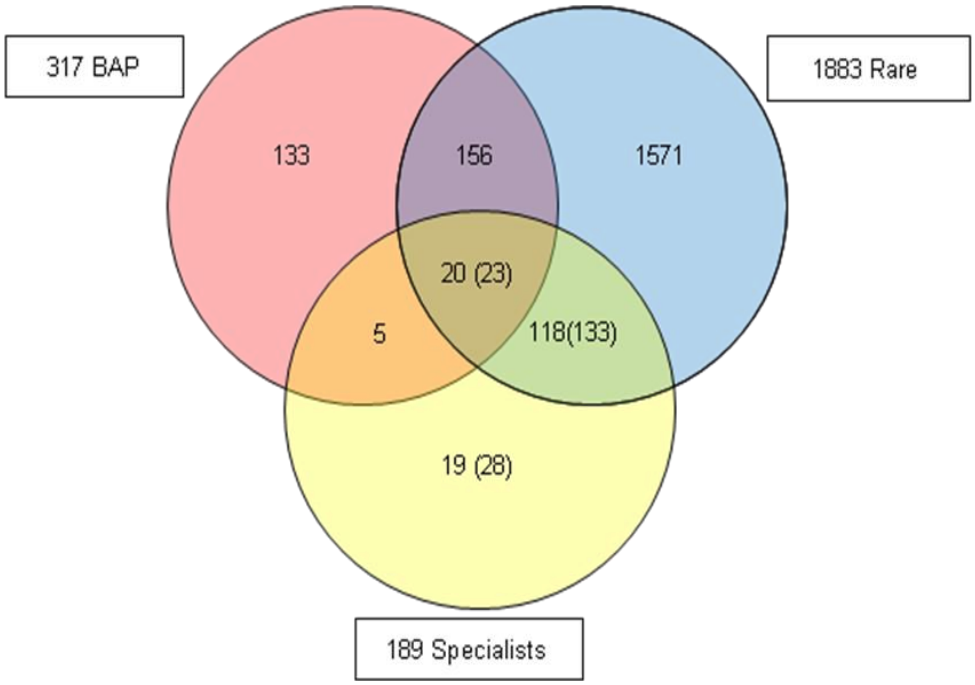


Figure 14. Venn diagram showing the number of species (including birds and mammals) designated as BAP, those designated as RDB, Notable, Rare and Scarce or Bird: Red ('Rare') and those selected as Breckland specialists (coastal Breckland specialists are given in parentheses).

Differences in the Conservation Status of Rare Species in Breckland

For the rare species in Breckland, there was considerable variation in the designation of conservation statuses. For example, there are a large number of rare species that do not have a BAP status. In contrast, 43% of BAP species had no other conservation status, i.e. they were not designated as nationally threatened, rare and were not regionally distinctive (Figure 14).

There is also considerable variation in conservation statuses across taxonomic groups. 52% of BAP species in Breckland are vertebrates, moths and butterflies; other groups are less represented, for example, whilst 29% of butterfly species occurring in Breckland are designated as BAPs, only 0.2% of Diptera species are. The designation of a species as BAP requires a high level of knowledge of the distribution and population status of the species, for example by demonstrating population declines over 25 years. With the exception of moths and butterflies, there is a lack of such detailed information for most invertebrate groups, such as Diptera. The BAP process is one important mechanism for prioritising conservation efforts. The BBA indicates that other priority taxa may be missing out.

Conservation effort cannot prioritise more than 2,000 species individually in one area. The use of BAP species as flagship species in order to protect a wider range of species may be a pragmatic and effective approach. However, we need to understand clearly which individual BAP species can best serve as indicators for wider assemblages. This requires firm evidence before this can be accepted. The effectiveness of BAP species as indicators for guilds of Breckland conservation priorities is examined within the classification of assemblages and guilds.

Conservation statuses of Breckland specialists show great variation. Twenty three Breckland specialist species have BAP status. These include six species which are entirely restricted to the region:

Pashford pot beetle *Cryptocephalus exiguus*
Field wormwood *Artemisia campestris*
Perennial Knawel *Scleranthus perennis*
Spanish catchfly *Silene otites*
Fingered speedwell *Veronica triphyllos*
Spring speedwell *Veronica verna*

However, 19 Breckland specialist species had no conservation status (Figure 14), i.e. they were not recognised as nationally rare, despite their restricted distribution. Of these, ten have a secondary stronghold in Breckland (most of which are moth species and three have a primary stronghold in Breckland (two flies, one moth species). There are six species that are largely or entirely restricted to Breckland, but have no conservation designation; these include two crustaceans associated with meres, a hymenopteran parasite of a regionally important moth, a beetle associated with deadwood, a spider and a snail-killing fly. For most of these species, the lack of UK designation reflects the fact that there are few UK records and data are insufficient to allow an assessment and designation of conservation status. However, for some species such as the micro-moths the Breckland conch *Falseuncaria degreyana* and Blue-fleabane Conch *Cochylidia heydeniana*, the lack of designation may be an oversight (D. White *pers. comm.)*.

Recommendations:

- Further investigate the UK distribution of Breckland specialists without conservation statuses. Encourage further recording of these species.

Distribution of Breckland Conservation Priority Species

Within the Breckland region, conservation priority species were not confined to designated sites (Figure 15). Although the majority of the hottest spots for biodiversity were located within SSSIs, these were also the areas that received the greatest recording effort (Figure 10). It was not possible to separate biodiversity and recording hotspots. However, a number of 1 km grid squares that did not coincide with a conservation site had high densities of conservation priority species. These included a number of moth trapping sites within Thetford Forest.

Breckland specialist species were concentrated within the Breckland NCA. However, Breckland specialist species were found in a large number of squares (Figure 16).

Recommendations:

- Further investigate of the locations of Breckland specialist species that are outside of the NCA and are not designated sites. This will improve understanding of the dispersal ability of specialist species and aid the strategic planning of networks.

Rarest and Most Widespread of the Priority and Specialist Species

The majority of Breckland conservation priority species were recorded in fewer than 10 1 km squares in the region (Table 16). However, 29 Red Data Book species were recorded in more than 100 1 km squares, including corn spurrey *Spergula arvensis* and grey carpet moth *Lithostege griseata*.

Seventeen Breckland specialist species were recorded in only one 1 km square in Breckland; a number of these were Red Data Book species, classified as Insufficient Data or Data Deficient and all were very rare in the UK (Table 16).

Two of these 17 species were entirely restricted to Breckland. These species were the small rove beetle *Gyrophaena pseudonana* (RDB: INDE), only recorded in a wooded part of Chippenham Fen living in the sulphur-tuft fungus (*Hypholoma fasciculare*), and fenland snail killing fly, *Anticheta atriseta* (undesignated, recent addition to the UK) recorded from alongside the river Ouse, near Hockwold Fen. Two species of these species are largely restricted to Breckland; the histerid beetle *Hololepta plana* (undesignated), formerly unknown to the UK, was newly recorded during the course of the Audit close to the Little Ouse at Stanton Downham, and the money spider *Meioneta fuscipalpa* (undesignated) is known from a few individuals recorded at RAF Mildenhall and is suggested to require open, sandy habitats.

Ten Breckland specialist species have been recorded in more than 100 1 km squares in the Breckland region. These include Spanish catchfly *Silene otites* (entirely restricted), purple-stem cats-tail *Phleum phleoides* and smooth rupturewort *Herniaria glabra* (largely restricted), and lucerne *Medicago sativa* and grey carpet moth *Lithostege griseata* (primary stronghold). This shows the importance of the combination of soil and climate to these species, but also that the land-use and conditions that these species require were once very widespread in the region.

It should be recognised that the Biodiversity Audit is not able to examine whether the designated sites are concurrent with the distribution of priority species, as monitoring and survey has been biased strongly towards designated sites. However, it is likely that important localities exist on farmland and waysides.

Table 16. Number of species with conservation designations or Breckland specialist status by the number of 1km squares (within the wider Breckland region of 23 10 km squares) in which they occur. Note a small number of species were only recorded on a 10 km basis and therefore are not included in this table

	Number of 1km squares				
Designation/Category	**1-9**	**10-24**	**25-49**	**50-99**	**≥100**
RDB	450	49	29	22	29
BAP	134	23	35	33	28
Notable/Status	1033	142	45	12	13
Breckland Entirely Restricted	11	1	3	3	1
Breckland Largely Restricted	2	1	1	0	2
Breckland Primarily Stronghold	25	10	1	2	2
Breckland Secondary Stronghold	45	23	10	6	5

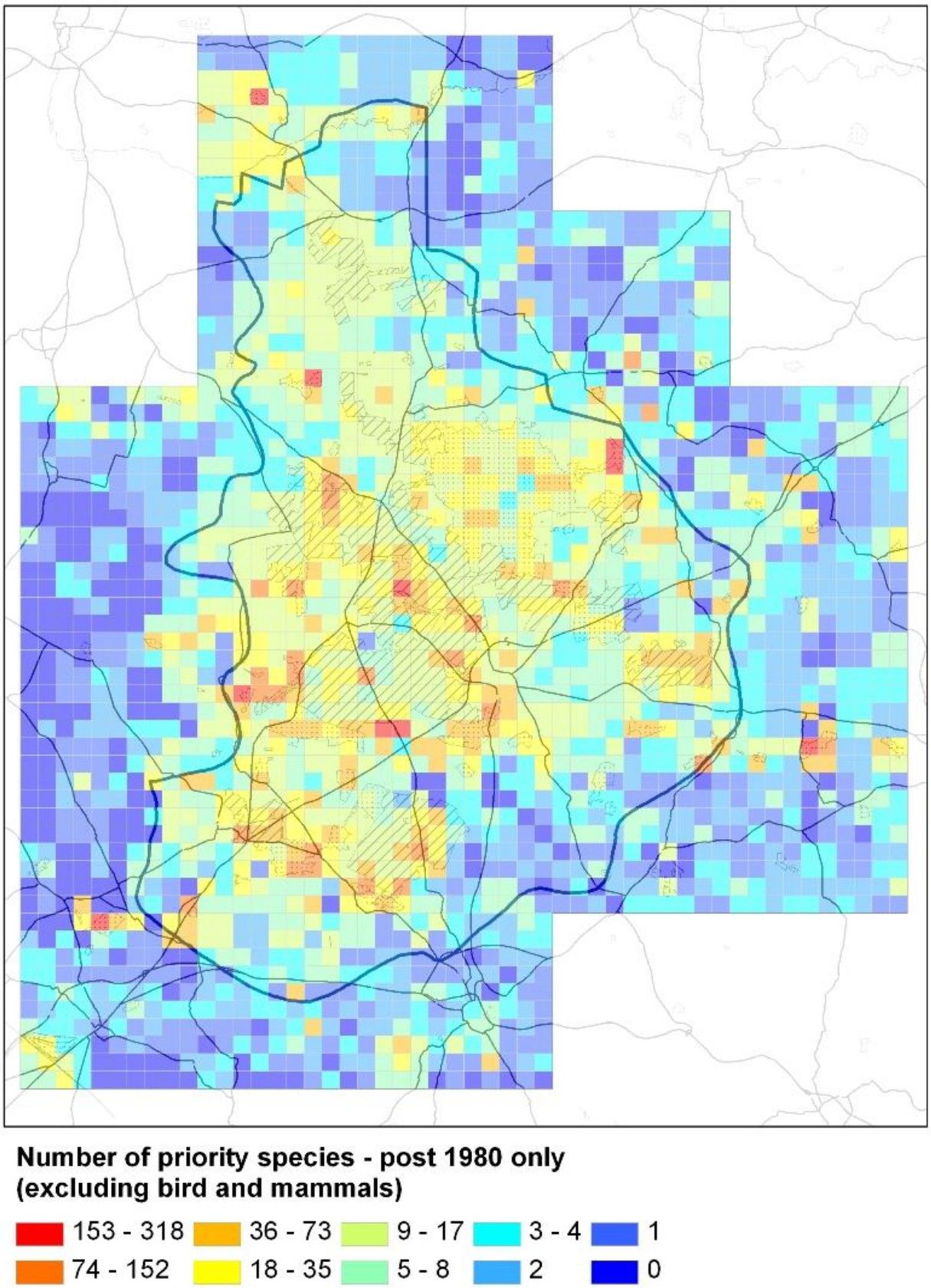


Figure 15. Number of Breckland conservation priority species (excluding birds and mammals) recorded during and subsequent to 1980 in each of the 1 km squares within the Breckland region

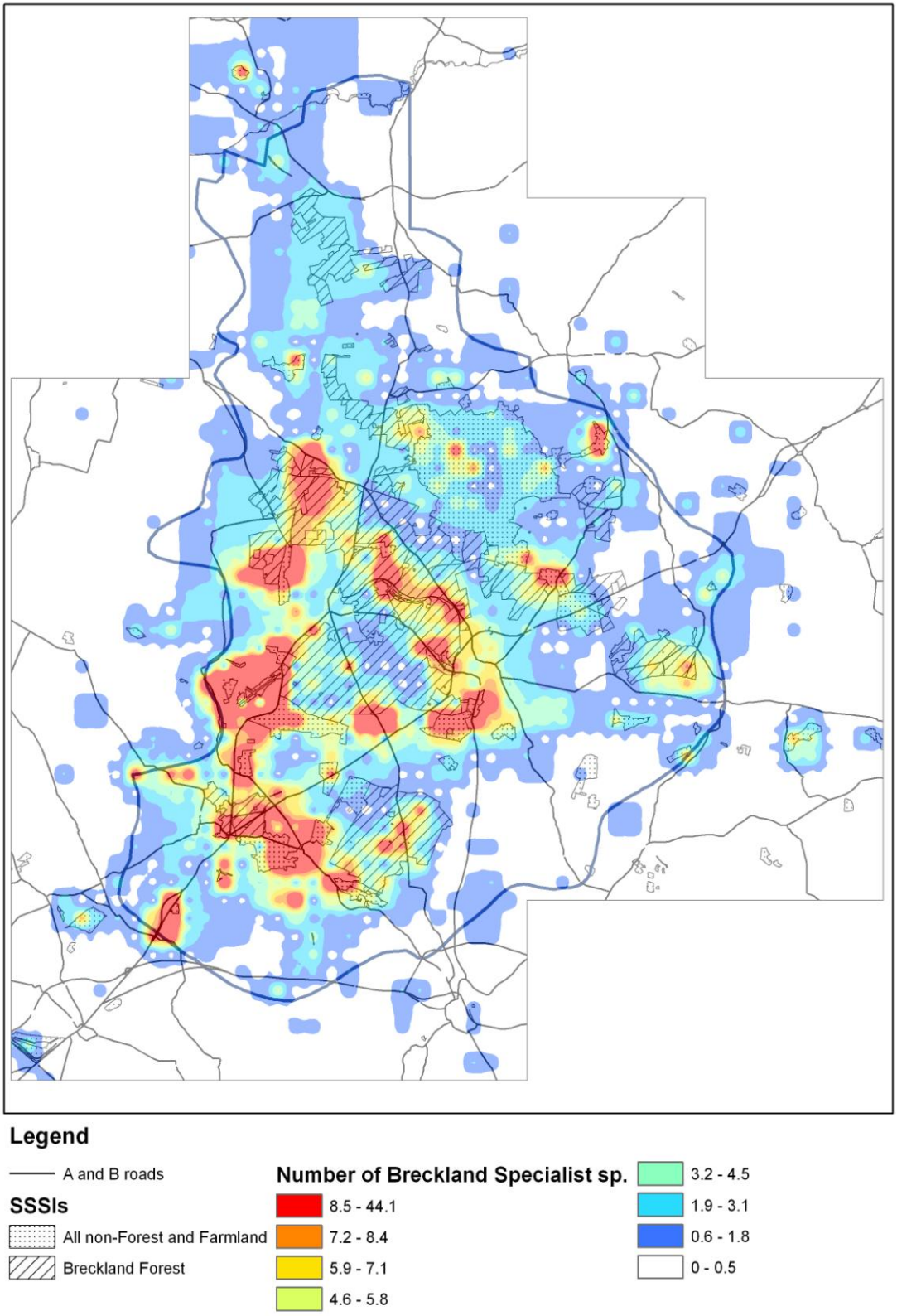


Figure 16. Number of Breckland specialist species (including those with a primarily coastal distribution) recorded subsequent to 1980 in each of the 1 km squares within the Breckland region. Data is plotted as inverse distance weighted, where the value of each point is influenced by its neighbours, with the weight of that influence inversely weighted with distance.

Evidence of Climatic Change: Long-Term Trends in Weather

Rainfall

Since 1905, Breckland has become wetter. Total rainfall in each of winter, spring and autumn increased significantly between 1905 and 2007 (Table 17). The biggest seasonal increase was for winter rainfall that rose by 21.2 mm (0.206 mm yr^{-1} ± 0.127 SE); 14.6 % relative to the winter mean over this time period. In contrast, the total rainfall recorded in summer showed no long term trend over this period (Figure 15).

The number of extreme rainfall events increased significantly for all seasons between 1905 and 2007 (Table 17). However, there were no changes in the number of extreme drought events per season.

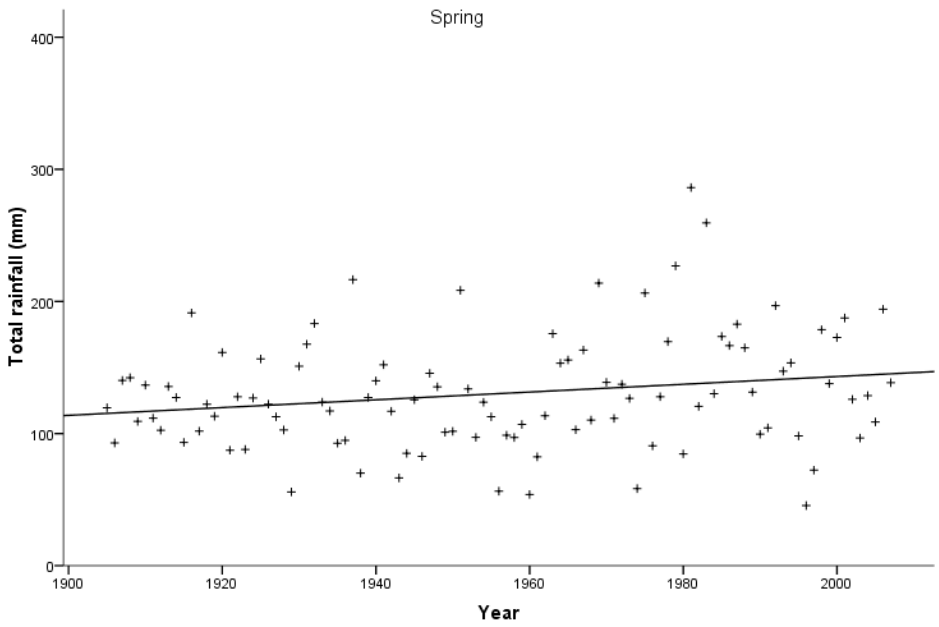
Temperature

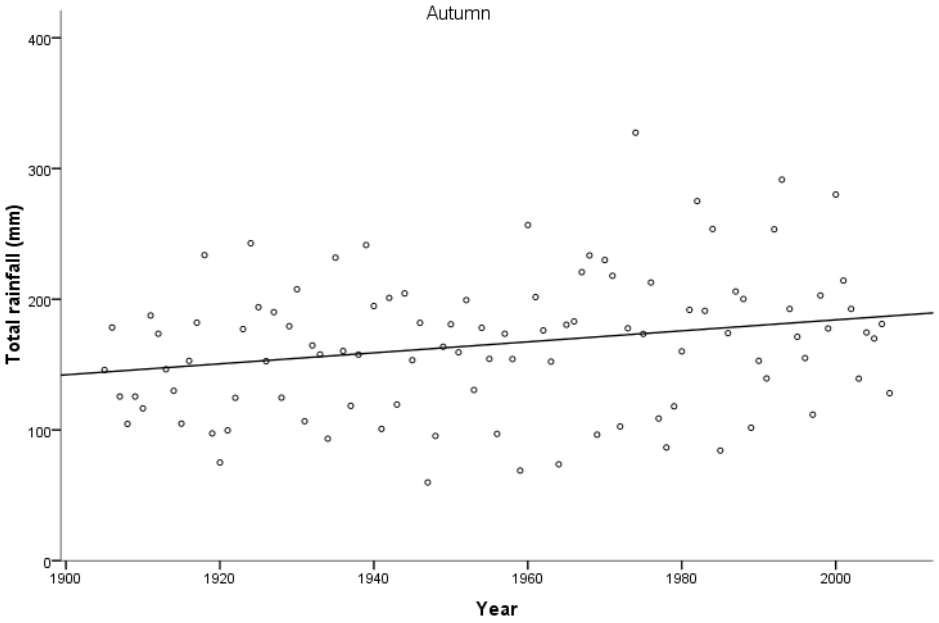
In Breckland the weather, in terms of temperature, has become less continental, with milder winters, milder nights in spring and summer and fewer frosts. Mean daily minimum air temperatures were lower in the mid twentieth century in all four seasons than in recent decades and increased significantly from 1949 to 2008, for all four seasons (Table 17, Figure 16). During winter, the increase in mean daily minimum temperature between 1949 and 2008 was 2.4 °C (0.04 °C yr^{-1} ± 0.009 SE), a substantial change compared to a long term winter mean minimum of 0°C. For spring, daily minima increased substantially, by 1.7 °C compared to a long term mean of 2.8 °C (an increase of 61%).

Air frost became significantly less frequent in both spring and winter between 1949 and 2008 (Table 17). Daily minimum air temperatures and number of air frosts are conservative estimates of the actual degree of frost stress for plants and invertebrates. Minimum air temperatures presented here are much higher than the minimum grass temperatures recorded; for example the average minimum air temperature for December 2007 was 1.16°C, however the average minimum grass temperature for the month was -2.35°C. The mean daily maximum temperature in winter and spring increased significantly between 1949 and 2008; for winter the temperature change is substantial, 1.9 °C compared to a long term mean of only 7.2 °C (26%). However, mean daily maxima during summer and autumn have not changed; since 1949 Breckland has not become hotter.

Table 17. Seasonal precipitation and temperature in Breckland

	Precipitation 1905-2007 (n=103)			**Temperature** 1949-2008 (n=60)		
	Total rainfall per season (mm)	Number of drought events per season (>9 days without rainfall)	Number of extreme rainfall events per season (>11.5mm in a day)	Mean daily maximum temperature (°C) per season	Mean daily minimum temperature (°C) per season	Total number of days of air frost per season
	Mean ± SD F=, P=, R^2 = β =, SE =	Mean ± SD χ^2 =, P= β =, SE =	Mean ± SD χ^2 =, P= β =, SE =	Mean ± SD F=, P=, R^2= β =, SE =	Mean ± SD F=, P=, R^2= β =, SE =	Mean ± SD χ^2 =, P= β =, SE =
Spring (Mar-May)	**130.3 ± 43.6** **4.271, 0.041, 0.041** **0.201, ±0.142**	1.0 ± 0.8 0.939, 0.332 0.003, ±0.0034	**1.4 ± 1.3** **7.092, 0.008** **0.007, ±0.0028**	**13.4 ± 1.0** **5.851, 0.019, 0.091** **0.018, ±0.007**	**2.8 ± 0.9** **22.880, <0.001, 0.283** **0.029, ±0.006**	**24.6 ± 6.8** **15.188, <0.001** **-0.006,0.0015**
Summer (Jun-Aug)	165.6 ± 55.5 3.009, 0.086, 0.029 0.170, ±0.182	1.3 ± 1.1 0.064, 0.800 0.000, ±0.0030	**3.1 ± 1.7** **8.290, 0.004** **0.005, ±0.0019**	21.2 ± 1.3 3.027, 0.087, 0.050 0.016, ±0.007	**9.5 ± 0.8** **31.221, <0.001, 0.350** **0.028, ±0.005**	0.9 ± 1.4 2.119, 0.145 -0.012,0.0080
Autumn (Sep-Nov)	**165.7 ± 52.5** **6.123, 0.015, 0.057** **0.170 ±0.239**	8.0 ± 0.8 0.007, 0.935 0.000, ±0.0037	**3.0 ± 2.0** **16.888, <0.001** **0.008, ±0.0020**	14.6 ± 0.9 3.349, 0.072, 0.055 0.012, ±0.007	**5.0 ± 1.0** **9.848, 0.003, 0.145** **0.022, ±0.007**	15.4 ± 5.9 1.102, 0.294 -0.002,0.0019
Winter (Dec-Feb)	**145.5 ± 39.0** **4.475, 0.037, 0.42** **0.206, ±0.127**	0.4 ± 0.6 1.324, 0.250 0.006, ±0.0052	**1.5 ± 1.3** **10.043, 0.002** **0.009, ±0.0028**	**7.2 ± 1.4** **12.084, 0.001, 0.172** **0.032, ±0.009**	**0.0 ± 1.4** **21.125, <0.001, 0.267** **0.040, ±0.009**	**43.8 ± 11.2** **36.066, <0.001** **-0.007, ±0.0011**





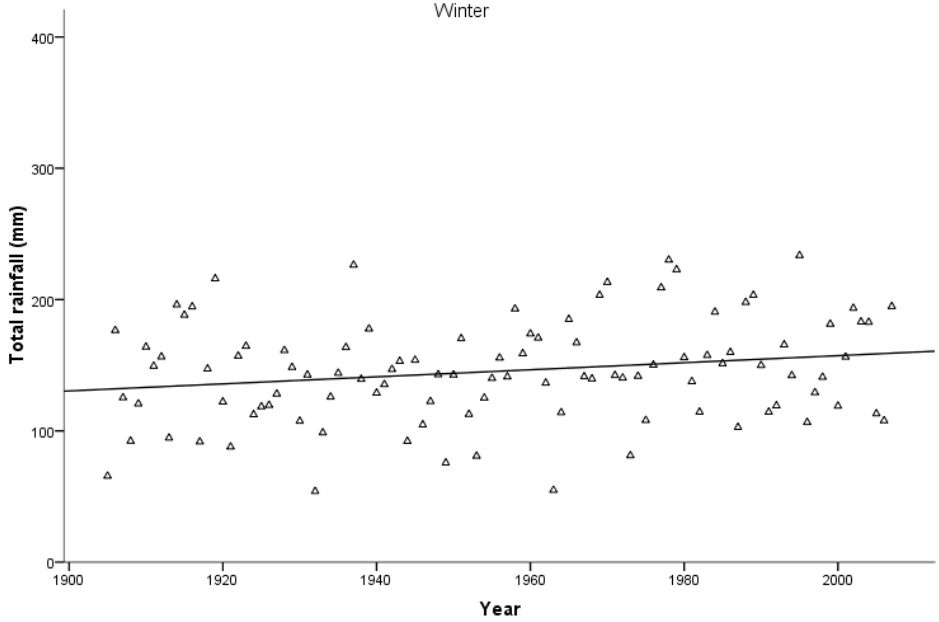


Figure 17. Total seasonal precipitation per year (1949-2008, n=60) at Santon Downham weather stations in spring (+), autumn (○) and winter (Δ). All relationships between year and total rainfall are significant ($p<0.05$) and details are given in Table 17.

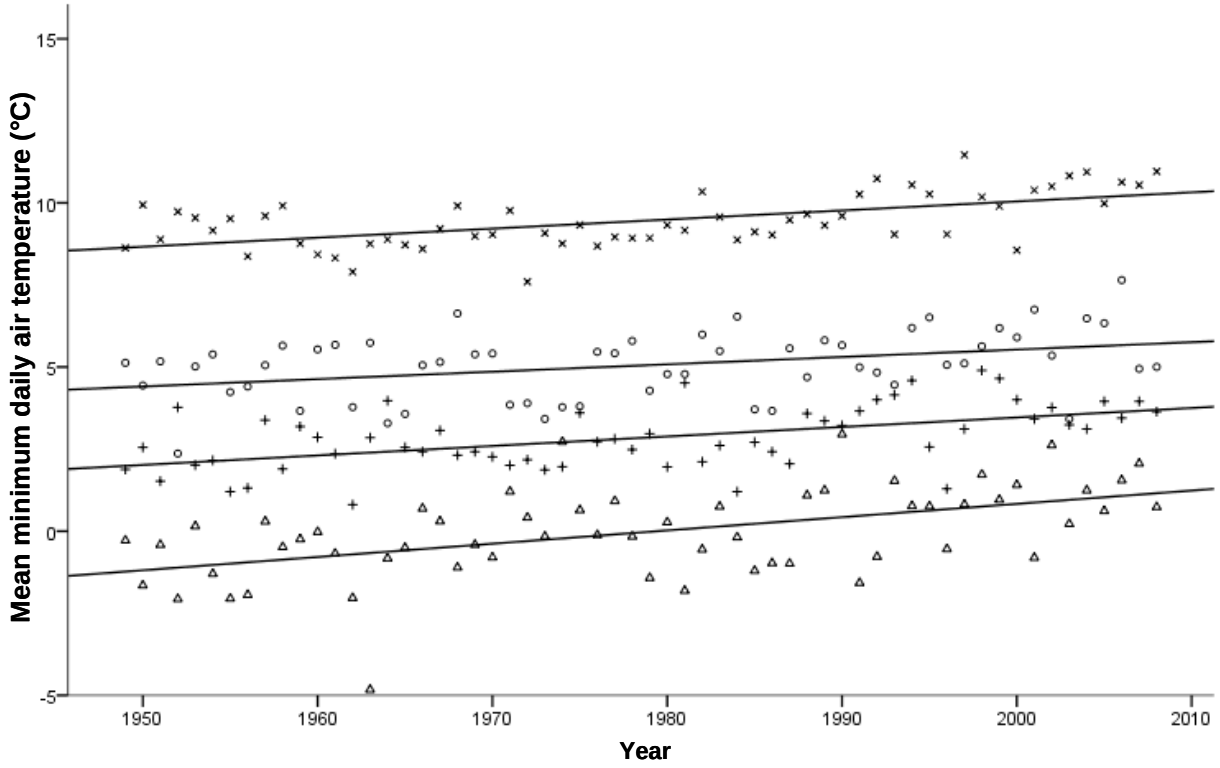


Figure 18. Mean daily minimum air temperature between 1949 and 2008 (n=60) at Santon Downham weather stations in spring (+), summer (x), autumn (○) and winter (Δ). Details of relationships between year and air temperature are given in Table 17.

Predicted Future Climatic Change in the Breckland Region

Climate changes in the East of England have been modelled by the UK Climate Predictions (UKCP09) based on various scenarios of emissions of greenhouse gases (Murphy et al. 2009)

By the 2050s and under medium emissions scenario, the East of England is predicted to experience:

- **Hotter summers.** Summer mean temperatures are predicted to increase by 2.5 °C with an increase of 3.4°C in summer mean daily maximum temperature
- **Drier summers.** Mean summer precipitation is predicted to decrease by 17% in summer mean precipitation
- **Milder winters.** Winter mean temperatures are predicted to increase by 2.2 °C
- **Wetter winters.** Winter mean precipitation is predicted to rise by 14%.

The values given above are central estimates; more details of probabilities and climate changes are available at http://ukclimateprojections.defra.gov.uk.

The UK Climate Impact Programme (UKCIP02) also predicted a significant decrease in soil moisture content.

Biodiversity Implications of the Changing Breckland Climate

Breckland has become wetter in autumn, spring and especially in winter with an increase in the frequency of extreme rainfall events in all seasons. Breckland temperatures have become less continental, with much milder winters, milder nights in spring and summer, and fewer frosts. These changes are predicted to continue under current climate change scenarios. Note that the magnitude of change in temperature may have been under-estimated in our analysis, due to the relocation of the Santon weather station from Grimes Graves to Santon Downham – making our test conservative.

These changes are likely to have profound consequences for ecological processes, for vegetation, and for species. These can only be considered qualitatively and with a large degree of uncertainty. Possible effects may include:

- Wetter winters may favour leaching of mineralisable nitrogen down soil profiles, making the use of soil disturbance treatments to reduce soil fertility more effective.
- Greater winter ground-water recharge may occur, with positive benefits for fen and pingo (fluctuating waterbodies) systems. However, it is recommended that ground water scenarios be explored by models that combine temperature and precipitation in equations for potential evapo-transpiration.
- Milder and wetter winters are likely to result in greater growth of perennial grasses that were previously kept in check by low winter temperatures and frost. Anecdotal evidence suggests this is already occurring within Thetford Forest. Greater grass growth would result in more rapid sward closure and encroachment onto bare ground to the detriment of species requiring bare sand or exposed mineral soil. This may be mitigated by greater use of soil disturbance treatments, and adjustments in grazing regimes to remove excess biomass. Current climate predictions indicate that summers will be warmer and drier; if summer droughting increases significantly, this may mitigate some of the effects of the milder, wetter winters.
- Many of the Breckland speciality and coastal species are more widely distributed in continental steppe or Mediterranean ecosystems. These are often stress tolerant but vulnerable to competition, or to pathogens that can be active in damper or more temperate conditions. Thus wetter autumn, winter and spring soil conditions may be detrimental to seeds, aestivating plants or soil dwelling insect larvae. For example, beetle larvae adapted to xeric conditions may have less resistance to fungal pathogens that can be important in population dynamics (Holland 2002).
- In addition, frost can reduce the vigour of competitors, while also providing small scale local soil disturbance in frost heave; both processes will be reduced.

It will be hard to disentangle responses to changing weather from other changes (land-use, habitat extent), particularly for species whose ecology, distribution, and past and current status are poorly known.

Recommendation:

- Ground water scenarios should be explored by models that combine temperature and precipitation in equations for potential evapo-transpiration.
- Attempt to mitigate increased vegetation productivity from milder and wetter winters by greater use of soil disturbance transpiration and adjustments in grazing regimes to remove excess biomass.

Nitrogen Deposition: Potential Impacts and Mitigation

Grass-heath communities depend on low nutrient conditions

Ericoid (heather) heathland vegetation, in common with chalk grassland, dune and grass-heath vegetation, depends on the low nutrient status of the soil for the characteristic stress tolerant plant communities to persist. With increased nutrients, less competitive stress-tolerant species are replaced by more vigorously competitive species. The diversity and composition of vegetation is fundamentally altered, generally resulting in a loss of scarce species, low growing species, lichens and bryophytes.

Experimental work conducted in the Netherlands has shown the susceptibility of heather heathland vegetation to increased nitrogen deposition, with dwarf shrub heather species being replaced by perennial grass species as nitrogen loads increase (Berendse et al. 1993). Effects include the replacement of ling heather *Calluna vulgaris* by wavy-hair grass *Deschampsia flexuosa* on dry heaths (Heil and Diemont 1983) as well as replacement of both ling heather *Calluna vulgaris* and cross-leaved heather *Erica tetralix* by purple moor grass *Molinia caerulea* on damp or wet heaths (Heil and Bruggink 1987; Aerts et al. 1990; Berendse 1990; Berendse et al. 1993).

Experimental work shows that addition of either phosphorous or nitrogen to calcareous Breckland grass-heath vegetation results in greater dominance and growth of perennial grasses and loss of lichens and other low-growing stress-tolerant plants, together with a reduction in vascular plant diversity in the sward (Davy and Bishop 1984). Similar effects have been demonstrated on ecologically similar habitats , including sand dune vegetation, with a decline in annual species, mosses and lichens and increase in red fescue *Festuca rubra* (Willis 1963; Boorman and Fuller 1982), and on calcareous grassland in which *Festuca rubra* became vigorous and dominant (Smith, Elston and Bunting 1971).

In Breckland, nitrogen appears to be the primary limiting nutrient (Davy and Bishop 1984), as both sand dune soils (Boorman and Fuller 1982) and chalk grasslands (Bobbink et al. 1989). Unpublished work carried out by P. Dolman and S. Lake showed that diverse lichen-heath sub-communities of U1 acid grassland occurred on soils that were higher in phosphorous than grass dominated sub-communities, as long as their nitrogen status was very low. The effects of nitrogen enrichment are partially linked with those of grazing (Berendse 1985). Work by both Davy and Bishop (working at Deadman's Graves, Breckland) and Boorman and Fuller (working on dune vegetation on the Norfolk coast) showed that grazing was not sufficient to offset the impacts of nitrogen addition on lichen rich grass-heath.

Increased nitrogen deposition in the UK and Breckland

There has been a very large reduction in the emissions of nitrogen attributable to domestic coal since the peak of that source in c.1900. Despite this, overall reduced nitrogen (NH_3 and NH_4+) emissions have continued to increase throughout 1900-2000 due to large increases from the agricultural sector (Fowler et al. 2004). Oxidised nitrogen emissions (NO_3- , NO_2 and HNO_3) form c80% of total emissions and have decline since a peak in 1980. Overall emissions have thus declined in recent decades (Fowler et al. 2004).

Ariel depositions to agricultural soils are small in relation to fertiliser inputs. However, deposition to semi-natural soils may be very important in modifying the carbon economy as well as in changing the species composition of the flora (Pitcairn et al. 1998). Depositions during the last century (1900-2000) were equivalent to an average of 1.2 t N ha^{-1} (range, 1 t N ha^{-1} to 5 t N ha^{-1} at national and local scales) and appears to be accumulating in soils (Fowler et al. 2004) (Figure 19). Deposition in Breckland over the century ranged 1-2tNha^{-1}. Rates of nitrogen deposition in Breckland were higher than in other areas of the country. In the mid 1990s, Breckland had rates of nitrogen deposition almost double those measured in Dorset (Pitcairn, Fowler and Graze 1995).

Intensive livestock units release ammonia gas that can cause severe localised impacts on semi-natural habitats as well as contributing to regional nitrogen deposition. In the Netherlands effects have been found close to poultry units (e.g. Berendse, Lurijsen and Okkerman 1988). Sutton, Pitcairn and Fowler (1993) found that 60-80% of total nitrogen inputs may be due to ammonia emissions, largely from agricultural sources.

Intensive livestock (pig and poultry) units over a certain size have been required to apply to the Environment Agency for a Pollution, Prevention and Control (PPC) permit, within the framework of the Environmental Permitting Regulations. Natural England is a statutory consultee in this process. A number of pig and poultry units are located close to nature conservation sites, including SSSIs and SACs. An assessment of the likely impact on SSSIs/SACs of existing pig and poultry units has recently been carried out by the Environment Agency as part of its PPC licencing process. Investigation as to whether evidence of site condition is indicative of damage from nitrogen deposition from these sources to SSSI heathland sites in Breckland is being examined by the Natural England's Evidence Team and the Norfolk & Suffolk Area Team.

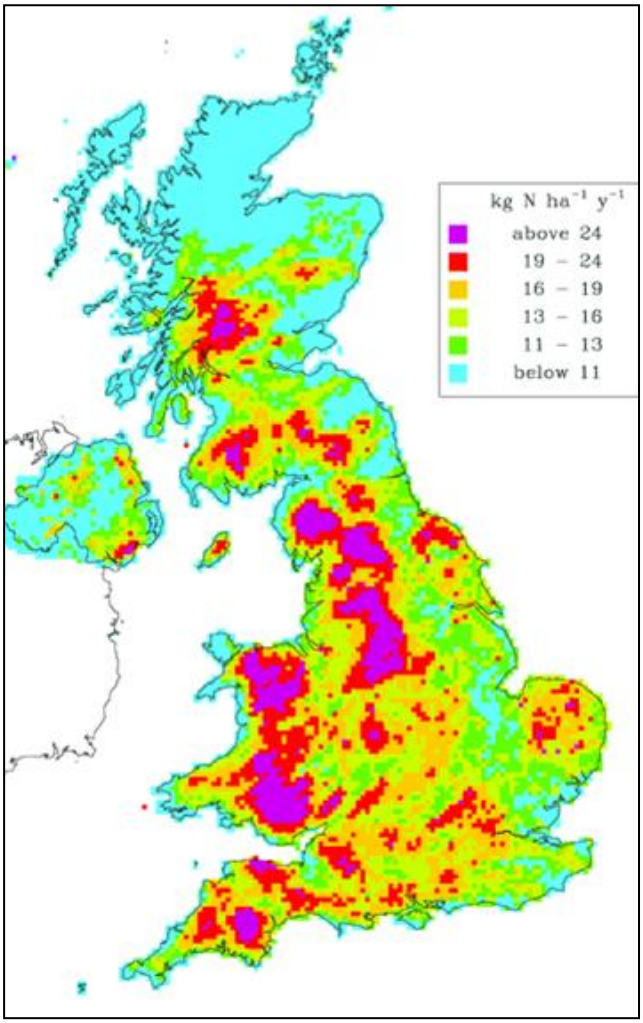


Figure 19. Total deposition of nitrogen (kg N ha^{-1}) across the UK in 2005. Source: Centre for Ecology and Hydrology, UK

Deleterious change in Breckland grass-heaths consistent with nitrogen impacts

Bio-monitoring has been recommended as an early warning system for deleterious effects of nitrogen deposition (Leith et al. 2005; Hall, Bealey and Wadsworth 2006). However, air pollution effects can be difficult to distinguish from confounding effects of changes in management. Effects of nitrogen deposition can be exacerbated by changes in management, particularly a reduction in physical disturbance or periods with no or light grazing.

Cessation of grazing management for decades during the 20th century allowed accumulation of organic material on many heathland sites. Species such Yorkshire fog *Holcus lanatus* and Wavy-hair grass *Deschampsia flexuosa* are highly competitive in nitrogen enriched environments. *H. lanatus* is now often dominant on areas restored by scrub removal or bracken control.

During the early 20th century acid grass-heath vegetation (e.g. U1/H1), comprised acidiphilous sheep's fescue - common bent grass *Festuca ovina-Agrostis capillaris* grass-heath, and lichen heath vegetation (e.g. Watt 1940) while wavy hair grass *Deschampsia flexuosa* was almost entirely absent. This is in marked contrast to the dominance of *Deschampsia flexuosa* across large areas of Breckland heathland by the late 20th century. At Lakenheath Warren, Alex Watt recorded wavy hair-grass *D. flexuosa* in just one patch in 1936, but stated that by 1960 it formed several colonies. By 1971 Gigi Crompton noted that "The most striking change in the vegetation of Lakenheath Warren has been in

the status of *Deschampsia flexuosa*. This plant is highly palatable to rabbits, and only two plants were recorded before the war; today it is widespread and occurs as an abundant component of grassland" (Crompton 1971). A comprehensive and detailed report of vascular plants at Foxhole Heath prepared by S.M. Walters following site visits in 1950 and 1953 (Tansley and Watt, undated) did not include *Deschampsia flexuosa*; however in 1971 Eric Duffey noted a small patch of this grass "which I had not seen before during the period we were there working on the fauna" (i.e. during the mid 1950s).

Within Breckland, *D. flexuosa* is particularly associated with sites where an organic horizon has accumulated overlaying the mineral sand. In contrast *Festuca ovina* may occasionally be found close to *D. flexuosa* dominated swards, but in patches retaining mineral soil with minimal or no overlying organic material (e.g. on track verges with disturbance; P. Dolman *pers. obs*.). Thus, the increase in *D. flexuosa* is compatible with reduced grazing intensity, the accumulation of nutrients through reduced management and with the effects of nitrogen deposition.

Pitcairn, Fowler and Grace (1991) quantified change in three Breckland heathlands (Cavenham, Knettishall, Tuddenham) and concluded that reductions in the cover of *Calluna vulgaris* was at least partly attributable to increased nitrogen deposition. However, changes occurred over a period that also experienced greatly reduced grazing pressure.

For calcareous grass-heath vegetation in Breckland (e.g. CG7), changes in composition noted by Rodwell by the 1970s (in contrast to the composition described by Watt in the 1940s and 1950s) included a reduction in abundance and diversity of both bryophytes and lichens, an overall increase in grass and an increase in particular grass species that are more competitive with high levels of nutrient availability or moisture, such as yellow oat-grass *Trisetum flavescens* and Yorkshire fog *Holcus lanatus* (Rodwell 1992). These changes are compatible with the effects of nitrogen deposition.

Potential management techniques to mitigate effects of nitrogen deposition

Leguminous herbs including birds-foot trefoil *Lotus corniculatus* and black medic *Medicago lupulina* can fix large volumes of nitrogen within grassland ecosystems (e.g. 30-100 kg ha^{-1} yr^{-1}, Marrs et al. 1983), similar or greater than rates of nitrogen deposition. Wells et al. (1976) suggested that intensive selective rabbit grazing can effectively exclude nutritious legumes from the sward and that this was important in reducing nutrient accumulation in lichen rich CG7 vegetation on raw chalk soils of the Porton Ranges, Wiltshire.

In addition, it is highly likely that disturbance of vegetation and root mats by scraping and burrowing by rabbits and the concentration of dung and urine in latrine areas where vegetation is killed-off, both favour leaching of volatilised nitrogen at least during winter rainfall. Thus rabbits may be key to maintaining low nutrient status in grass-heaths. Schwinning and Parsons (1996) showed that nitrogen concentrations in urine exceed the ability of grassland swards to utilise and capture the nitrogen, leading to losses through volatilisation and leaching. However, experimental research quantifying nitrogen budgets and fluxes in different grass-heath management systems is lacking.

Enhanced levels of grazing to remove biomass can contribute to mitigation, but grazing cannot in itself prevent deleterious changes in vegetation composition with enhanced nitrogen availability. Soil disturbance treatments involving rotovating, ploughing, sub-soiling, or turf stripping and removal of surface organic material, are probably the most effective ways of mitigating nitrogen deposition.

Turf stripping has been effective in rejuvenating dwarf shrub heather vegetation from swards dominated by purple moor grass *Molinia caerulea* and wavy-hair grass *Deschampsia flexuosa* in Surrey. Turf stripping has been shown to reduce the nutrient status of heathland soils (with reduced soil organic matter and nitrogen mineralisation rates) in the Netherlands (Bernedse 1990). For heathlands, almost all nitrogen entering the ecosystem accumulates and losses are small (Berendse et al. 1993). To balance inputs in the Netherlands, modelling and experimental data showed it was necessary to strip turf once every 22-33 years in order to retain dwarf shrub vegetation (Berendse et al. 1993).

Turf stripping and surface scraping has produced good results, for example at East Wretham Heath, with regeneration of sheep fescue *Festuca ovina*, ling *Calluna vulgaris* and the lichen *Cladonia furcata* in mineral sand (Yaxley 2004). Trenching and sub-soiling has been used successfully in regeneration of *Calluna* at Brettenham Heath.

At Weeting and Thetford Heaths, plots that had been repeatedly annually rotovated for 14 years and 10 years respectively, had significantly less soil organic matter than surrounding untreated areas (Dolman and Sutherland 1992). During a subsequent period of low rabbit populations, vegetation in treated plots continued to support high quality calcareous lichen-rich grass-heath vegetation, with greater abundance of bare ground, annuals and cushion forming mosses, compared to species-poor tussocky grassland in surrounding untreated grass-heath (Dolman and Sutherland 1994). As a consequence, a programme of annual rotovation has been implemented on plots at both sites; at Weeting Heath three plots have been rotovated annually since 1992/3 (18 years) and one additional larger plot since 1997 (13 years); at Thetford Heath five plots have been rotovated annually since 1992/3. Rotovation has been conducted in autumn or early-mid winter, to provide opportunities for mineralisation and leaching of nitrogen during winter rainfall prior to summer evapo-transpiration deficit. However the consequences of this long term management for soil nutrient qualities have not been assessed.

On soils with greater organic matter content, vegetation can recover rapidly following rotovation treatments. In such cases, ploughing may provide longer opportunities for leaching of mineralised nitrogen to occur, however understanding is unclear.

On sites where vegetation closure following rotovation is not immediate, alternate rotovation of a larger number of plots on a two or three year cycle may benefit a wider spectrum of plant and invertebrate species than annual rotovation, while still providing opportunities for leaching of nitrogen.

Recommendations:

- Nitrogen deposition is a significant pressure for Breckland grass-heath eco-systems. Management tools to mitigate nitrogen accumulation impacts are imperfectly understood, but the use of soil disturbance, turf stripping and encouraging high density rabbit populations are possible approaches.
- Soil nutrient properties of annually rotovated plots should be assessed, in comparison with adjacent untreated control areas of similar basic soil type. Managers should examine results and consider whether these repeatedly rotovated plots should be continued further, or left to fallow and develop oligotrophic grass-heath while beginning soil disturbance management on new plots.

- The relative effects of ploughing, rotovating and turf stripping on soil nutrient properties should be investigated, across a range of soil types differing in pH and organic content. This could first be explored by systematic review of available studies, but if insufficient information is available, it will be necessary to undertake experimental research and monitor soil and leachate in replicated experimental trials.
- Current research commissioned by Natural England aimed at examining whether intensive livestock and poultry units have had, or are having localised impacts on nearby grass-heath sites is not sufficient in design or sensitivity to show whether there is an effect. Further research is required, but this should include direct measurements of nitrogen deposition rates as well as vegetation dynamics in both existing and experimentally manipulated swards (i.e. with manipulated *Festuca-Deschampsia* composition on mineral and organic soils).

Trenching to create bank and calcareous exposure

At Little Heath and Deadman's Grave trenches were dug and the removed material was immediately re-deposited as a bank. This removes the need for transport of arisings, reducing costs and provides free draining calcareous substrates. *Monitoring would identify the species that have benefitted.*
Photographs © B. Nichols

Turf removal to create calcareous exposure

At Thetford and Weeting Heath NNR's turf and organic soil was removed to expose chalky drift. Vegetation development is relatively rapid but bare chalk persists after 5 years. *Monitoring would identify the species that have benefitted.* Photographs © B. Nichols

Trends in Species Status: Extinctions and Declines

Species Extinctions in Breckland

25 species previously or recently recorded in Breckland, are now considered to be extinct within the UK or England (Table 18). Of these, eight (32%) are associated with physically disturbed and ungrazed (or uncertain grazing) conditions, a significantly greater proportion (chi-square = 12.5, $p<0.001$) compared to 220 of the 2149 priority species in Breckland (10%) that are associated with disturbed and ungrazed (or uncertain grazing) conditions.

However, for ten of the 25 species thought to be extinct in the UK or England, our database contains recent records or records that post-date the suggested data of extinction in the UK (for example in Brown et al. 2010 or in RDB reports). This demonstrates that proving extinction is always more difficult than showing that a species still persists! Examples include; the plant bug *Stictopleurus punctatonervosus* (Hemiptera), which was regarded as extinct until 1999 (and is still listed as extinct in JNCC designations) but is now recorded regularly in its former areas and further afield. *Gyrinus natator* (Coleoptera) was recorded three times at Chippenham Fen between 1991 and 1999 and *Andrena (Micrandrena) floricola* (Hymenoptera) has been recorded almost every year since 2004 during the Elveden Center Parcs surveys. The status of these species requires confirmation and further survey, but suggests some species recoveries. This further emphasises the value of collating data across disparate recording schemes and reviewing and updating designation of species. These and other species of uncertain status can now be targeted for urgent survey work.

In addition to the 25 species considered to be extinct, a further 24 species were thought by local experts to be extirpated within the Breckland region. Of these, 16 are believed to have been lost, either as they were well monitored and the last known sites no longer support the species (e.g. scrambled egg lichen *Fulgensia fulgens*, high brown fritillary *Argynnis adippe*, small blue *Cupido minimus*, silver-studded blue *Plebejus argus*, red squirrel *Sciurus vulgaris*) or because no record has been made of the species for many years (e.g. the burrowing shield bug *Odontoscelis fuliginosa,* heart moth *Dicycla oo* and the flies *Leopoldius brevirostris, Meroplius minutus, Stratiomys chamaeleon* and *Orimarga juvenilis*). Of these 16 species, four are associated with grazed and physically disturbed conditions (e.g. *Arenocoris waltii*), a significantly greater proportion (chi-squared = 7.89, $p=0.005$) compared to the 149 (7%) of the total 2,148 priority species that are associated with grazed and disturbed conditions. The remaining species in this table require urgent re-survey.

It is likely that there will be some doubt of the validity of records for a small number of priority species. These require further investigation and we encourage experts to indicate further doubtful species occurrences.

Recommendation:

- Survey work should be encouraged or commissioned to improve understanding of the status abundance and distribution of those species considered to be Extinct in the UK according to the Natural England Lost Life report, but for which the audit has collated recent records.

Table 18. Species recorded in Breckland, but now considered to be extinct in the UK or thought to be locally extirpated. The year of last record in Breckland is given, with the year of extinction according to Nature England's Lost Life report given in parentheses

Group	Species	Status	Breckland specialist	Source	Last record	Guild
Extinct in UK (RDB:EX)						
Flowering plant	*Arnoseris minima*	RDB:EX, BAP		Lost Life	1944 (1971)	OPEN/DIST-NGRAZ
Flowering plant	*Caucalis platycarpos*	RDB:EX		Lost Life	1950 (1971)	OPEN/DIST-?GRAZ
Flowering plant	*Euphorbia peplis*	RDB:EX		Lost Life	1995 (1951)	OPEN/DIST-?GRAZ
Flowering plant	*Tephroseris palustris*	RDB:EX		Lost Life	1750 (1947)	WLAND
Moss	*Orthotrichum striatum*	RDB:EX		RDB	1998	VETERAN
Coleoptera	*Bembidion (Trepanes) octomaculatum*	RDB:EX	Secondary stronghold	RDB	1993	LITT/DETRI
Hemiptera	*Stictopleurus abutilon*	RDB:EX		RDB	2009	OPEN/DIST-?GRAZ
Hemiptera	*Stictopleurus punctatonervosus*	RDB:EX		RDB	2009	OPEN/SWARDM
Moth	*Caryocolum huebneri*	RDB:EX		Lost Life	1874 ($C19^{th}$)	WOODLAND
Moth	*Eurhodope cirrigerella*	RDB:EX		Lost Life	1899 (1960)	OPEN/INFDIST-LGRAZ
Moth	*Laelia coenosa*	RDB:EX		Lost Life	1980 (1879)	WLAND/NGRAZ
Moth	*Loxostege sticticalis*	RDB:EX	Secondary stronghold	Lost Life	2001 (1950s)	OPEN/DIST-NGRAZ
Moth	*Trachea atriplicis*	RDB:EX		Lost Life	1937 (1905)	WLAND
Extinct in England (as listed in Natural England: Lost Life)						
Lichen	*Buellia asterella*	Status:NS	Largely restricted	Lost Life	1999 (1992)	OPEN/DIST-GRAZ
Hymenoptera	*Bombus (Subterraneobombus) subterraneus*	Notable: A, BAP		Lost Life	1999 (1990)	OPEN/INFDIST-LGRAZ
Hymenoptera	*Andrena (Cnemidandrena) tridentata*	RDB:EN		Lost Life	1910 (1944)	OPEN/JUXT
Hymenoptera	*Andrena (Micrandrena) floricola*	RDB:EN		Lost Life	2009 (1939)	O-S
Coleoptera	*Gyrinus natator*	RDB:EN		Lost Life	1999 (1912)	SW
Moth	*Dichomeris derasella*	RDB:EN		Lost Life	1889 (1933)	O-S
Moth	*Emmelia trabealis*	RDB:EN	Primary stronghold	Lost Life	1990 (1960)	OPEN/DIST-NGRAZ
Moth	*Hadena irregularis*	RDB:EN	Primary stronghold	Lost Life	1973 (1968)	OPEN/DIST-NGRAZ
Butterfly	*Carterocephalus palaemon*	RDB:EN, BAP		Lost Life	1913 (1976)	O-W
Diptera	*Tachydromia halterata*	RDB:EN		Lost Life	1921 (1937)	STRUC+MOIST ECO
Araneae	*Dipoena coracina*	RDB:EN		Lost Life	1940 (1913)	OPEN/GRAZ-NDIST

Group	Species	Status	Breckland specialist	Source	Last record	Guild
Locally extirpated in Breckland						
Mammal	*Sciurus vulgaris*	BAP		N. Armour-Chelu	2004	WOODLAND
Lichen	*Fulgensia fulgens*	RDB:EN, BAP		NE Bury Office records	1994	OPEN/DIST-GRAZ
Hymenoptera	*Andrena (Micrandrena) falsifica*	Notable: A		Workshop	2009	OPEN/JUXT
Hymenoptera	*Bombus (Thoracombus) humilis*	BAP		Workshop	2009	OPEN/JUXT
Hymenoptera	*Bombus (Thoracombus) ruderarius*	Notable: B, BAP		Workshop	2009	OPEN/SWARDM
Coleoptera	*Bidessus unistriatus*	RDB:EN, BAP	Secondary stronghold	G. Foster	1988	LITT/DIST
Coleoptera	*Hydroporus rufifrons*	RDB:VU, BAP		G. Foster	2008	WLAND
Hemiptera	*Arenocoris waltlii*	RDB:VU	Primary stronghold	B. Nau	1993	OPEN/DIST-GRAZ
Hemiptera	*Odontoscelis (Odontoscelis) fuliginosa*	RDB:R		NBN	1960	OPEN/DIST-GRAZ
Moth	*Pechipogo strigilata*	BAP		BAP	1982	VETERAN
Moth	*Dicycla oo*	BAP		Workshop, BAP	1870	VETERAN/O-W ECOTONE
Butterfly	*Argynnis adippe*	RDB:EN, BAP		Workshop	1951	O-S/DIST-NGRAZ
Butterfly	*Boloria selene*	RDB:EN, BAP		Workshop	2006	O-W
Butterfly	*Cupido minimus*	RDB:NT, BAP		Workshop	1984	OPEN/DIST-NGRAZ
Butterfly	*Plebejus argus*	RDB:VU, BAP		Workshop	1993	OPEN/DIST-GRAZ
Diptera	*Leopoldius brevirostris*	RDB:VU		Falk, 1991	1941	WOODLAND
Diptera	*Bombylius discolor*	Notable		I. Perry	1898	O-W/DIST
Diptera	*Eurithia intermedia*	Notable		I. Perry	2009	UNASSIGNED
Diptera	*Meroplius minutus*	RDB:R		I. Perry	1913	VARIETY/CARRION-DUNG
Diptera	*Myopa fasciata*	RDB:R		I. Perry	1983	OPEN/JUXT
Diptera	*Stratiomys chamaeleon*	RDB:EN		I. Perry	1953	SW/AQVEG
Diptera	*Asilus crabroniformis*	Notable, BAP		I. Perry	2005	OPEN/GRAZ-NDIST
Diptera	*Myopa polystigma*	RDB:R		NBN	2005	O+W
Diptera	*Orimarga juvenilis*	Notable		NBN	1978	LITT/DIST

Note: Records include occasional vagrant individuals, but extinctions refer to breeding populations (e.g. *Loxostege sticticalis*)

Losses of Characteristic Lichens

Of the assemblage of rare crustose lichens growing on compacted exposed chalk, two were restricted to Breckland in the UK and a third was only recorded inland in the Breckland. These species have been subject to surveillance and survey over the last three decades and this shows that:

- the Starry Breck Lichen *Buellia asterella* is now extinct in the UK (post 1997).
- by 2002 the Scaly Breck Lichen *Squamarina lenitigera* (restricted to Breckland within the UK) had been lost from three of the four sites at which it still occurred in the 1980s and now survives as only c.10 thalli at a single site (B. Nichols *pers. comm.*).
- Scrambled-Egg Lichen *Fulgensia fulgens* within the UK known inland at only a single locality in the Wangford area of Breckland (where it had been recorded since the late 1800s), was extirpated in Breckland in 1993 or shortly after.

Breckland colonies of these species occurred on areas of exposed chalk drift created between 1880-1945, by flint mining, soil trenching, track-ways, removal of material for road building and creation of anti-glider trenches and mounds. There was a long delay before it was recognised that physical disturbance and creation of fresh bare chalk was essential for the rejuvenation and continued vigour of colonies. Other factors including encroaching trees, reduced wind and drought exposure and possible effect of aerial nitrogen deposition may also have contributed to declines and losses[2]. Turf stripping was eventually carried out at Lakenheath Warren in 1997 and a positive response of *Squamarina lentigera* and *Buellia asterella* was initially noted. Turf stripping was also carried out at other key sites in the late 1990s (including Weeting and Thetford Heaths). However, by this time *Fulgensia fulgens* had already been lost, despite attempts at translocation, *Squamarina lentigera* was restricted to just two colonies and *Buellia asterella* to a single locality, with surviving colonies of both species already greatly reduced in extent. At Lakenheath Warren the last remnants of *Buellia asterella* and *Squamarina lentigera* were lost following introduction of cattle grazing to the site in 2000. Following loss of the original *Squamarina lentigera* colony at Weeting Heath in 1990/91 (Gilbert 1991), a new colony of this species was discovered at this site by Bev Nichols in 1997, that initially appeared to be stable in numbers, but this too now appears to be extinct, despite attempts to create suitable new exposed chalk substrate.

Recommendation:

- Surveillance and monitoring of created chalk exposures should be repeated intermittently to examine whether rare terricolous lichen species re-colonise by long-distance spore transport.

[2] For a long time air pollution was blamed as causing simultaneous region-wide declines in these rare lichens and certainly may have been a synergistic and contributing factor. However, in 1991 vigorous and thriving colonies of *Squamarina lentigera* occurred where bare compacted chalk was rejuvenated along a trackway, while abundant fruiting of larger thalli was noted at remaining colonies at declining sites in 1992 and 1997. Data held by Natural England shows that, between 1973-1991, at Lakenheath Warren, most colonies were encroached by perennial grasses, *Hieracium pilosella*, *Cladonia rangiformis* and creeping mosses (particularly *Hypnum cupressiforme*). Crucially, the surface pH of substrates was reduced, Watt (1940) recorded pH 7.9-8.2 for the top 4cm of Grassland A sites (Gilbert 1991; Hitch & Lambley 1993) in contrast on the *Fulgensia* mounds in 1991, values were substantially lower (pH 7.0-7.6 for soil 0-2cm or 0-4cm).

In addition to the loss of rare lichens, a number of other invertebrate and plant species previously recorded in Breckland are now considered to be extinct in the UK (24 species) or to have become extinct in Breckland i.e. regionally 'extirpated' (24 species) (Table 18).

Breckland Specialist Vascular Plants have Suffered Severe Population Declines

For a small number of vascular plants that are largely or entirely restricted to Breckland, all known populations remaining in the later twentieth century have been identified and subject to repeated surveying. Estimates can therefore be made of the changes in the status of these seven species. The results show very serious declines. Of a total of 209 native populations known during 1900-1985, only 113 remained post-1985, which equates an overall loss of nearly one half (46% lost). Across species, the average loss of populations was 54%, while for spiked speedwell *Veronica spicata* and perennial knawel *Scleranthus perennis*, more than 80% of the naturally occurring populations known during the twentieth century had been lost by the 1990s Table 19. If introduced and re-established populations are also included, losses are less severe but still profound; the total number of extant populations declined from 219 to 139, with an average loss per species of one third (mean 33%, range 0% - 52%) (Table 19).

Table 19. The number of populations of 7 Breckland vascular plant specialists over different time periods, showing percentage change over time. The species all have been subject to repeated survey.

Species	Status	Pre 1900	1900-1985	>1985	% change 1900-'85 to post 1985	
			Total (introduced)	Total (introduced)	Native populations only	Including introduced populations
Alyssum alyssoides	Neophyte	0	6 (0)	5 (4)	-83%	-17%
Artemisia campestris	RDB VU	6	26 (5)	16 (6)	-52%	-38%
Muscari neglectum	RDB VU	2	28 (0)	19 (0)	-32%	-32%
Scleranthus perennis ssp prostratus	RDB EN	0	23 (2)	11 (6)	-76%	-52%
Silene otites	RDB EN	14	92 (1)	50 (3)	-48%	-46%
Thymus serpyllum	Status: NR	0	30 (0)	30 (1)	-3%	0%
Veronica spicata	Status: NR	1	14 (2)	8 (6)	-83%	-43%
ALL SPECIES			*219 (10)*	*139 (26)*		

Qualitative Evidence of Profound Change

Conservation management and perceptions of the success of interventions or ecological changes taking place is often made difficult by the problem of shifting reference points. Within conservation organisations there is frequent turn-over of individuals and managers, each of whom tends to consider the condition of sites at the time that they arrived as their reference point. The result of this is generally a lack of long term perspectives on changing conditions. When subjective and quantitative accounts are examined, it can be surprising to discover the enormity of changes that have occurred.

Changes in the extent of structures and conditions within the grass-heath resource can be inferred by changes in abundance of breeding birds that serve as proxies of structure, by historic accounts of their appearance, and by the descriptions and vegetation surveys conducted by the earlier ecologists. These are considered in turn below.

Changes in the abundance of some ground-nesting bird species provide a qualitative indication of change in the structure of grass-heath vegetation over the last 100+ years.

- Ringed plover *Charadrius hiaticula* bred widely across the fallow brecks and warrens of Breckland in the late 19th and early 20th century (Dutt 1904; Clarke 1925), which resembled sandy and shingle coastal habitat. Ringed plover does not now breed on any of the grass-heaths remaining in Breckland.
- Wheatear *Oenanthe oenanthe*, which requires extremely closely grazed turf, was also a characteristic breeder on the Breckland grass-heaths. On surviving grass-heath sites, by 1970 wheatear had declined to 30% of their 1950 abundance, and by 1990 to <5% of their pre-myxomatosis abundance (Dolman and Sutherland 1992). They ultimately ceased breeding in the 1990s (Dolman 1994) though records are confused by the continuing arrival of passage migrants.
- Stone Curlew *Burhinus oedicnemus* requires closely grazed short turf and areas of bare and disturbed soil (Green and Griffiths 1994). Numbers nesting on grass-heath sites are trivial compared to numbers supported by the same sites a few decades ago. For example, Grimes Graves held six pairs in 1968 (NE data) (though increase in disturbance may be a factor here) while STANTA held 16-18 in 1968, and 22 pairs in 1980 (Green and Bowden 1987) but in recent years has only held 1-3 pairs annually. The nature of change in STANTA is further illustrated by changes described by entomologists who have worked on the site. For example, *Cymindis axillaris* is a notable (Na) carabid associated with short-turfed calcareous grassland and stabilised shingle as well as Breck heaths. “Hooper recorded *Cymindis axillaris* commonly in 1978, but I have yet to find a single specimen using similar trapping methods”, “areas of bare sandy heath have now been replaced extensively by grassland” (Collier, 1991).
- Woodlark *Lullula arborea* breeding on grass-heaths requires a mosaic of closely grazed short turf or moss, bare ground, and tussocks or clumps of vegetation for cover and nest concealment. Woodlark were lost from Breckland heaths by the late 1980s, when they became restricted to Thetford Forest. Following a combination of woodlark population recovery and the reintroduction of grazing management to many heathland sites, woodlark have now re-colonised a number of grass-heath sites (Wright et al. 2007).
- Common curlew *Numenius arquata*, is a species that breeds in tall grassland swards. Common Curlew have colonised the Breckland heaths since myxomatosis (Dolman and Sutherland 1992) and now have a significant regional population breeding on the grassier areas of heathland, and in cereal fields.

The nature of change is so great that it is hard to recognise the type of assemblages described by ecologists in the mid 20th century. Examining notes of site visits made by Nature Conservancy staff in the 1950s the description and species lists compiled are hard to recognise for a botanist who has only experienced Breckland grass-heaths in recent decades. For example, visits in 1950 and 1953 to the (then) extensive mosaic of acidic and calcareous grass-heath spanning the Foxhole Heath – Codson Hill complex in (prior to a large part of it being ploughed) recorded the rarities *Alyssum alysoides*, *Silene otites, Silene conica,* purple fescue *Vulpia ciliata* subsp. *ambigua, Thymus serpyllum,* Breckland spring sedge *Carex ericetorum, Medicago minima, Phleum phleoides, Veronica verna* and wall

bedstraw *Galium parisiense* (Tansley and Watt, undated). We do not know of a single locality remaining in Breckland where such an assemblage could be found today.

From these independent lines of qualitative evidence, it is likely that many species that depend on physically disturbed and grazed conditions and a continuous supply of bare sand or chalky soil, will have suffered severe and profound declines in their extent and abundance.

Recognising Changes in Vegetation Over Time: an Example of Grass-Heath Vegetation

Rodwell (1992) analysed samples of CG7b (the *Cladonia* spp. Sub-community of *Festuca ovina-Hieracium pilosella-Thymus praecox/pulegoides* grassland Table 3, classified by Watt as his 'grassland B') obtained in the mid 1970s. Rodwell commented on marked changes since Watt's time (e.g. Watt 1940, 1957). Notably, Rodwell commented that "the vegetation is now generally grassier" with apparently greater amounts of more mesic grass species such as *Holcus lanatus* and *Trisetum flavescens* as well as mesic herbs such as *Trifolium repens*. Second, Rodwell commented that the therophytes (small annual plants that require small scale disturbance and open swards, for example parsley-piert *Aphanes arvensis,* early forget-me-not *Myosotis ramosissima,* wall speedwell *Veronica arvesnsis,* annual pearlwort *Sagina apetala,* shepherds cress *Teesdalia nudicaulis* and spring speedwell *Veronica verna*) were "now apparently much rarer". This situation is compatible with a reduction in the frequency of small scale disturbance, most likely due to a reduction in rabbit populations, and also with an accumulation of nutrients and/or closed matted swards. However, the samples analysed by Rodwell also showed "marked reductions in the frequency and variety of bryophytes and lichens" (Rodwell 1992). This is compatible with both a decrease in grazing intensity and an increase in nutrient status.

Rodwell did note caution in interpreting too much from a single snapshot in time – however, it is notable that these data were collected in the drought year of 1976 which would have hit mesic species hard and would not explain a reduction in lichens (although annuals may have been crisped up and hard to detect by summer).

There seems to be a consistent and continuing pattern of deterioration of the grass-heath resource, as shown by measured change and perception of change across successive periods. This has continued in the last 20 years despite the restoration of livestock grazing across most grass-heaths. The evidence is summarised below.

Period	Source of information	Change in grass-heath
1940s to 1970s	calcareous grass-heath vegetation plant species composition data examined by Rodwell (1992)	• Became grassier • Mesic grass species increased in frequency • Annuals became rarer • Bryophytes and lichens were reduced in abundance and diversity
1981 to 1989	Repeat survey of grass-heath surveyed seven years earlier (see Dolman and Sutherland 1992)	• Became grassier • Annuals became rarer • Lichens and cushion forming mosses became rarer
1990s to 2007	Qualitative perception of change from land managers (Perkin and Norden 2007)	• Became grassier • Broken turf was rarer

Compared to detailed surveying of key areas of lichen heath in 1989 (Dolman and Sutherland 1992), recent (2009) inspection (e.g. at Foxhole Heath) suggests sites have undergone gradual succession to late-stage closed lichen mats (e.g. comprising *Cladonia arbuscula. C. portentosa, C. furcata*). The earliest successional stages, characterised by the lichen *Cornicularia aculeata* and the moss *Polytrichum pilulifera* and a high diversity of lichens such as *Cladonia uncialis* and *Cladonia gracilis* appear to be much harder to find at sites such as Icklingham Plains and Wangford Warren than they were twenty years ago. For example, an extensive area of lichen heath on Horn Heath surveyed in the mid-1990s (P. Dolman and S. Lake) has now all but disappeared (B. Nichols *pers. comm.*).

A major survey of the condition of remaining heathland resource, "The Grass-heaths Assessment" is currently being undertaken by the RSPB and Natural England. This will assess the current and potential extent of conditions suitable for breeding stone curlew. The data will provide an invaluable broad assessment of site conditions and vegetation structures, in terms of sward heights, and availability of bare ground conditions.

Recommendations:
Given concerns and uncertainties regarding long term changes and the relative condition of remaining grass-heaths, the following are recommended:

- Available quantitative data for vegetation species composition at known sites could be collated and analysed to examine trends in species composition. Data used could include that of Watt's surveys, data considered by Rodwell, data collected by P. Dolman in 1989, NVC surveys of chalk grassland commissioned by English Nature in 1992, more recent SSSI condition assessment species lists held on file by Natural England. Trends could be compared among sites with different combinations of sheep and rabbit grazing to examine correlates of change. As all sites are subject to nitrogen deposition, evidence could be qualitatively examined to see if trends are consistent with predicted impacts of nitrogen eutrophication, as no sites have escaped deposition conclusive proof of cause and effect could not be obtained.
- A field based survey and audit of the acidic grass-heath could be conducted to examine the extent and successional status of the remaining resource, in order to guide priorities for management.

- The relative extent of lichen rich and ephemeral / therophyte rich NVC sub-communities compared to grass and herb-rich NVC sub-communities (including mesic vegetation with *Holcus*, *Anthoxanthum* and *Trisetum*), compared to *Deschampsia* dominated sub-communities be assessed across a suite of Breckland grass-heaths, considering both the acidiphilous and calcareous resource. This may be possible using data held by Natural England, or may require commissioning of field based surveys.

Ecological Requirements of Breckland Biodiversity: Broad Habitat Associations

The majority of species (85%) were not unique to a single broad habitat type(Table 20). Furthermore, many species were found to be associated with habitats that do not occur in Breckland, e.g. 60 species, including two unique species, were associated with saltmarsh. This highlights the need to assess the requirements of conservation priority species in terms of micro-habitats and processes rather than broad habitats.

The largest numbers of species were associated with broadleaved woodland (689 species) and calcareous grassland (583 species) and these habitats also had the largest numbers of species unique to them, broadleaved woodland (89 species) and calcareous grassland (62 species). Only 19 species were unique to lowland heath (Table 20) but 14 were unique to coniferous woodland. The fewest number of species were associated with reliant on mammal burrows (24 species) and carrion (31).

A large number of species had requirements for detritus and leaf litter (263 species) and occurred in all broad habitat types. Dung and carrion associated species were also found in almost all habitats.

Breckland specialists were associated with almost all habitats, with the exception of moorland and mammal burrows, with the most species occurring in calcareous grassland and lowland heath **(**Table 20).

Table 20. Broad habitatassociation of conservation priority species from the Breckland region

	No of rare species	no. unique species	No. coastal	No. breck specialists	No. BAPs	Running water	Standing water	Fen	Mature fen carr	Bog	Moorland	Saltmarsh	Shingle	Sand dune	Wet grassland	Neutral grassland	Improved grassland	Acid grassland	Calcareous grassland	Lowland heath	Arable & horticulture	Brownfield/walls	Scrub	Hedgerow	Wood pasture	Broadleaved woodland	Coniferous woodland	Sand/chalk/gravelpits (not sandy)	Mammal burrows	Dung	Detritus/Leaf litter	Carrion	Deadwood
Running water	216	6	0	10	36	-	149	111	21	16	5	14	13	12	29	7	3	10	18	14	10	4	6	6	14	41	2	24	0	0	64	2	10
Standing water	319	15	1	21	44	149	-	205	27	43	11	18	7	16	58	7	4	12	12	22	10	3	14	3	12	33	3	44	1	0	49	1	8
Fen	554	46	5	32	86	111	205	-	66	83	16	25	13	47	103	48	25	49	101	77	23	12	52	14	77	129	11	43	6	3	95	4	27
Mature fen carr	108	2	0	2	8	21	27	66	-	12	1	0	0	6	14	3	1	3	6	5	2	2	9	4	25	65	6	6	0	0	21	0	11
Bog	118	3	0	5	14	16	43	83	12	-	9	4	0	9	17	3	0	6	9	21	3	1	6	1	13	24	5	15	2	2	11	2	8
Moorland	61	0	0	0	31	5	11	16	1	9	-	8	1	14	6	19	13	16	19	33	7	3	10	2	19	20	7	9	0	2	3	1	1
Saltmarsh	60	2	3	1	11	14	18	25	0	4	8	-	10	20	9	9	5	7	20	11	11	6	3	2	2	6	0	11	0	1	4	0	2
Shingle	95	0	5	15	11	13	7	13	0	0	1	10	-	49	3	24	8	23	39	26	8	10	6	5	11	9	2	26	1	3	10	2	9
Sand dune	300	16	19	38	44	12	16	47	6	10	14	20	49	-	17	52	21	64	130	126	23	26	21	10	26	41	7	85	7	26	37	10	33
Wet grassland	144	3	2	6	36	29	58	103	14	18	6	9	3	17	-	26	16	23	37	22	6	1	9	3	17	28	1	7	1	0	24	1	10
Neutral grassland	239	2	2	26	71	7	7	48	3	3	19	9	24	52	26	-	87	165	192	77	35	27	50	27	71	70	3	37	1	12	31	6	17
Improved grassland	90	0	1	6	50	3	4	25	1	0	13	5	8	21	16	87	-	87	88	40	21	15	35	19	40	28	3	6	0	5	13	3	6
Acid grassland	251	5	2	4	75	10	12	49	3	8	16	7	23	64	23	165	87	-	215	101	33	29	46	24	63	60	6	32	1	9	32	4	22
Calcareous grassland	583	62	4	66	129	18	12	101	6	10	19	20	39	130	37	192	88	215	-	176	71	50	87	47	110	146	10	104	10	19	63	9	32
Lowland heath	382	19	10	58	91	14	22	77	5	24	33	11	26	126	22	77	40	101	176	-	33	30	72	24	75	102	24	89	7	37	42	15	33
Arable & horticulture	146	8	0	19	49	10	10	23	2	3	7	11	8	23	6	35	21	33	71	33	-	32	19	22	21	21	5	32	3	9	20	4	4
Brownfield/walls	101	3	1	7	36	4	3	12	2	1	3	6	10	26	1	27	15	29	50	30	32	-	15	11	17	18	4	23	7	12	29	6	4
Scrub	180	1	0	7	67	6	14	52	9	6	10	3	6	21	9	50	35	46	87	72	19	15	-	45	86	103	10	22	1	6	16	2	14
Hedgerow	129	3	0	6	35	6	3	14	4	1	2	2	5	10	3	27	19	24	47	24	22	11	45	-	63	79	5	13	3	7	11	2	14
Wood pasture	391	2	0	9	107	14	12	77	25	13	19	2	11	26	17	71	40	63	110	75	21	17	86	63	-	322	24	25	0	6	33	3	92
Broadleaved woodland	689	89	0	19	86	41	33	129	65	26	20	6	9	41	28	70	28	60	146	102	21	18	103	79	322	-	61	43	5	9	68	4	129
Coniferous woodland	103	14	0	7	14	2	3	11	6	7	7	0	2	7	1	3	3	6	10	24	5	4	10	5	24	61	-	4	0	1	7	0	13
Sand/chalk/gravelpits (nc	249	2	9	24	31	24	44	43	6	15	9	11	26	85	7	37	6	32	104	89	32	23	22	13	25	43	4	-	9	32	29	15	20
Mammal burrows	24	0	0	0	3	0	1	6	0	2	0	0	1	7	1	1	0	1	10	7	3	7	1	3	0	5	0	9	-	5	10	4	2
Dung	56	3	2	12	9	0	0	3	0	2	2	1	3	26	0	12	5	9	19	37	9	12	6	7	6	9	1	32	5	-	21	18	6
Detritus/Leaf litter	263	2	2	30	41	64	49	95	21	11	3	4	10	37	24	31	13	32	63	42	20	29	16	11	33	68	7	29	10	21	-	13	34
Carrion	31	3	1	5	4	2	1	4	0	2	1	0	2	10	1	6	3	4	9	15	4	6	2	2	3	4	0	15	4	18	13	-	4
Deadwood	211	13	5	17	5	10	8	27	11	8	1	2	9	33	10	17	6	22	32	33	4	4	14	14	92	129	13	20	2	6	34	4	-

The Feasibility and Usefulness of the Ecological Assemblage Approach

It proved possible to attribute 84% of species to an assemblage, based on an objective analysis of individual ecological requirements collated from documentary and expert sources. Where there was uncertainty regarding responses to important ecological processes such as grazing or disturbance, then species were retained within a general guild for their key habitat type.

65 guilds were identified of which 25 were dry terrestrial guilds and 31 wet habitat guilds (Figures 20 and 22). The remaining nine guilds comprised species requiring damp conditions and those that needed specific ecological processes or structures, such as dung, but could occur in any habitat or ecotone. The mean number of species within all the guilds was 29 species.

For wetland species, 31 assemblages were identified that ranged in size from 1 to 94 priority species (mean 19.3 species per guild) (Figure 23). Of these, 10 guilds contained fewer than five priority species. In many cases this reflects our difficulties in collating suitably detailed knowledge or ecological understanding for large numbers of the wetland species. For example, in the open wetland guilds (open wetland associated species with no aquatic life-stage) only two species were attributed to require disturbance or disturbance in combination with grazing, while 94 species were placed in a category of uncertain response to disturbance and grazing. Similarly for standing and running water assemblages, a few individual species were attributed to ungrazed, or disturbed and grazed conditions, while for the large majority we were uncertain of their response to disturbance and grazing. Other small assemblages may reflect highly specialist groups that are poorly represented in Breckland, for example species of deadwood in damp woodland and species of veteran trees in wet woodland.

For dry terrestrial species, including open woodland and woodland associates, fewer but larger assemblages were identified compared to the wetland guilds. Twenty five assemblages, ranging in size from 2 to 156 priority species (mean 46.8 species per assemblage) (Figure 21). Only three of guilds comprised fewer than five priority species and all were associated with woody vegetation. These were guilds of species requiring:

- Veteran trees in open woodland (a specialist group poorly represented in Breckland).
- Open, grazed habitats without a requirement for disturbance, but that also have a requirement for scrub – a guild better regarded as a sub-group of a larger assemblage.
- Open, ungrazed woodland (compared to a much larger assemblage of open woodland species for which the grazing and disturbance requirements were unknown).

The largest guilds were; woodland (156 species), open with disturbance no/light grazing (136 species) and open with disturbance and grazing (117 species). The guilds with the highest numbers of Red Data Book species were; open with disturbance no/light grazing (67 species), wetland with requirements uncertain (44 species) and woodland (43 species).

Breckland specialists occurred in almost half of all the guilds (34). The largest number of specialists were in the open with disturbance and grazing guild (30 specialist species) and the open with disturbance no/light grazing guild (also 30 specialists), followed by the open with disturbance but uncertain grazing (17 specialists). The disturbance-and-grazing guild contains 136 Breckland conservation priority species and 23% (30 species) of these are Breckland specialists.

Many guilds had numerous designated priority species, but had comparitively few Breckland specialists, for example the woodland guild contained 156 Breckland conservation priority species, but only 2.5% (4 species) of these were specialists to Breckland. Other large guilds contained no Breckland specialists, for example the Structure-and-Moisture-Ecotone and Veteran tree guilds.

38 Breckland specialists occurred in wet habitat guilds, with the largest number of specialists (7 species) in the open standing water guild.

Obligate species

Many species have important obligates which should be considered when interpreting guilds and formulating management plans. A large number (120) of species, particularly beetles and flies, were found to have important obligates with fungi or lichen species. A number of species (at least eight) are associated with willow and poplars, including beetles (e.g. *Aromia moschata* – see Box) and flies such as the cranefly *Gnophomyia viridipennisa* (Notable: B), whose larvae develop in the layers beneath the bark of fallen poplar and possibly willow trees.

Another important wetland obligate is Common Reed (*Phragmites australis*), with at least 10 species, including moths, such as the Reed Leopard (*Phragmataecia castaneae*) and various Wainscot species, and flies such as the BAP and RDB fly *Lipara similis* and its associated RDB fly species *Cryptonevra consimilis* (see Box).

Another frequent, but rarely considered, obligate is yarrow, which depending on the obligate invertebrate species would require different management considerations. For example, the larvae of the Notable B tortoise beetle *Cassida prasina* feeds in a free-living state on the plant and could therefore, tolerate moderate or possibly intensive. However, plants in the same conditions would be unsuitable for other obligates, such as the Notable B weevil *Microplontus triangulum* whose larvae feed in the upper stems, and the Notable B flower beetle *Olibrus millefolii*, whose larvae feed in the flowers heads. An intensive or moderate grazing regime would not allow for the tall stems and numerous flowers that support these obligate beetles.

Also there are numerous priority parasitic species, including at least 23 snail killing-flies (of the family Sciomyzidae) that require snails or other molluscs and may be quite selective in host choice. There are also numerous parasitic Hymenoptera and Coleoptera species that have obligate host species or genuses . It is therefore important to determine and consider the ecological requirements of the host. Such species include the spider hunting wasp *Aporus unicolor* (Hymenoptera – Notable A) and the tiger-beetle wasp *Methocha articulata* (Hymenoptera – Notable B). The tiger-beetle wasp is a psammophilous flightless wasp, associated with warm, sunny areas with plenty of bare ground and sparsely-vegetated areas. It is a larval parasite of *Cicindela* larvae (a genus of tiger beetles) within their burrows. The adult female avoiding the ferocious jaws of the beetle larvae, squeezes round its large thoracic shield, which the beetle ulitises to fill most of the burrow entrance. The female repeatedly stings the larvae then lays the egg in the burrow and then fills in the burrow sealing both within.

Figure 20. Matrix of the classification of dry terrestrial guilds

PROCESSES			ECOLOGICAL SUCCESSIONAL GRADIENT (From open habitat into woodland / forest with glades)			
			Open dry terrestrial habitats	Open with Scrub	Open-Woodland	Woodland
VARIETY			VARIETY Species occuring in a wide variety of habitats, but associated with certain processes e.g. carrion, dung, walls etc.			
Veteran/ Deadwood					VETERAN/O-W Veteran trees in open-context (open woodland, hedges, parkland, heath or farmland)	VETERAN Veteran Trees
				DEAD/O-W Deadwood in open context (open-woodland, hedges or open habitat)		DEAD Deadwood
Within-patch processes	Grazing and disturbance requirements unknown			O-S Open with Scrub - grazing and disturbance requirements unknown	O-W Open woodland - grazing and disturbance requirements unknown	WOOD Woodland - grazing and disturbance requirements unknown
	No Grazing		OPEN/InfDIST-LGRAZ Open with infrequent small-scale disturbance and only light grazing. Can included light grazing/biomass harvest to prevent scrub and frequently to maintain early successional stages/open conditions. Disturbance not essential	O-S/nfDIST-LGRAZ Open with infrequent small-scale disturbance and only light grazing. Can included light grazing/biomass harvest to prevent excessive scrub domination. Disturbance not esssential	O-W/NGRAZ Open woodland, no grazing	
		Disturbance	OPEN/DIST-NGRAZ Open with disturbance and only light grazing. Disturbance is required but medium to high grazing is undesirable	O-S/DIST-NGRAZ Open-with-scrub with disturbance and only light grazing. Disturbance is required but medium to high grazing is undesirable		
			OPEN/DIST-?GRAZ Open habitats with disturbance, but grazing requirements unknown		O-W/DIST Open woodland and disturbance, grazing requirements unknown	
	Grazing		OPEN/DIST-GRAZ Open habitats, disturbance required and medium to high intensity grazing (for example rabbitgrazing or sheep grazing with rotovating)	O-S/DIST-GRAZ Open-with-scrub, where disturbance is required and medium to high intensity grazing (for example rabbitgrazing or sheep grazing with rotovating)		WOOD/GRAZ Grazing in woodland
			OPEN/NDIST-GRAZ Medium to high intensity grazing, disturbance not essential (for example sheep grazing)	O-S/NDIST-GRAZ Medium to high intensity grazing, disturbance not essential (for example sheep grazing)		
	Grazing Flux		OPEN/SWARDM Open habitats with a mosaic of successional structures within the ground vegetation, from short grass to tall grass. May result from episodic grazing regimes, relaxation / cessation of grazing, or expanding margins	O-S/SWARDM Open-with-scrub habitats with a mosaic of successional structures within the ground vegetation, from short grass to tall grass. May result from episodic grazing regimes, relaxation / cessation of grazing, or expanding margins		
Across patch arrangement	Landscape complexity		OPEN/JUXT Open habitats with a juxatposition mosaic of disturbance to create bare ground that may be grazed, with access to nearby ungrazed tallgrass or flower rich areas is also required	O-S/JUXT Open-with-scrub habitats with a juxatposition mosaic of disturbance to create bare ground that may be grazed, with access to nearby ungrazed tallgrass or flower rich areas is also required		
			WBS Wind blown sand required			
			W-O-W(S+M ECOTONE) Moisture Ecotone across either open or woodland structures e.g heath to fen /dune slack or wet woodland: requires extensive grazing within complex sites			
			O + W Open and wooded habitats - generalist species and those incompletely understood			

Figure 21. Matrix of the classification of dry terrestrial guilds. The numbers given are the total number of species, number of RDB species, number of BAP, number of Breckland specialists (including coastal specialists)

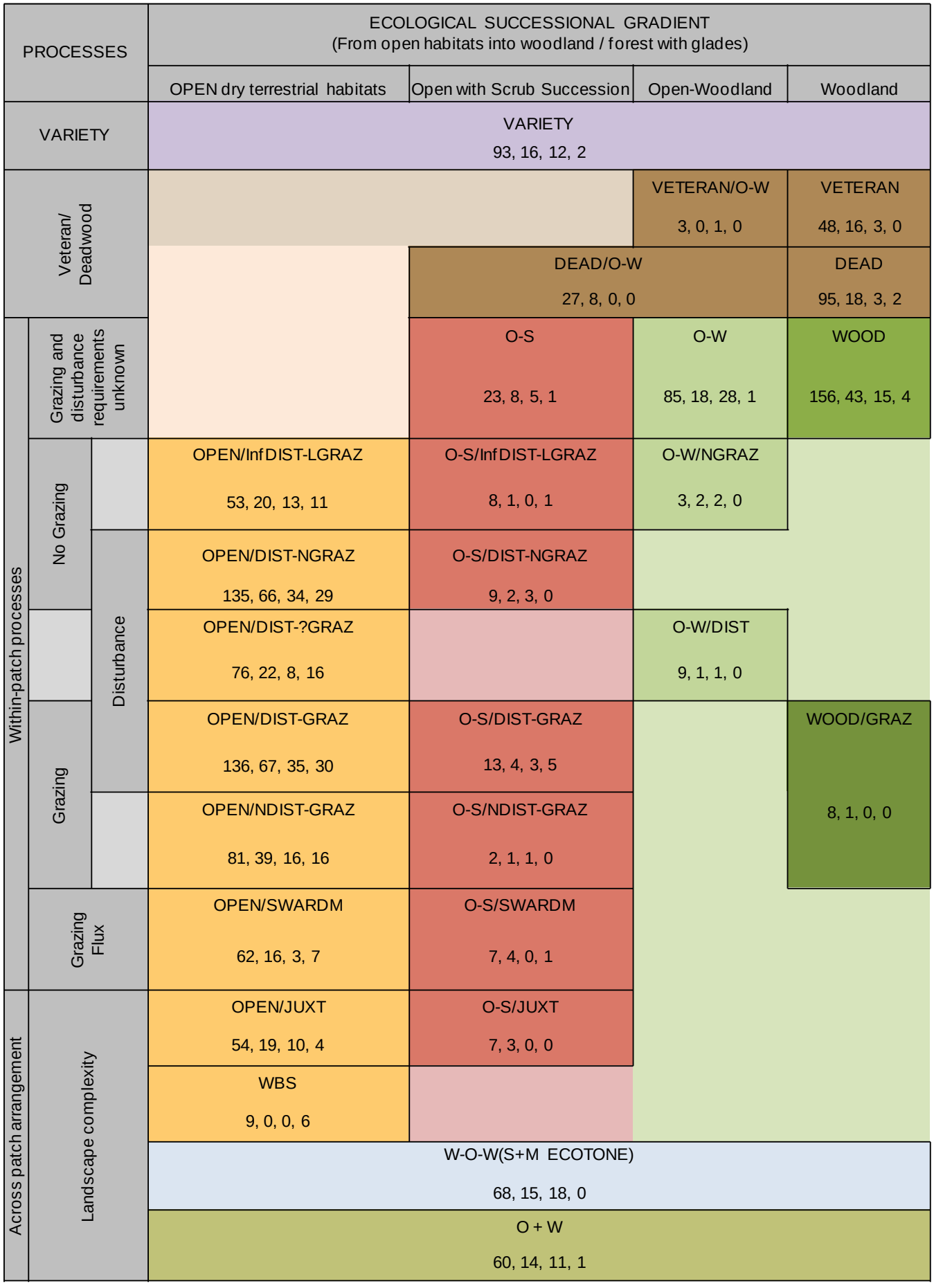
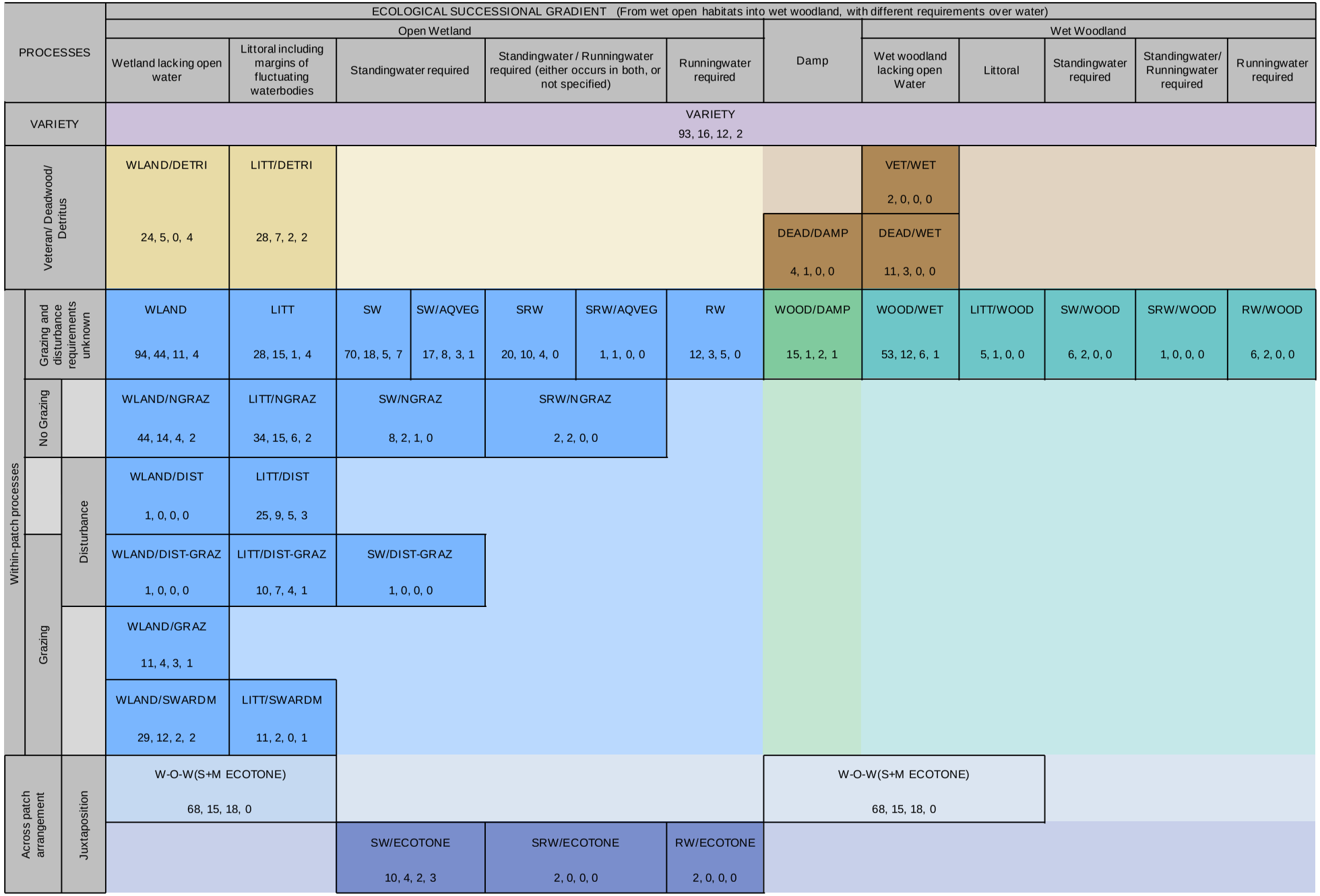


Figure 22. Matrix of the classification of wetland guilds

PROCESSES			ECOLOGICAL SUCCESSIONAL GRADIENT											
			Open Wetland					Damp	Wet Woodland					
			Wetland lacking open water	Littoral including margins of fluctuating waterbodies	Standingwater required	Standingwater / Runningwater required (either occurs in both, or not specified)	Runningwater required		Wet woodland lacking open Water	Littoral	Standingwater required	Standingwater/ Runningwater required	Runningwater required
VARIETY			VARIETY Species occuring in wide variety of habitats, but associated with certain processes e.g. carrion, dung, walls, ivy etc.										
Veteran/ Deadwood/ Detritus			WLAND/DETRI Wetland detritus	LITT/DETRI Littoral detritus				DEAD/DAMP Damp deadwood	VET/WET Veteran trees in wetland DEAD/WET Wet saturated deadwood, including rotholes				
Within-patch processes	Grazing and disturbance requirements unknown		WLAND Open wetland (species have no essential requirement for open water)	LITT Species of wet littoral margins, in a variety of open situations	SW Standing water, non-specific or unshaded with aquatic vegetation, can be within wetlands or open	SW/AQVEG Aquatic vegetation also required	SRW Standing or runningwater required, can be within wetlands or open	SRW/AQVEG Aquatic vegetation also required	RW riverine habitats, or other runningwater required (e.g. trickles and flushes or slow moving water)	WOOD/DAMP	WOOD/WET Wet woodland and Carr habitats	LITT/WOOD Shaded littoral habitats	SW/WOOD Wet woodland with standingwater, including shaded aquatic habitats lacking submerged aquatic vegetation	SRW/WOOD Shaded running or standingwater (e.g. woodland or carr pools and streams)	RW/WOOD Woodland and Carr habitats but runningwater required
	No Grazing	Disturbance	WLAND/NGRAZ Species of plentiful vegetation and tall grass. Light grazing or biomass harvest is necessary to maintain open conditions. Disturbance not an essential requirement	LITT/NGRAZ Species of plentiful vegetation and tall grass, requiring standing water. Light grazing or biomass harvest is necessary to maintain open conditions. Disturbance not an essential requirement	SW/GRAZ Species of plentiful vegetation and tall grass, requiring standing water. Light grazing or biomass harvest is necessary to maintain open conditions. Disturbance not an essential requirement.		SRW/NGRAZ Species of plentiful vegetation and tall grass, requiring standing or running water. Light grazing or biomass harvest is necessary to maintain open conditions. Disturbance not an essential requirement.								
			WLAND/DIST Wetland with bareground/ no vegetation (by disturbance) required for species	LITT/DIST Littoral margins unvegetated / with bareground required (by disturbance)											
	Grazing		WLAND/DIST-GRAZ Within wetlands shortgrass (by grazing/biomass harvest) and bareground/poaching is required	LITT/DIST-GRAZ Littoral margins with shortgrass (by grazing/biomass harvest) and bareground/poaching required	SW/DIST-GRAZ Shortgrass (by grazing/biomass harvest)and bareground/poaching required with standingwater										
			WLAND/GRAZ Grazing with wetland, no requirement for disturbance												
			WLAND/SWARDM Wetland with sward mosaics	LITT/SWARDM Littoral margins with sward mosaics											
Across patch arrangement	Juxtaposition		W-O-W(S+M ECOTONE) Moisture Ecotone across either open or woodland structures e.g heath to fen /dune slack or wet woodland: requires extensive grazing within complex sites		SW/ECOTONE requires an ecotone of open habitats, and woodland/scrub, with standing water		SRW/ECOTONE requires an ecotone of open habitats, and woodland/scrub, with water		RW/ECOTONE requires an ecotone of open habitats, and woodland/scrub, with running water	W-O-W(S+M ECOTONE) Moisture Ecotone across either open or woodland structures e.g heath to fen /dune slack or wet woodland: requires extensive grazing within complex sites					

Figure 23. Matrix of the classification of wetland guilds. The numbers given are the total number of species, number of RDB species, number of BAP, number of Breckland specialists (including coastal specialists)



Delivery of Multiple Species by Integrated Species Biodiversity Action Plans

One aim of this Audit was to examine whether a focus on providing the requirements of the priority Biodiversity Action Plan species would comprehensively deliver the full suite of priority species requiring conservation in Breckland.

- Priority species of dry terrestrial habitats were better represented by BAP species overall (0.17 BAP species per priority species) than were wetland priority species (0.13 BAP species per priority species).
- Larger assemblages contained more BAP species (for wetland assemblages, $r = 0.81$, $p<0.001$, $n=31$; for dry assemblages, $r = 0.81$, $p <0.001$, $n = 25$).

Most, but not all, assemblages that comprised more than a few members were represented by at least one BAP species. However, there were notable exceptions that reflect specialist groups of rare species that have so far been poorly served by the BAP species selection process.

For the 31 wetland assemblages, 10 had fewer than 5 members each. Excluding these, the remaining 24 assemblages had an average of 3.5 BAP species (range 0 - 18). However, six had no BAP representative. Three of these groups lacking a BAP figurehead were very small (comprising only five or six members), the remaining three un-represented groups were larger:

- Wetland with detritus (24 priority species, including 5 RDB species and 4 regional specialists),
- Dead wood in wet woodland (11 priority species, 3 RDB),
- Littoral margins supporting mosaic sward structures (11 priority species, 2 RDB).

For the 25 dry terrestrial assemblages, only 3 had fewer than 5 members. Excluding these, the remaining 22 dry terrestrial assemblages had an average of 8.7 BAP species (range 0 – 35), while six had no BAP representative. Of these, five were small (comprising 7-9 members). However, the assemblage of species requiring deadwood in open woodland or scrub habitats contains 27 priority species, including 8 RDB species, but is not represented by any BAP figurehead species.

Overall, a series of habitat-based prescriptions constructed on the basis of understanding the requirements of BAP species would provide conditions for the majority of priority species. However, a number of small groups requiring unique and specialist conditions would be overlooked. Importantly, there are a few larger specialist groups that are poorly represented by BAP figurehead species. These include wetland species associated with deadwood or detritus, and dry terrestrial species associated with deadwood in open woodland or scrub mosaics.

Recommendation:

- Spatial analysis should be conducted to examine whether, within species-rich assemblages, sites known to support one or more of the BAP representatives for the guild are also the sites that are overall richest in the guild. If so, targeting management resource at sites known to hold BAP species will be an effective strategy for conserving the overall guild. If not, then it may be better to target guild-based prescriptions at sites known to support guild members.

Breckland Species Assemblages

Requirements of Dry Terrestrial Assemblages

Disturbance and Intensive Grazing Guild

The results of the compilation of Breckland conservation priority species and analysis of their requirements has confirmed what people have long expected – that Breckland is vitally important for an assemblage of plant and invertebrate species dependent on intensely grazed and disturbed habitats, particularly species of coastal or dune habitats. For the first time, this has been quantified.

149 species require open habitats with both disturbance and grazing, including the sub-guild that also require associated scrub. However, it should be noted that individual species within this guild are associated with varying intensities and frequencies of physical disturbance (see Table 21).

The species of this disturbance and grazing guild include many beetles (30 species, 23% of the guild). Invertebrate species in this guild are often closely associated with ruderal plants or other plant species both requiring disturbance and being tolerant of grazing. For example, species of flea beetle in the genus *Longitarsus* are associated with ragwort *Senecio* spp. (e.g. *Longitarsus dorsalis*, *Longitarsus ganglbaueri*), hound's-tongue and viper's-bugloss (*Cynoglossum officinale*, *Echium vulgare* - *Longitarsus quadriguttatus*) and mullein (*Verbascum* spp. - *Longitarsus tabidus*). Other rarely considered species in this guild, include a number of Diptera and the cylindrical whorl snail (*Truncatellina cylindrical*, RDB: VU and BAP).

Many of species in this guild are indicators of a community with areas of bare ground and a lichen and moss dominated turf, associated with rabbit grazing. Lichens are particularly important in Breckland and 42% of the priority lichen species occur in this guild, more than in any other (excluding the unassigned species). These lichen species include the scrambled egg lichen *Fulgensia fulgens*, the starry breck lichen *Buellia asterella* and many priority species in the genus *Cladonia*. Consequently, this guild contains many species associated with the lichen community, such as the cylindrical bark beetle, *Orthocerus clavicornis* (Notable: B), which is associated with *Peltigera* lichens.

Hemiptera are also well represented in this guild with 16 species, 12% of guild (Figure 29). These species often require specific plant species, for example the Breckland specialists squashbug *Arenocoris waltlii* (Hemiptera), and the weevil *Hypera (Antidonus) dauci,* both of which feed on common stork's-bill *Erodium cicutarium*.

The open, disturbance and intensive grazing guild shows Maidscross Hill (TL7282) to be a key site, containing 29 species recorded from this guild. Other key hotspots include; RAF Lakenheath, Weeting Heath, Grimes Grave, the Icklingham triangle area, Red lodge, Wangford and Eriswell Low Warrens.

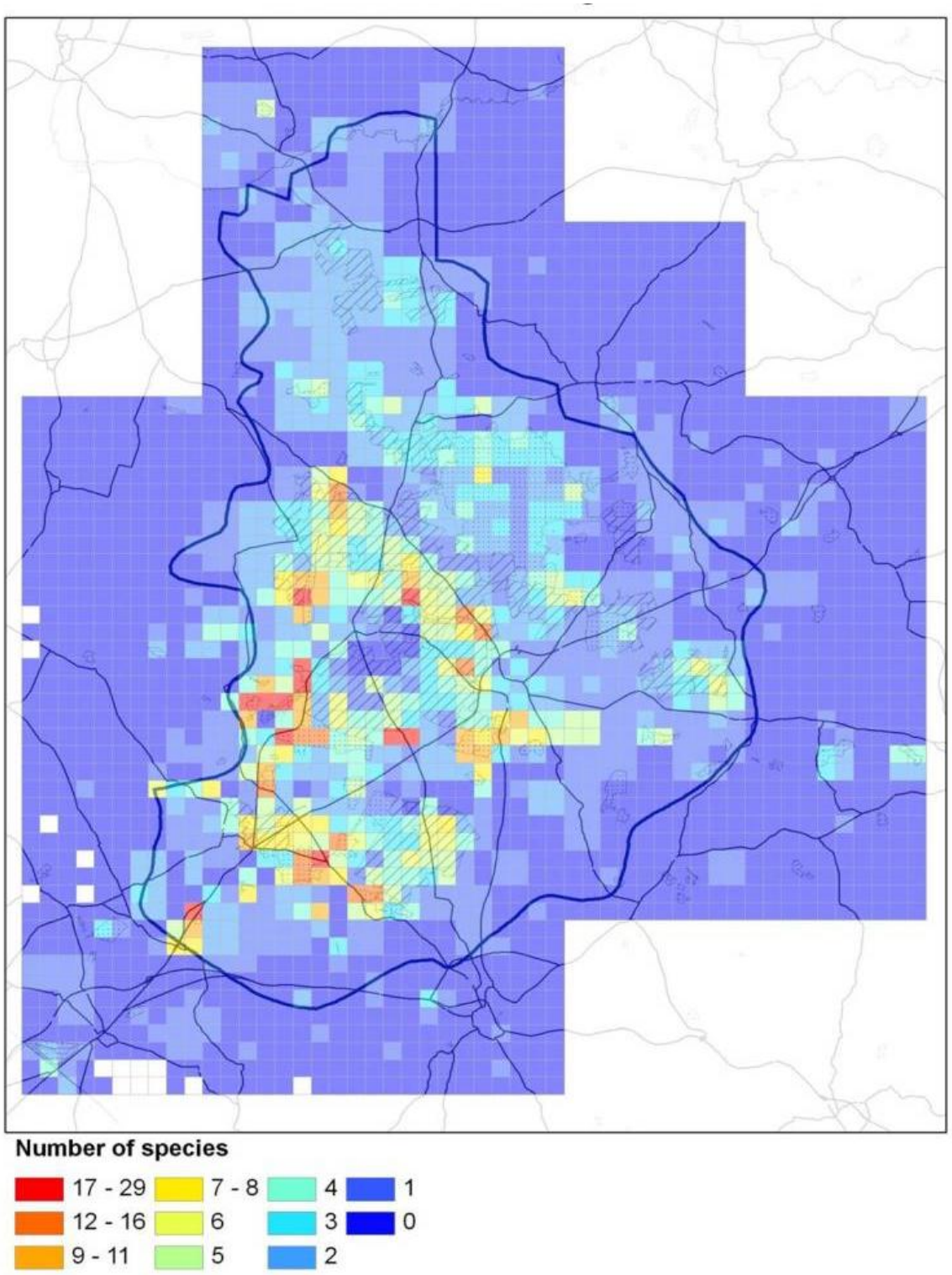


Figure 24. Number of Breckland conservation priority species from in the open disturbance and intensive grazing guild (DIST+GRAZ) guild in each of the 1 km grid squares in the Breckland region. There are 136 species in this guild. Species requiring these conditions plus scrub were excluded. White indicates areas for which no records were obtained.

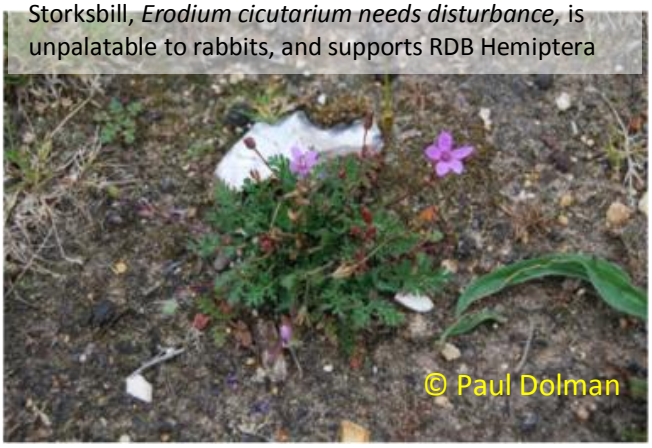
Physical disturbance and grazing

Grass-heath disturbed by rabbits, Icklingham

Lichen-rich grass-heath disturbed by rabbits, East Wretham Heath

Spring speedwell *Veronica verna*

Breckland thyme *Thymus serpyllum* colonising rabbit disturbed soil



Storksbill, *Erodium cicutarium needs disturbance,* is unpalatable to rabbits, and supports RDB Hemiptera

Bur medick *Medicago minima* regenerating in rabbit disturbed ground

Physically disturbed and grazed conditions can be provided by rabbit populations that create bare sand in addition to selective grazing

Mechanical disturbance to create broken ground can supplement sheep grazing requirements

Rotovating at Weeting Heath NNR to create bare ground plot for invertebrates and management of soil nitrogen
Cultivated firebreak at Thetford Heath NNR, supports population of *Sclernathus perennis* ssp. *Prostratus.*
Photographs © B.Nichols

Disturbance and intensive grazing guild
Hypera (Antidonus) dauci – Notable: B
Coleoptera – Curculionidae (Weevil)
This weevil is frequently found in sandy habitats, including grassland and dunes, but also disturbed ground. It is phytophagous and associated with common stork's-bill (*Erodium cicutarium*) and the larvae feed externally on the foliage. Disturbance, such as rotovation has been recommended by some sources, however it may benefit greater from the small scale disturbance resulting from rabbit grazing.

Wind-blown sand guild

Species requiring windblown sand include many coastal species rarely occurring inland elsewhere in the UK. This guild consists of nine species of which six are Breckland specialist species, including four coastal specialists. This guild comprised beetles, e.g. *Notoxus monoceros* and *Calathus mollis* and Hymenoptera species (Figure 29), including *Colletes marginatus* and *Megachile (Eutricharaea) dorsalis* (detailed below). Wind-blown sand species are concentrated in only small number places (Figure 21). The highest density of these species occurs at Maidscross Hill (TL7282) and the RAF Lakenheath area.

Wind-blown sand guild

Megachile (Eutricharaea) dorsalis – Notable: B, Coastal Hymenoptera – Megachilidae (Mason/Leafcutter Bees) The Silvery Leaf-Cutter Bee is primarily a coastal species associated with the wind-blown sands of coastal dunes, where it frequents mid-dunes in southern England. However there are a small number of inland records, including recent ones from Breckland (Santon Downham) and Kent. On coastal sites its requirements are for warm, sunny areas (e.g. south-facing slopes) and sheltered locations for nesting (e.g. dune slacks). Inland sites are characterised by dry, sandy locations in heathland and sand quarries. Due to the requirement for loose wind-blown sand, these locations are associated with fairly regular disturbance. Nesting sites are dry, sandy areas, fully exposed to the sun and at some sites, nesting often occurs at the base of grass tussocks. The nests of *M. dorsalis* consist of a series of linear cells constructed from cut leaf sections of a variety of plants. A range of pollen sources are used, including various legumes, *Echium vulgare*, *Thymus*, *Sedum* and *Rubus*. As for all the species in the Wind Blown Sand (WBS) guild on coastal dunes excessive disturbance is regarded as detrimental and can result in erosion. However inland disturbance should be regarded as a requirement to create the conditions occurring on dunes. Rabbit grazing should be considered important, as myxomatosis has had significant impacts on certain sites in allowing succession and reducing bee populations. However, it should be noted that the full range of successional stages are often beneficial, as are unimproved grassland occurring adjacent to nesting sites for foraging.

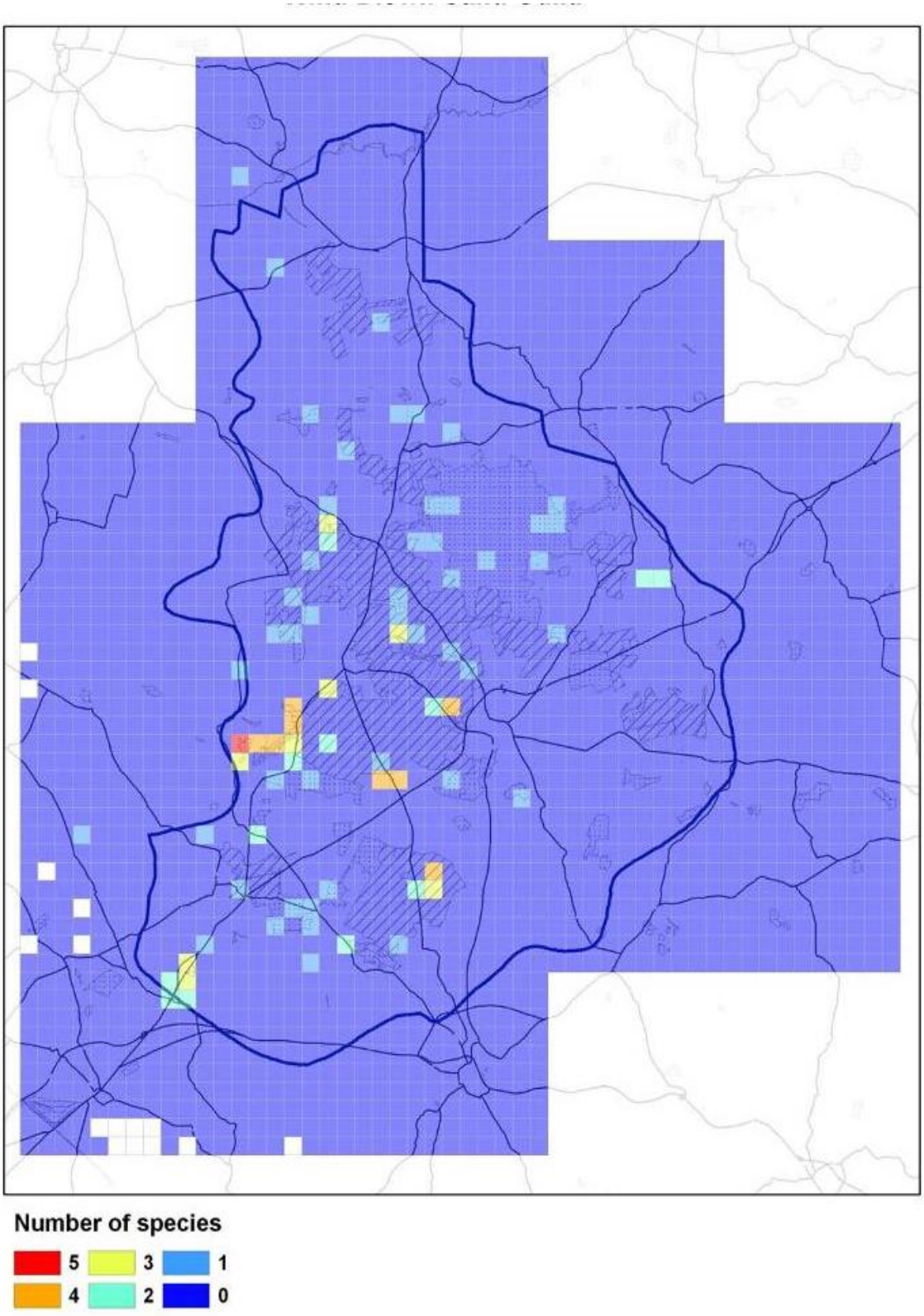


Figure 25. Number of Breckland conservation priority species from the wind-blown sand (WBS) guild in each of the 1 km grid squares in the Breckland region. There are 9 species in this guild. White indicates areas for which no records were obtained.

Physically Disturbed, Ungrazed Guild

Large numbers of priority species for conservation in Breckland are associated with physically disturbed but ungrazed conditions. Including those for which grazing requirements are unclear (but with no indication that grazing is required) these amount to 220 priority species for conservation in Breckland, approximately 10% of the 2149 priority species in Breckland. These include 96 RDB species, and 45 Breckland specialities. This is a slightly greater number of specialities, and a considerably greater number of priority species, than are clearly associated with physically disturbed and grazed conditions.

Compared to species requiring disturbance in grazed conditions, the current assemblage comprises greater numbers of moths and vascular plants but fewer flies, beetles and spiders, though all of the latter groups were still well represented (Figure 29).

There is strong evidence that priority annual plants of arable habitats (specialist species, rare arable weeds and key invertebrate foodplants) historically benefited from land-use patterns comprising low intensity arable habitats, periodic cultivation and fallowing in 'outfields' of the open field system, and brecks. 46 priority species are associated with known ruderal species, while for many species the exact food plant is not known but they are associated with the community of species.

Many key invertebrate foodplants species associated with cultivated and fallowed fields are annuals (for example fat hen *Chenopodium album* and flixweed *Descurainia sophia*) or biennials. Similarly, many of the characteristic Breckland speciality vascular plants, historically or currently associated with arable, are also annuals (e.g. sand catchfly *Silene conica* and Breckland speedwell *Veronica praecox*), as are many of the scarce arable weeds characteristic of chalky arable soils that occur more widely across southern England (such as henbane *Hyoscyamus niger*, venus looking glass *Legousia hybrida* and fine-leaved fumitory *Fumaria parviflora*). For such annual or short-lived species, annual or frequent intermittent cultivation with short fallow periods can be an ideal disturbance regime. It prevents their exclusion by perennials that would gradually dominate a closed sward in the absence of regular disturbance, annual plants growing in open low competition conditions can grow large and robust and seed prolifically, annually replenishing the seedbank.

Species associated with physically disturbed and ungrazed or lightly grazed conditions may have fared particularly badly during the last century, in view of the intensity and scale of change in the arable landscape. These include changing crop types, loss of fallows, use of herbicides and fertilisers, irrigation, and cropping up to margins, together with the loss of disturbed sandy and chalky track-ways, and the formalisation with surfacing and more intensive use of those that remain. Compared to their relative abundance within the priority species for conservation in Breckland, species of physically disturbed ungrazed habitats are significantly more likely to be extinct or facing extinction (See Table 18).

For example, the spotted sulphur moth, *Emmelia trabealis*, fed on field bindweed - a plant that would have been common in fallow brecks of the early 20th century. Although the plant persists after fallow fields develop into closed grass-heath sward, closed grassland does not provide suitable conditions for the moth. Spotted Sulphur was locally common in Breckland in the early 1900s (Morley 1908) and was described as "plentiful" at Worlington in 1925 (Suffolk Moth Group 2009). With increasing intensification of farming, the species declined through the 1950s and became increasingly

restricted to road verges, with the last colony in an asparagus field lost to arable intensification in 1960 (Chiperfield 1961).

Some other species associated with ungrazed disturbed arable habitats are now extremely scarce. With agricultural intensification throughout England, Breckland has become the last stronghold for a number of species that were once more widespread on chalky arable through southern England. However, some of these appear to be restricted to only a handful of sites within Breckland. Examples include:

- the flixweed flea beetle *Psylliodes sophiae*, was previously more widespread within England but has only one recent confirmed site record (in 1996) from the Norfolk Breckland (Thompson, 2008), although it may still occur at other sites.
- The brush-thighed seed-eater beetle, *Harpalus froelichii* feeds on seeds of a common annual arable plant, fat hen *Chenopodium album,* on sandy soils at the margins of agricultural fields and on coastal sand dunes. Although previously recorded near heathlands in Dorset , the Norfolk coast and east Suffolk, all records since 1935 are from Breckland (Thompson 2007; Telfer 2009b), where it is extremely localised (with four post 1990 sites known in the Suffolk Breckland, and three localities in the Norfolk Breckland: see Telfer 2009b).
- The Set-aside Downy-back beetle *Ophonus laticollis* feeds on seeds at the interface of cultivated field margins and perennial grassland, on well drained chalky sandy soil. Norfolk Breckland is now the national stronghold for this formerly much more widespread species, that has contracted from a wide scatter across southern England before 1970 to just the counties of Oxfordshire, Cambridgeshire, Norfolk and Suffolk since 1970 (Telfer 2009). However, it is currently known from only two localities in Breckland.

© Mark Telfer

Disturbance and no/light grazing guild
Ophonus laticollis – Notable:A, BAP, Secondary Stronghold
Coleoptera –Carabidae (Ground Beetle)
The Set-aside Downy-back beetle is a rare species, requiring a good supply of arable weed seeds, at the interface of cultivated arable margins and permanent grassland on well drained chalky sandy soil. It is currently known from only two localities in Breckland, where work conducted by Mark Telfer with the support of the Norfolk Biodiversity Partnership, has revealed its ecological requirements.

There is a large gap in the evidence base and understanding of what invertebrate species are supported by the very large resource of cultivated field margins now distributed across Breckland. The Breckland ESA, recently superseded by Environmental Stewardship, provides a potentially invaluable resource of approximately 400 km of cultivated margins. However, both nationally and regionally, the design, delivery and evaluation of these prescriptions have largely focused on vascular plants, particularly declining arable plants. The value of this management for poorly recorded invertebrate groups is incompletely known.

Physical disturbance without grazing – on cultivated field margins

Cultivated field margins provide disturbed ungrazed conditions suitable for annual plants including Breckland specialities, declining arable weeds of sandy chalky soil, and rare specialist invertebrates requiring seed rich soil or particular annual foodplants.

Physical disturbance without grazing – in the forest landscape

Physically disturbed, ungrazed nectar sources are abundant along flower-rich track-way margins in the forest landscape, particularly on calcareous soils. Nectar resources are key to hymenoptera and other invertebrates. Flower-rich verges can occur in remnant grassland along farmland track-way on calcareous soils if protected from spray drift, and excessive disturbance. Photographs © Paul Dolman

Physical disturbance without grazing – on ruderal sites

Physically disturbed, ungrazed, ruderal conditions, along track-ways, waysides and sand or gravel pits are important to perennial Breckland specialist plants dependent on regular but disturbance but that cannot persist in frequently cultivated arable field margins. These places are also key to important invertebrate assemblages including Coleoptera and Hymenoptera.

Records of species from this guild are widely distributed throughout the Breckland NCA and beyond (Figure 23), probably due to their association with arable situations. There are important hotspots at Maidscross Hill and Cranwich Heath, and to a lesser extent at Barnham Cross Common/Thetford Heath and Weeting Heath. However, the arable areas of Breckland have been very under-recorded.

ADAS monitoring of arable, cereal field margins (ADAS, 1997; 2001) was focussed towards the value of these for plants. Whilst this monitoring involved the collection of a small number of invertebrate samples, very few were identified to species level and included very few priority species.

When surveying had been conducted along good quality cultivated field margins selected because they are known sites for, or are hoped to harbour, focal indicator BAP carabid species, invariably other rare and poorly recorded species have also been found (e.g. Telfer 2009). We need much greater effort and surveys of arable field margins to develop better understanding of what is present and where.

Recommendation:

- There is an urgent need to conduct extensive survey work, examining a wider range of invertebrate taxonomic groups, in order to improve understanding of the conservation value of cultivated arable margins and other elements of the (poorly known) farmland landscape. Recording effort in the terrestrial habitats are currently highly biased to the heath SSSI.
- Work should seek to improve understanding of how species and assemblage responses differ in relation to: soil type, aspect, exposure, crop rotation, boundary features (e.g. grass banks, hedges, shelter belts) and geographical location within Breckland, and what are their management needs (e.g. cultivation frequency, timing and type).

Some more mobile and dispersive specialist species, including some moths and carabid beetles, now appear to be widely scattered in Breckland

- the grey carpet moth *Lithostege griseata* feeds on flixweed *Descurainia sophia*, an arable weed of regularly disturbed or cultivated ground. In 1870, in the sandy district around Thetford flixweed was described as " in many places one of the commonest corn-weeds" (Wratislaw 1870). Grey carpet was previously widespread through Breckland, but is now restricted to scattered colonies, reflecting the severe reduction in frequency of flixweed populations. However, experimental soil disturbance recently conducted by Butterfly Conservation at a range of sites across Breckland (Hearle 2010) shows that flixweed can be recovered from buried seedbanks, with positive results for grey carpet.
- Tawny Wave *Scopula rubiginata* was locally abundant in the 1880s (Suffolk Moth Group 2009) but declined during the mid-late 20th century through intensification of arable (Baron de Worms 1953; 1963), with only scattered records from 1979 to 1987 (Foster 1987) and was considered to be extremely scarce by the late 1980s ("All known sites were visited in 1988 and 1989 without success and the species may be extinct in the UK" R. Ely *pers. comm.* 1989). However, it appears to have had resurgence and is now recorded regularly, including at sites within the Thetford Forest landscape.

A large number of species in this guild are moths or beetles that feed on developing seedheads or fallen seeds of palatable foodplants, which are susceptible to grazing by vertebrate herbivores, such as sheep or rabbits. These include many invertebrates that require ruderal plant species or others such as *Microplontus triangulum* a weevil that requires yarrow (*Achillea millefolium*) but as it feeds in the upper stems moderate and heavy grazing would be unsuitable. Others include species that

require access to nectar resources that are similarly provided by grazing intolerant flowering plants. Among these species, there are those that also have a direct requirement for bare ground, physical disturbance, and others that rely on foodplants that require disturbance for regeneration. These conditions are rarely met on the heaths. In this context, concentration of conservation efforts predominantly on the heaths and other semi-natural habitats with traditional grazing practices is unlikely to secure a future for these species.

Entomologists, botanists and some ecologists have long been aware of the importance of ungrazed, physically disturbed, ruderal and brownfield sites (Haggett 1951; 1952; Watt 1971; Rothera, 1998; Harvey 1994). To paraphrase one leading Lepidopterist with a lifetime of experience of the rare Breckland moths,

> " when you wanted to find the interesting species you always went to look in the brecks, not on the heath".

However, this guidance had not fully translated into recommendations for land managers, while increasing numbers of species initially regarded as being characteristic of heathland habitats are now being recognised as requiring ungrazed, physically disturbed conditions. For example, the brush-thighed seed-eater beetle *Harpalus froelichii* was long regarded as a rarity of the Breckland grass-heaths rather than as an arable specialist (e.g. Rothera 1998), but recent work (Telfer, 2004) instead made it clear that arable field margins and other recently disturbed sandy ground (often with abundant *Chenopodium album* in August) are the preferred habitat. The foodplant is preferentially grazed and will not persist in a grazing regime on a heathland site, even if suitable soil disturbance is present.

The vital importance of ungrazed ruderal habitats (arable / wayside and disturbed ground) was recognised by the Natural England Natural Area Profile (Rothera 1998). However, the number of species attributed to this habitat (for vascular plants and invertebrates: 22 RDB species; 11 BAP species) was far fewer than were attributed to heathland or grass-heath (90+ RDB and 17 BAP). The more complete and systematic treatment in the BBA has reversed this finding.

Physical disturbance without grazing – trackways

Trackways can provide a gradation of disturbance: with occasionally disturbed broken turf adjacent to bare sand, suitable for annual plants, coastal spiders and some burrowing hymenoptera.

Some examples of priority species. From top right clockwise:

Open habitats with disturbance and grazing requirements uncertain

The monoceros beetle, *Notoxus monoceros* (Coleoptera - Anthicidae), Coastal Specialist.

The dune chafer, *Anomala dubia* (Coleoptera - Scarabaeidae), Coastal Specialist.

Open habitats with disturbance and grazing

An ironclad beetle, *Orthocerus clavicornis* (Coleoptera - Colydiidae), Notable:B, Coastal specialist.

Open habitats with a sward mosaic

A jumping spider, *Aelurillus v-insignitus* (Araneae - Salticidae), Notable:B.

Open habitats with disturbance and no/light grazing

A robber fly, *Eutolmus rufibarbis* (Diptera - Asilidae), RDB:R, Secondary Stronghold.

Open with scrub, disturbance and no/light grazing

A ground bug, *Aphanus rolandri* (Hemiptera – Lygaeidae), Notable:A.

Some examples of priority species. Top left clockwise:

Open habitats with the juxtaposition of tall grass/flower rich areas and bare ground

The hairy legged mining bee, *Dasypoda hirtipes* (Hymenoptera - Melittidae), Notable:B.

A spider hunting wasp, Aporus unicolor, Notable:A.

Grayling, *Hipparchia semele* (Lepidoptera - Satyridae), RDB:NT, BAP.

Open habitats infrequent disturbance and light grazing

Roesel's bush cricket, *Metrioptera roeselii* (Orthoptera - Tettigoniidae), Notable:B.

Open habitats with grazing and no/light disturbance

Maid of Kent beetle, *Emus hirtus* (Coleoptera - Staphylinidae), RDB:EN.

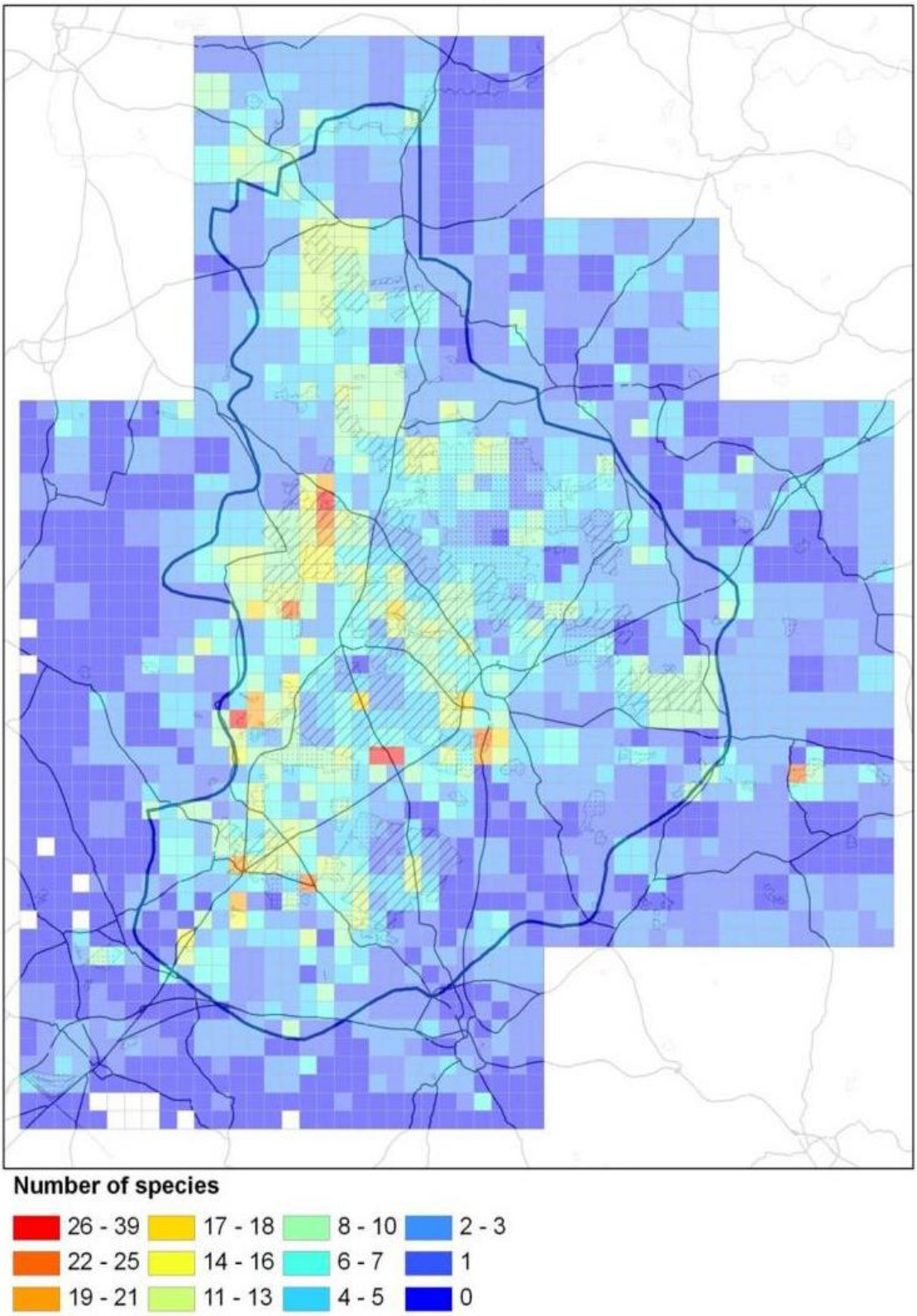


Figure 26. Number of Breckland conservation priority species from the disturbance, but no (or light) grazing (DIST-NGRAZ) guild in each of the 1 km grid squares in the Breckland region. There are 135 species in this guild. Species requiring scrub in addition to these conditions were excluded. White indicates areas for which no records were obtained.

Importance of Areas of Scrub Adjacent to Open Habitats

In addition to species requiring dry open terrestrial habitats comprising either grazed or ungrazed, disturbed or undisturbed conditions, species were also identified that required these combinations of conditions but that also depend on scrub. For many species, the juxtaposition of scrub and open habitats is very important, and the increased variety in habitat types helps promote species richness. These open with scrub guilds contains 69 species, 8 Breckland specialists, including 2 coastal. Hymenoptera form the majority of the guild, with 22 species (32% of the guild), other groups are beetles (17%), diptera (16%) and moths (16%) (Figure 29). For many species, the requirements for scrub are for the same reasons as that of sward mosaics, i.e. for shelter and wintering areas. However for other species the plant communities associated with scrub are important for nectar and deadwood.

Open-with-scrub, grazing, but no disturbance guild
Osmia (Neosmia) bicolour – Notable:B
Hymenoptera – Apidae
This carpenter bee is primarily a chalk downland species, found in calcareous grassland and its associated scrub or occasionally open woodland. It requires a warm, sunny areas and there is a close association with flowers of the legumes *Hippocrepis* and *Lotus* for pollen, but many other flowers are also utilised. Nesting occurs in empty terrestrial snail shells and the cells and outer plug is formed from masticated leaves. The shell is then camouflaged by the use of dry grass stems, dead leaves, the scales of beech twigs or interwoven pine needles. The finished mound is around 10-15cm round and 5-8cm high, resembling a small wood ants nest. The bee will also shelter in empty snail shells during poor weather. Large numbers of females have been observed consistently flying back and forth between a dry open hillside and adjacent woodland, carrying material in, presumably to build nests.

It has widely declined and was formerly a frequent species occurring in former large tracts of calcareous grassland. The loss of sheep grassing and rabbit grazing in sites is thought to have contributed to the decline, from the development of coarse vegetation and excessive scrub. However retaining some scrub areas, either as a scrub ecotone, or as a scattering of bushes or brambles will provide some shelter for nesting and during unfavourable weather. A balance is needed, between promoting a structural variety in the grassland, from open flower-rich areas to scrubby vegetation types.

Assemblages of priority species requiring sward mosaics

The sward mosaic assemblage is relatively small (69 species, 3% of total species). There was some difficulty identifying a species requirement for sward mosaics, due to the quality of available information, and it is likely that many more species would benefit from sward mosaics, in addition to those identified.

Diptera and Hemiptera were particularly common in this guild (32 and 11 priority species, Figure 29) are reliant on sward mosaics for shelter or overwintering areas.

Open with sward mosaics guild
Chrysotoxum elegans – RDB:R
Diptera – Syrphidae (Hoverfly)
This hoverfly is of dry, open grassland and heathland but also found in woodland glades. Larval habitats are suspected to be predatory on root aphids or occur in ant nests, while adults are found on flowers of umbelifers and blossom of various scrub species such as elder. The invasion of scrub and coarse grasses are regarded as detrimental. However, due to the uncertainty in ecological requirements, sward mosaics are considered beneficial, especially if grazing creates short mosaics desirable for ants.

Grazing and No/Infrequent Disturbance Guild

Stable ancient grasslands and meadows are important for a number of species, depending on the vegetation structure, which varies depending on the grazing regimes in place. Many of the species within this guild are associated with downland, indicated by the hotspot at the Devils Dyke SSSI (Figure 27). Other hotspots for this guild are located at Cranwich Camp and Barnham Cross Common, but also scattered in other SSSIs and occasionally the wider landscape. This guild comprises 81 species, of which 16 are Breckland specialists. This guild has the highest percentage of conservation priority vascular plants.

Such grasslands are frequently flower rich and may therefore be important to other species. Such stable grasslands are also very important fungi and their associated species, including numerous Diptera and Coleoptera; some of which are recorded nowhere else in the UK.

Grazing, but no or infrequent disturbance guild
Lycoperdina succincta – RDB: VU, Entirely restricted
Coleoptera – Endomychidae (Handsome Fungus Beetle)
This species has only been recorded in the Breckland within the UK. It occurs in open sandy ground with good populations of fungi (puffball and earthstars) in which both adults and larva occur. Grazing of habitats would help to maintain open conditions. The beetle *Caenocara affinis* (Anobiidae) is also only known in the UK from Breckland (Barton Mills), from the puff ball fungus (*Lycoperdon perlatum*), although it may well occur in other puff-ball fungi.

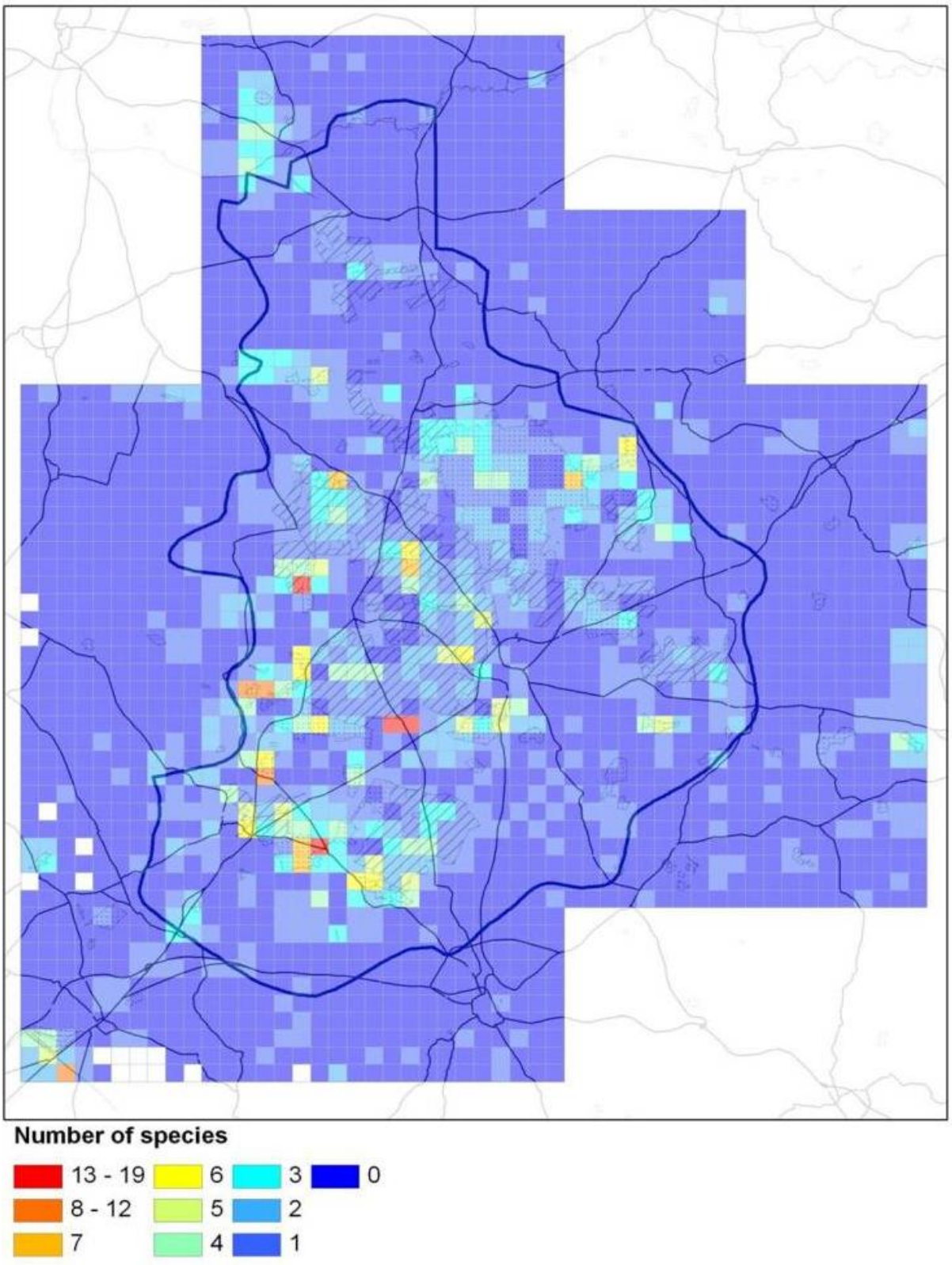
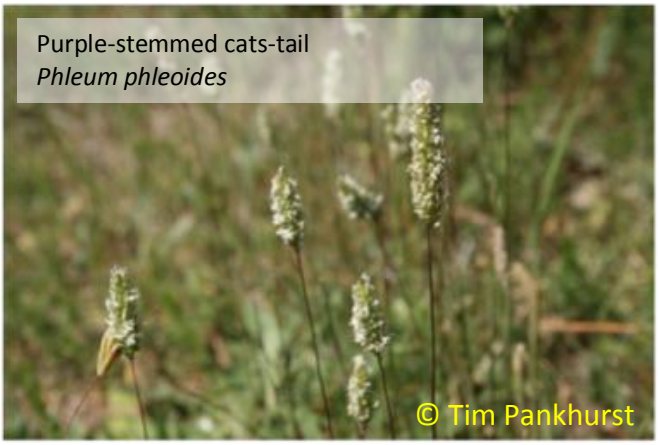


Figure 27. Number of Breckland conservation priority species from the grazed, but no or infrequent disturbance (GRAZ-NDIST) guild in each of the 1 km grid squares in the Breckland region. There are 81 species in this guild. Species requiring scrub in addition to these conditions were excluded. White indicates areas for which no records were obtained.

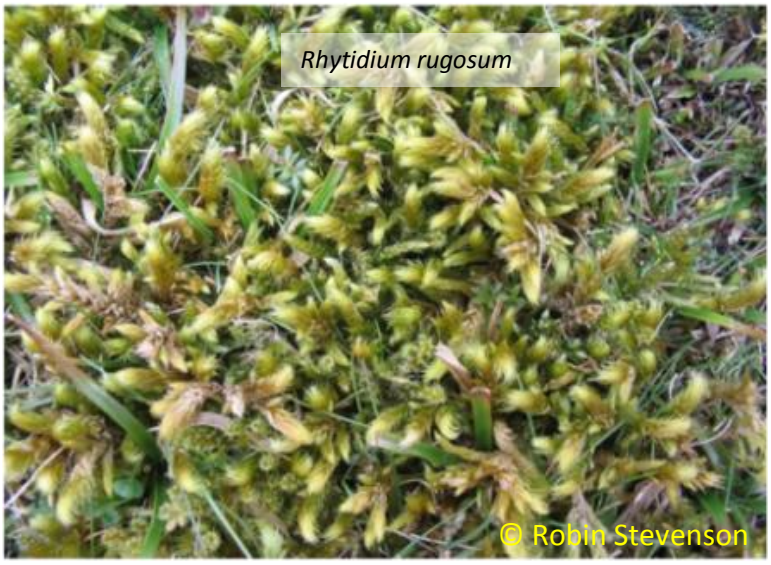
Grazing without physical disturbance


Maiden pink *Dianthus deltoides*


Purple-stemmed cats-tail
Phleum phleoides
© Tim Pankhurst


Blue Fescue
Festuca longifolia
© Neal Armour-Chelu


© Bev Nichols


Rhytidium rugosum
© Robin Stevenson

Grazed grass-heath: Some drought and stress tolerant perennial plant species persist in closed turf, where competitive perennial grasses are controlled by intensive grazing and drought. However, they require occasional physical disturbance to regenerate.

Woodland and open woodland guilds

The results of the audit also reveal more unexpected wealth of biodiversity. Counter-intuitively in light of the perception that Breckland was an intensively deforested region of open heathland and dune for many centuries of its history, the analysis of assemblages also showed the presence of a range of Breckland conservation priority species that depend on scrub, open woodland, woodland or even veteran trees and deadwood. This guild includes four Breckland specialists, two Diptera, one reliant on woodland fungi and the other associated with coniferous woodland, and two Coleoptera one of sandy woodlands and the other associated with woodland fungi.

A large number of nationally important species open woodland species were recorded, but very few local specialists. Species in woodland habitats are extremely numerous (164 priority species), but the proportion of these that are Breckland specialists are comparatively few (only 2.5%, 4 species). The woodland guild contains few RDB (only 25%) and is primarily a guild of notable species (71%). The species in these guilds were dominated by Diptera and Coleoptera (Figure 29).

Deadwood and veteran tree guilds

There were also many species (137) requiring deadwood, in both open and woodland conditions. These species are mostly beetles and flies (58% and 30% respectively), which live in the deadwood or associated fungi. The veteran tree guild contains (containing 53 species) is also dominated by flies (43%) and beetles (39%), which often live within the living or dead wood or require associated feature such as rot holes. Many of these species in both guilds are species of ancient woodland, associated with ash and oak, while there are also some species associated with veteran trees in open conditions such as oak and poplar.

This guild shows an interesting distribution with a scattering of records primarily associated with STANTA, but also some key areas of Breckland Forest (Figure 28). The main hotspot, containing 29 species is outside of the Breckland NCA, at Ixworth Park where the mix of woodland and open habitats from the managed parkland is very suitable for these species.

Some species within this deadwood community also occur in open habitats, ranging from woodland rides, frequently with flower rich areas, to open to scrub or woodland ecotones species.

Recommendations:

- There is a need for strategic review of the extent, location and value of the Parkland / Lowland Wood Pasture resource in Breckland (as first recommended by the Brecks Workshop Report; Perkin and Norden 2007) and of how this relates to mapped biodiversity provided by the Biodiversity Audit. Groups and sites for further survey should be identified.

Deadwood

Hololepta plana – Largely restricted
Coleoptera – Histeridae (Hister Beetle)
A very recent discovery in Breckland, showing that new species are still being recorded in Breckland, it is associated with deadwood particular in riverine and lowland woodland habitats and possibly popular (*Populus*).

Deadwood in an open-woodland ecotone

Chrysis gracillima – RDB: VU

Hymenoptera – Chrysididae (Cuckoo Wasp)

This wasp has been recorded from a range of habitats such as heathland, hedge and chalk downland. This is unsurprising given the species requirements. The species is a parasitoid of the larvae of aculeates (hosts uncertain), but has a requirement for deadwood for host nesting. Due to the open flower-rich habitats also needed for the hosts, deadwood in open conditions such as fence posts and old stumps should be regarded as beneficial. Furthermore, the presence of scrub and brambles for host nesting is also recommended, therefore this species should be considered in a wider context, with open conditions maintained and flower-rich areas grading into small patches of scrub, with plentiful deadwood.

These species is only a small hymenopteran, approximiately 6mm. However, for larger species, or those with good dispersal abilities (larger hymenoptera, some beetles and moths), in this guild management in a wider landscape context should be considered. It may not be necessary to manage for these species within-site, as long as strategic plans are in place.

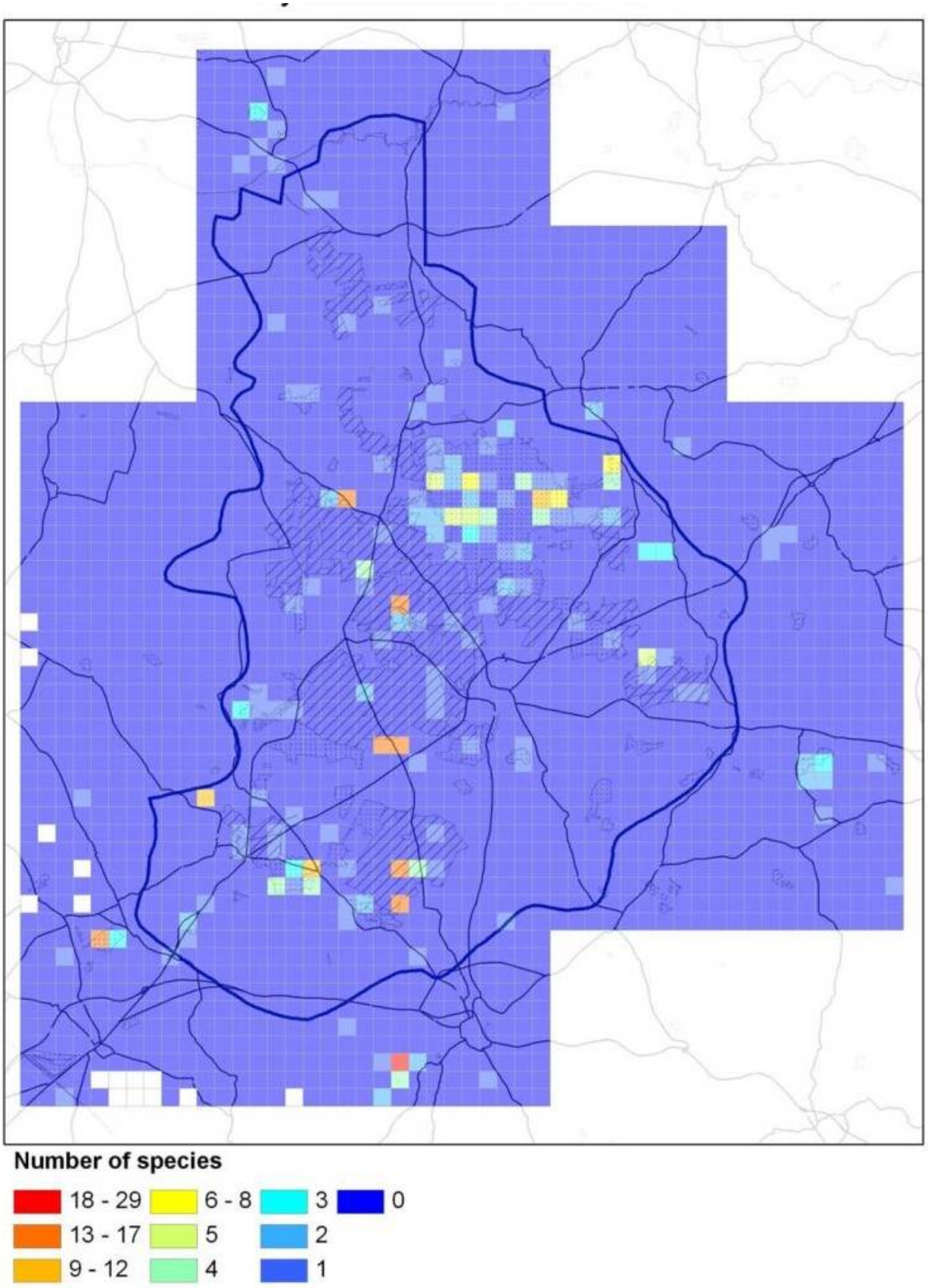


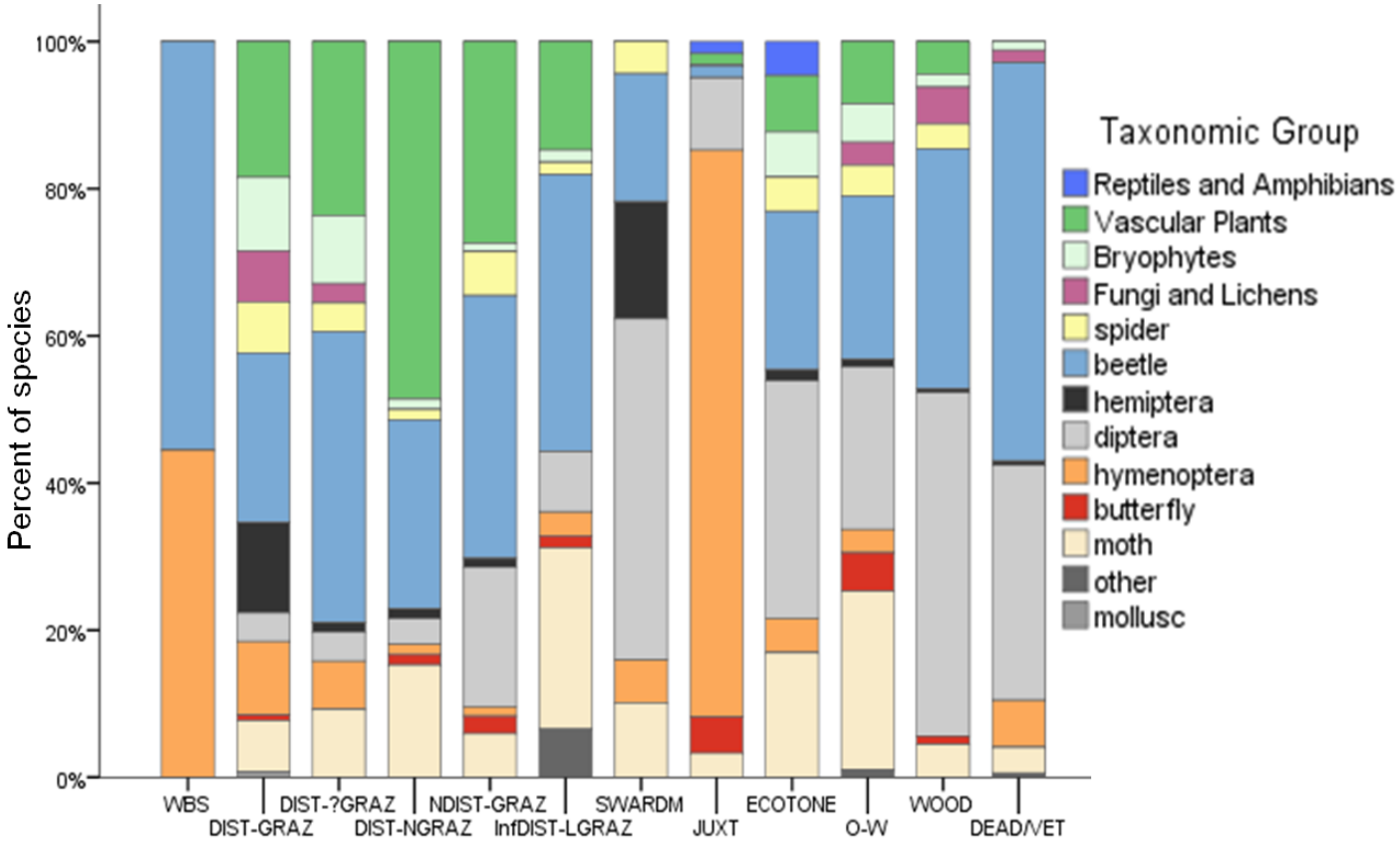
Figure 28. Number of Breckland conservation priority species from the dry deadwood or veteran tree guild (DEAD/VET) guild in each of the 1 km grid squares in the Breckland region. There are 81 species in this guild. Species requiring wet deadwood were excluded. White indicates areas for which no records were obtained.

Specific Requirement in a Variety of Habitats

Ninety three priority species occur in variety of habitats but with a specific requirement, such as dung and/or carrion (27 species) or detritus (25 species). For those species requiring dung, grazing would be best form of management, for example a total for 56 species required dung most of which are assigned in the grazing guild. However, a number of species require specific dung types, e.g. carnivore or varying types of herbivore dung.

Dung in a variety of habitats
Polietes steinii – RDB:EN
Diptera – Muscidae (House/Stable Fly)
With very few records of this species, it is apparently only known from a handful of locations where it has been found in meadows and woodland. However, it appears to have very specific process requirements, having only been found in areas of horse grazing as it develops in dung seeming only that of horses.

Figure 29. Proportion of species from different taxonomic groups associated with selected guilds.
Guild definitions: WBS – wind-blown sand; DIST-GRAZ – disturbance and moderate or intensive grazing; DIST-?GRAZ – disturbance, grazing requirement unknown; NDIST-GRAZ – moderate or intensive grazing, but no disturbance; InfDIST-LGRAZ – infrequent disturbance and only light grazing; SWARDM – sward mosaics; JUXT – juxtaposition of disturbed bare ground and nectar sources; ECOTONE – structure and moisture ecotones; O-W – open woodland; WOOD – woodland; DEAD/VET – deadwood or veteran trees



Some examples of priority species: Clockwise from top left:

Variety of habitats, but dung required.

A scarab, *Onthophagus (Paleonthophagus) fracticornis* (Coleoptera - Scarabaeidae), RDB:INSU.

Variety of habitats, but detritus required.

A rove beetle, *Anotylus insecatus* (Coleoptera - Staphylinidae), Notable.

Veteran trees

A hoverfly, *Brachyopa bicolor*, (Diptera - Syrphidae), RDB:R.

A hoverfly, *Callicera aurata,* (Diptera - Syrphidae), RDB:R.

Open and Woodland habitats

A thick-headed fly, *Myopa polystigma* (Diptera - Conopidae).

Management to Sustain Dry Terrestrial Assemblages

In this section we provide guidelines for land managers to support and enhance the various assemblages of priority species for conservation in Breckland. We also identify areas of uncertainty, recommendations for research and emphasise the need for monitoring outcomes.

An important priority must be to restore appropriate conditions for specialist assemblages of Breckland conservation priority species across the existing resource of designated sites, including both statutory (SSSIs) and non-statutory (CWS). At many terrestrial sites, there is a lack of disturbed ground with dominance by later successional stages. Many sites are managed by homogenous grazing regimes and would benefit from some heterogeneity of sward structures, creation of nectar resources and juxtaposition of ungrazed disturbed ground.

Current approaches to grass-heath management

We were able to compile habitat management questionnaire responses for a total of 2,446 ha of Breckland grass-heath, covering most key heath SSSIs. Of this area, all but 45 ha was grazed (98.2% grazed), with sheep used to graze all sites. Cattle were also present on areas of one large heathland.

The intensity of sheep grazing varied between sites and compartments. While grazing intensity was described as moderate or high (e.g. Thetford Heath, c. 25 ewes ha^{-1}) on many sites (comprising 41% of the aggregate area), on 32% of the aggregate area sheep density was described as low or light (e.g. c0.7 ewes ha^{-1}, 0.8 ha^{-1}, 1.5 $ha^{-1}$and 2 ha^{-1}). Grazing density information was not obtained for the remaining area. Considering just the area for which sheep density was supplied, 57% was moderate to high, but 43% had low intensity of grazing.

Rabbit population density was described as virtually absent to low on 57% of the total grass-heath, and as moderate to high for 25%. When just the sites for which we obtained rabbit information were considered, 70% had no or very few rabbits.

Qualitative assessment of the extent of bare ground was available from 95.5% of the area of grass-heath. Bare ground was described as:

very rare or rare:	52%
occasional:	25%
abundant :	19%

Accurate information quantifying the extent of physical disturbance treatments was available for 9 SSSIs covering a total of 1387 ha. Across these, physical disturbance plots amounted to 11 ha, or 0.8% of the area. It should be noted that these include key sites in which disturbance treatments have been pioneered and most widely applied. Thus, across the grass-heath conservation resource physical disturbance will amount to much less than 1%.

In conclusion although some sites receive intensive sheep grazing, and some sites have rabbits, 43% of sheep grazed area was managed by low intensity grazing, 70% of the area extent had no or few rabbits and disturbance treatments covered less than 1% of the grass-heath extent.

Management Recommendations for Priority Assemblages in Grass-Heath Habitats

In this section we examine the ecological requirements of species in a range of grass-heath habitats including dune, heath, grass-heath, scrub and woodland ecotones and propose techniques to provide these conditions.

Graze hard

In view of the ecological requirements of characteristic stress-tolerant Breckland plant specialists that are mostly intolerant of competition in a closed sward, it is recommended that grazed sites should be grazed hard and intensively. This is particularly relevant in face of nitrogen deposition.

However, grazing should not be entirely homogeneous and uniform across sites. Evidence from Brettenham Heath shows that grazing of short closed swards appears consistent with creating conditions required by a range of stress-tolerant invertebrates of litter, upper saltmarsh and littoral margins.

However, grazing on its own is not sufficient. It is also important to provide bare ground, broken turf, sward mosaics and a complex juxtaposition of habitats, to provide the conditions required by other assemblages of priority species for Breckland conservation (see below).

Do not be constrained by heather when revising grazing regimes

The presence or otherwise of heather on a site should not be a constraint or objective of site management. Heather is not particularly important in a Breckland context.

The number of Breckland conservation priority species which are obligates of *Calluna* and *Erica* is generally few. Exceptions include the leaf beetle *Altica ericeti*, which is phytophagous on the foliage. Heather is important for the heath rustic *Xestia agathina*, neglected rustic *Xestia castanea* and shoulder-striped clover *Heliothis maritima* moths that all feed primarily on *Calluna* in Breckland. Species associated, but not obligates of heather, include the RDB fly *Myopa fasciata,* which is a parasite of mining bees and is associated with *Calluna*.

Heather is useful as a late and long lasting pollen and nectar source for Hymenoptera and some Lepidoptera species, but this can be provided by heather plants in a pioneer state. At very low patchy densities it can also help provide a heterogeneous structure, particularly suitable for a number of spider species.

In a Breckland context, there is little point in making a distinction between grass-heath and *Calluna* heath (Rothera, 1998), particularly because:

- These inter-grade in terms of their plant communities (Rodwell, 1991; 1992) and can occur in mosaics due to patterned soil. Historic accounts (e.g. Farrow 1915; 1917) emphasise that heather was sporadic, dynamic and responded to the spatial distribution of rabbit grazing being absent in the immediate vicinity of warrens.
- At a number of sites, heather only re-appeared in the above ground vegetation after myxomatosis although it must have been represented in the soil seed bank from earlier episodes of grazing relaxation.

Heather should rather be considered as a useful indicator of appropriate structure, with the aim to ensure most heather present is in the pioneer stage – representing hard grazing and recent physical disturbance (for seedling regeneration).

It is difficult to reconcile the requirements of priority biodiversity in Breckland, with the idea that cattle should be removed from a site, or that the intensity of sheep grazing should be reduced, in order to avoid 'damage to heather'. The grassy condition of vegetation at sites maintained with a low to moderate grazing intensity in order to maintain building or mature stage heather bears no relation to the exposed mineral soil between individual heather plants that is apparent in some historic photos. This emphasises the unsuitability of such grazing regimes in mitigating the effects of nutrient deposition and accumulation.

Recommendations:

- Grazing intensity should not be constrained by the presence of heather on a site. Heather *Calluna vulgaris* is best regarded as an indicator of site structure, not as an objective of management.
- If most of the heather present on a site occurs as tightly grazed cushions of pioneer growth, within a matrix of bare mineral sand this indicates that:
    - Recent appropriate disturbance has occurred.
    - Grazing levels are appropriate for the long term persistence of oligotrophic vegetation.
    - Dite conditions are probably appropriate for a wide range of specialist Breckland species that require early succession conditions and disturbed soil.

Under-managed *Calluna*-dominated heaths

Ungrazed or lightly grazed heaths become encroached by mature heather, bracken and scrub.

Such conditions are of little value to priority species for conservation in Breckland.

The sites shown include ungrazed heath as well as lightly sheep grazed SSSI's managed under ES agreements.
Photographs. © Bev Nichols.

Grazing

Lightly sheep-grazed calcareous grass-heath:
Dense closed sward and nutrient accumulation. Such sites would be improved by hard grazing and or mechanical disturbance.

Thetford Heath NNR:
Tightly sheep grazed calcareous grass-heath sward.
Short turf but lacking broken ground.

Thetford Heath NNR:
Intense sheep grazing facilitated recovery of rabbit population.
Combined sheep and rabbit grazing gave broken short turf and bare soil.

Thetford Heath NNR:
Combined sheep grazing and rabbit activity produced complex early successional vegetation structure.

Physical disturbance in grazed sites

A site that has intense grazing, but which also provides areas of physical disturbance will provide more priority biodiversity than a site with homogenous close grazing of closed swards (Figure 21).

Encouraging rabbits can provide the combination of intense grazing and small scale physical disturbance ranging from scrapes and burrows to whole scale removal of vegetation in extensive warren systems. Evidence from the invertebrate assemblages at Foxhole Heath and Weeting Heath shows that this is successful in sustaining assemblages that include Breckland specialists, coastal and dune species (Pedley and Dolman 2010).

Alternatively management by sheep grazing supplemented by rotovation, ploughing or other physical disturbance treatments across parts of a site can also provide the combination of grazed swards and bare disturbed ground and annual foodplants for invertebrates.

The importance of physical disturbance was recognised by the early ecologists in Breckland, who understood the requirements of key species and the ecological dynamics of the system and, following the loss of rabbits to myxomatosis, recommended treatments such as rotovating, ploughing and cultivation of arable crops on classic grass-heath or sand dune sites (See Box: Daring to Innovate).

Recommendation:

- The overwhelming importance of physical disturbance to very large numbers of Breckland conservation priority species must be recognised and acted upon if this biodiversity is to thrive.

Physical disturbance treatments can encompass a range of intensities, achieved by different management interventions. These could range from small-scale disruption of the sward, through destructive mechanical treatment, such as rotovating, spring or rigid tines, or ploughing, to whole-scale turf striping or bank creation. Each of these has differing physical and ecological effects and will provide benefits for different species (See Table 20). Prescriptions may also be applied at differing frequencies with different species benefiting from annual, regular or infrequent disturbance treatments. To illustrate this point, we have classified the response of a small selection of Breckland conservation priority species in Table 21**.** This is not exhaustive and there are many more Breckland conservation priority species that will benefit from each combination of intensity and frequency**.**

Physical disturbance is of key importance, the results will be useful for Breckland conservation priority species, even though the precise outcome may be highly unpredictable, depending on soil, seedbanks, weather and timing.

Constraints of archaeological interest and potential buried ordnance at former and current military sites may restrict options in some circumstances. Within these constraints, an ideal would be to create areas of:

- areas of turf stripped bare chalk drift,
- south facing banks of bare chalk or soil
- areas of turf stripped bare acidic sand,

- a mosaic of overlapping ploughed, and rotovated plots or strips, repeated at different intervals (some annually, some every 2-3-4 years),

In view of the large numbers of Breckland specialists that depend on physical disturbance in intensively grazed sites, different forms of disturbance could cover 20-60% of any grass-heath site. Alex Watt suggested that approximately 80% of Weeting Heath could be ploughed, with one quarter of this ploughed in any particular year on a four year rotation – so that 80% of the site would be disturbed within the last 4 years.

Examples of physical disturbance treatments have already been implemented across a range of sites, though often on relatively small plots. These are collated in a database of plots in Appendix Table A4.

Mechanical disturbance to create broken ground can supplement sheep grazing, to provide for a wider range of priority species assemblages than grazing alone

Rotovating at Weeting Heath NNR to create bare ground plot for invertebrates and management of soil nitrogen
Cultivated firebreak at Thetford Heath NNR, supports population of *Sclernathus perennis* ssp. *prostratus.*
Photographs © B.Nichols

One excellent example of an experimental approach to management has been established by the Forestry Commission. Six different disturbance treatments, swiping, forage harvesting, discing, agricultural plough, forestry ploughing and turf stripping have been carried out in plots of c. 10 m x 150 m along the verges of un-shaded forestry rides. There were nine replicates of each treatment and a further nine control plots. The experiment is being monitored for the responses of hymenoptera, spiders, carabids, vascular plants and vegetation structure by UEA, Plantlife and FC commissioned consultants.

Further physical disturbance plots have been established by Butterfly Conservation and are being monitored for populations of the importance ruderal foodplant flixweed *Descurainia sophia* and grey carpet *Lithostega griseata.*

Monitoring of experimental sites and regular disturbance of treatments is vital. A minimum level of monitoring would be to record vegetation structure (for example, as at East Wretham Heath, see Yaxley 2004). However, in most instances the outcomes of physical disturbance treatments have not been recorded. There is therefore an opportunity to capture much more information from the experimental management than has been undertaken to date.

Recommendations:

- Survey and monitoring be urgently undertaken at as many of these plots as possible, to cover key invertebrate groups as well as vascular plants. This will provide evidence to guide and inform future management.
- Keep disturbance database up to date

Experimental mechanical disturbance treatments

FC - UEA - Plantlife experiment investigates responses of spiders, carabids, plants and hymenoptera to different mechanical disturbance treatments in a replicated trial. Findings will guide management to enhance biodiversity value and network potential of forest ride networks.

Wind-blown sand

There is great uncertainty in how to best provide conditions for arenicolous species requiring deposited, loose, windblown sand. Previous and recent attempts to provide a supply of windblown sand at Wangford Warren with the aim of regenerating grey hair grass *Corynephorus canescens* do not appear to have been successful. It is tempting to think that carrying out mechanical disturbance such as ploughing to provide loose sand will provide the necessary conditions for arenicolous species. However, it is likely that some beetles requiring windblown sand require the deposition of mixed mineral sand grains and windblown seeds.

There is a need to experiment further and the following should be borne in mind:

- The source areas of open physically disturbed sandy soil that are intended to provide a supply for aerial transport should probably be extensive (i.e. field-scale), not small
- Wind fetch is key - trying to achieve results in areas with tree encroachment is unlikely to be effective.

Suitable opportunities may exist in the Icklingham Plains, south of Foxhole Heath (cultivation of the reverted former arable field in agri-environment management) and adjacent to Wangford Warren (by re-cultivating the entire Runway lights field, itself reverted former arable and now supporting closed vegetation).

Box: Daring to Innovate:

The heaths are not sacrosanct. The idea that the biodiversity value of grass-heath vegetation may be improved by rotational soil disturbance, ploughing, or the episodic cultivation of crops with periods of fallow is not new. Early ecologists and conservation advisers in Breckland recognised the potential value of such interventions.

In February 1955, immediately after rabbit populations were lost to myxomatosis, the famous ecologist Alex Watt recommended that ploughing be introduced on a 4-5 year rotation across both the southern part of Weeting Heath and across much of Thetford Heath (Watt 1955):

> "I suggest as a basis of management that we take one crop of each plot and then allow four years to elapse before taking another. When any one of the plots is cultivated the rest is fallow. South Weeting Heath I suggest should be managed in the way already outlined."
> "One part (of Thetford Heath) should be excluded from any plan of management at the moment, namely the part along the roadside next to the R.A.F. installation. This area shows very interesting phenomena, namely, fossil stone stripes the first to be identified from the lowland of this country. A strip (say 100 yards wide) to the north of this showing strips of *Calluna* should also be left intact. The rest of the area is available for management on the same plan as for South Weeting Heath"

Similarly, the entomologist Eric Duffey, who carried out pioneering work on the dune spider assemblages ofFoxhole Heath and the Icklingham Plains (see Duffey 1957; 1994) recommended areas of Foxhole Heath be rotovated to rejuvenate bare sand following the loss of rabbits in the decade after myxomatosis.

> "Our work on Foxhole Heath has shown that certain species of invertebrates require areas of bare sand for their survival. … In order to perpetuate this type of habitat, I would like to suggest that part of the old warren on Foxhole Heath is rotovated. If the Iveagh Estate is agreeable to this, I think a relatively small area (about 20 x 20 metres) only need be treated and we would of course, be prepared to study experimentally its effect on the fauna in future years. It is probable that all the species concerned require a mosaic of plant cover such as grass tussocks growing amongst bare sand so that it would never be desirable to rotovate large areas on Foxhole Heath. If the treatment we suggest is successful, it would probably not be necessary to rotovate small areas more often than once every three years. PS By "old warren", I mean the south-facing slope not far from the road which was nearly all mobile sand prior to myxomatosis."
>
> Dr. E. Duffey, Conservation Research Section, Monks Wood, 8th October 1965

Table 20. Matrix showing immediate and longer term results of different intensity and frequency of management actions

	Process	Technique	Immediate Effects	Examples of vegetation response			
				Infrequent	Intermittent	Frequent	Annual
				every 10 - 60 years	every 3-4 -(9) years	every 2-3 years	every year
Intensity	Compaction	trampling, wheelings	impeded drainage, germination sites				
	small-scale shallow disturbance within sward	Discing, scarifying, forage harvest scuffs, rabbit scrapes	localised uprooting and destruction of vegetation, creating patches of loose bare ground and reduced competition within or alongside undisturbed sward, allows germination and seedling establishment and vegetative regeneration				
	small-scale moderate disturbance within sward	rabbit burrow aprons, track margins					
	moderate disturbance	rotovation	aggressive disturbance, kills much of the perennial vegetation but with some recovery from root/tussock fragments, creates extensive bare ground, upper soil layer disturbed, encouraging germination from seedbank	Establishment of long-lived perennials that subsequently seed:	Establishment of perennials that subsequently seed	Establishment and regeneration of annuals / paucennials	regeneration of annuals:
	intensive disturbance, moderate extent	ploughing	overturns perennial vegetation though regeneration can occur from intact partly buried root mat, creates extensive bare ground, brings up (nutrient poor) mineral sub-soil, allows regeneration from seedbank, buried organic matter may be available to deep rooted perennials, may break up compacted chalk favouring establishment of deep rooted perennials	establishment of deep rooted perennials that persist after sward closure	regeneration from seed, persistence during closure, eventual exclusion by grass sward	regeneration, recharge seedbank subsequently decline or disappear from above ground vegetation	
	devastating disturbance	turf stripping + spoil heaps	Removes vegetation, litter and organic humus layers, exposes low-nutrient soil or chalk, can expose long-buried seed or create opportunities for arriving seed. long closure time, particularly on chalk				
		pits, exposures, bank creation	exposes mineral substrate, allows continuous erosion prolonging open conditions				
	massive mechanical reorganisation across large scales	building sites, gravel workings	creates opportunities for mobile ruderals				

Table 21. Species benefitting from the range of actions indicated in Table 20. Unless otherwise indicated, species are flowering plants. For listed invertebrate species with a known foodplant, this species is given in brackets

	Technique	Frequency						
		Infrequent	Intermittent		Frequent		Annual	Continuous
		every 10 - 60 years	every 3-4 -(9) years		every 2-3 years		every year	
Intensity	trampling, wheelings	-	-		-		-	*Crassula tillea*
	Discing, scarifying, forage harvest scuffs, rabbit scrapes	-	*Astragalus danicus*, *Veronica spicata*, *Thymus serpyllum*, *Clinopodium acinos*		*Arabis glabra* *Neofriseria singular* – moth (*Rumex acetosella*)	*Arenocoris waltlii* – true bug (*Erodium cicutarium*) *Gronops lunatus* - weevil (*Spergularia* spp.)	*Trifolium scabrum*, *Trifolium glomeratum*, *Medicago minima*, *Minuartia hybrid*	
	rabbit burrow aprons, track margins	-		*Ceutorhynchus geographics* - weevil (*Echium vulgaris*)				
	rotovation	*Thymus serpyllum* ?	*Silene otites*, *Muscari atlanticum*, *Clinopdium acinos* *Hadena irregularis* – moth (*Silene otites), Emmelia trabealis* – moth (*Convolvulus arvensis*)		*Scleranthus perennis* ssp *prostrates. Harpalus froelichii* – ground beetle (*Chenopodium album*)		*Spergularia arvensis*, *Filago lutescens*, *Filago galica*, *Medicago minima*	-
	ploughing	*Pastinaca sativa*, *Daucus carota* *Hypera pastinacae* - weevil (*Daucus carota*)			*Fumaria parviflora*, *Veronica triphylos*?, *Veronica verna*?, *Veronica praecox*?, *Alysum alysoides*? *Psylliodes sophiae* - flea beetle **(***Descurania sophia*)		*Fumaria parviflora*, *Veronica triphylos*, *Veronica verna*, *Veronica praecox*, *Silene conica*, *Herniara glabra* *Stenocarus fuliginosus*- weevil (*Papaver* spp.)	-
	turf stripping + spoil heaps	*Clinopodium acinos* *Buelia asterela & Squamarina lenitigera* - lichens *Eurhynchium pulchellum* - moss	-		*Harpalus froelichii* – ground beetle (*Chenopodium album*)		-	-
	pits, exposures, bank creation		*Petorhagia prolifera*, *Artemisia campestris*, *Galium parisense*?, *Silene otites* *Loxostege sticticalis* – moth (*Artemisia campestris*)		-		-	-
	building sites, gravel workings		-		-		-	-

Complex Sward Mosaics

Complex sward structures of tussocks amidst open bare ground or closely cropped turf are a key requirement of many species, for example for moths or other invertebrates with complex life history requirements for basking, oviposition or feeding sites, shelter and aestivation or hibernation sites. The BAP moth, the Lunar yellow underwing *Noctua orbona* may be an exemplar or umbrella species for this assemblage.

Providing such complex sward mosaics is not straightforward and is hard to achieve by a static approach to management. Changing patterns of grazing, with intensity varying spatially and or temporally, together with physical disturbance in some situations, is the most likely way to generate such structured sward mosaics. An ideal could be the creation of extensive grazing systems, including a mix of livestock (e.g. sheep, cattle, and small numbers of horses) at a landscape scale so that the free-ranging movements of animals and their responses to shelter, vegetation fertility and water, would create patterns of spatially varying grazing intensity. However, for most sites this is clearly not feasible without ambitious and expensive habitat recreation, buffering and consolidation of site networks. This therefore is not an appropriate recommendation in the short or medium term.

More practicable options that have been discussed with or proposed by site managers include:

- The ebb and flow of gradients of grazing, that occur as rabbit populations fluctuate and their territory expands and recedes. This may result in incursion of new grazing and burrowing activity into recently ungrazed longer tussocky swards, and later the abandonment of short grazed turf and the development of discrete tussocks among open conditions. However, the deliberately reduction from a high density rabbit population has inherent risks, as subsequent recovery of rabbit populations from a low point is notoriously difficult, particularly as low density populations are susceptible to being limited by predators such as fox *Vulpes vulpes*. Therefore, we recommend that site managers should encourage rabbits but not be too concerned where rabbit numbers decline, provided rabbits recover within a reasonable time (e.g. 3-5 years).

Other possibilities proposed in consultation include:

- The possibility of mobile or electric fencing to intensively graze compartments for a number of years followed by a year of relaxation from grazing. This may be possible to achieve by rotation within larger contiguous sites.
- Erection of blind fences and partial barriers extending part way across a site, so that stock movement is funnelled in areas prone to erosion, creating bare and trampled ground, while grazing pressure is simultaneously reduced in corners and peripheral areas due to the dynamics of stock movement and congregation.

Nested Heterogeneity

A further important principle is that of Nested Heterogeneity. Fine-scale heterogeneity, in terms of sward mosaics, is important at scales of tens of centimetres or a few metres within habitat patches. Some assemblages, particularly Hymenoptera, require the local juxtaposition of grazed swards or trampled and compacted bare ground very close to ungrazed (but often intermittently disturbed ground) that can provide nectar resources. Other examples of species needing fine-scale heterogeneity include those that require the juxtaposition of scrub margins and open grazed habitats e.g. *Osmia (Neosmia) bicolour* (see box) and those that require the juxtaposition of contrasting habitat across ecotones, for example forest and heath, heath and fen, or dry heath and wet woodland e.g. *Crabro scutellatus*

Wet open woodland (structural and moisture ecotone)
Crabro scutellatus – Notable:A
Hymenoptera – Sphecidae (thread-waisted wasps)
A psammophilus black and yellow sphecid wasp which nests in dry, bare sandy fully exposed to the sun. However, it preys on Dolichopodidae (long-legged flies) which are associated with wet areas such as pools, bogs, streamsides and wet heath, and adults require flower particularly umbellifers. Therefore a combination of fairly dry areas for nesting with wet areas for hunting are required. Management at sites would need to encourage bareground by disturbance on dry areas, while former peat diggings and new pond creation may promote good prey populations

A guiding principle would be to ensure that at least one or two margins of each heathland site supported:

- An internal rotovated fire break comprising an annually rotovated or cultivated strip adjacent to another strip disturbed in alternate years. This would provide for both annual and paucennial species and species requiring re-vegetating tussocky broken ground both located close to unbroken turf
- Wherever possible adjacent arable fields should incorporate an ungrazed cultivated margin alongside the grazed heath site, providing complex juxtaposition
- Homogenously grazed sites will be improved by a range of different physical disturbance treatments, more episodic variation in grazing intensity, and allowing some ungrazed scrub margin to develop alongside areas with intermittent disturbance.

Management for Assemblages of Lightly or Ungrazed, Undisturbed Conditions

Management for assemblages requiring only light-or no grazing guilds could include very light, seasonal grazing or occasional/seasonal biomass harvest. Natural disturbance by droughting, occasional trampling and slippage can also help maintain open site conditions particularly on slopes.

Juxtaposition of structures within open habitats

Andrena (Charitandrena) hattorfiana – RDB: R
Hymenoptera – Apidae (a mining bee)

This bee has declined substantially and is found in Southern England on dry, often calcareous grassland, habitats are both coastal and inland, including cliff tops, downland, chalk heath, road verges and dune. It nests in open warm sunny ground, with a mix of bare ground and more vegetated areas (perhaps short turf or long grass). The pollen sources is primarily field scabious *Knautia arvensis* for which there is a close, possibly obligate association However, other scabious *Knautia sp.* and small scabious *Scabiosa columbaria* have been known to be used, while other flowers can also be visited. Rotational management of swards is recommended to promote tall grass and areas of *Knautia*, next to short turf but also with bare ground (created by some form of disturbance). It is a reasonably large bee (17mm), with good dispersal abilities and therefore, provision of this species requirements do not have to occur within the same small site.

Open habitats with scrub, disturbance and intensive grazing

Cerceris quinquefasciata – RDB: R, BAP
Hymenoptera – Sphecidae (thread-waisted wasps)

A psammophilous BAP wasp, which is declining and is surprisingly more common inland than in coastal situations. It particularly frequents open sandy habitats such as heathland, sand and gravel pits and other disturbed areas. Nesting sites are characterised by warm, sunny locations with bare or sparsely vegetated ground on sandy soils, frequently compacted area, such as paths. Nest cells are stocked with the usual prey of beetles, often weevils, and adults also spend time visiting a variety of flowers, especially umbelifers. Rabbit grazing is suggested to be beneficial. However, the range of stages associated with additional areas of scrub helps provide for a plentiful source of prey. Moderate disturbance is beneficial in order to create large areas of bare ground; however intensive disturbance will often create a very loose unsuitable substrate. Therefore, moderate trampling of paths and moderate vehicle (not excessive activity e.g. motorbikes) would help promote compaction.

Sward mosaics are key to invertebrates with complex life history

Sward Mosaic: with bare sandy ground, grass tussocks and ungrazed kidney vetch *Anthyllis vulneraria*, regenerating after physical disturbance with the creation of a bank on chalky sandy soil.

Sward Mosaic at Lakentheath Warren, with broken short turf on old chalk mound, and nearby ungrazed / lightly grazed tussocky grasland

Juxtaposition of structures is key to many invertebrates

Juxtaposition: of bare ground for burrows and nectar resources is important to many hymenoptera

Complex juxtaposition: of bare ground, broken turf and elements of scrub

Management for Species of Physically Disturbed, Ungrazed Conditions: "Putting the brecks back in Breckland"

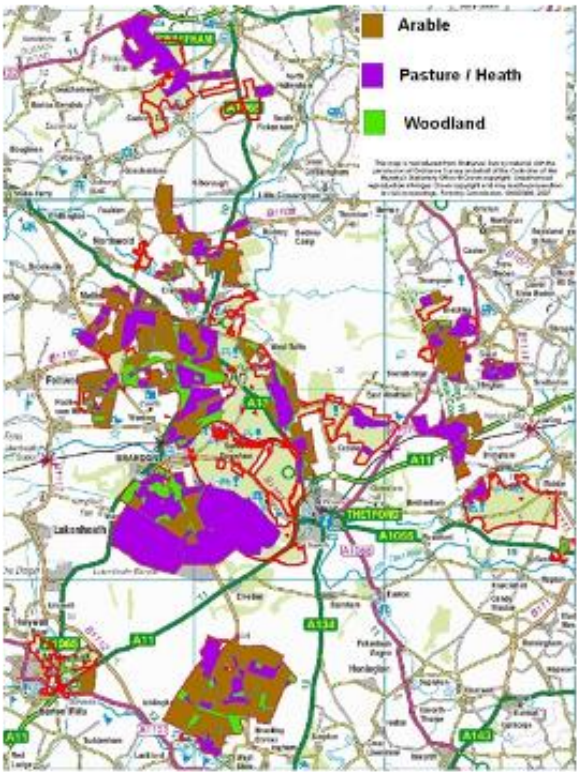
Physically disturbed conditions in an ungrazed context can occur:

- On farmland, particularly along field margins.
- In the lightly or ungrazed permanent open space within the forest landscape.
- In lightly or ungrazed early successional and disturbed ground in replanted forestry compartments, particularly those on calcareous soil on former arable land.
- On ungrazed 'brownfield' sites.
- In large, lightly or extensively grazed grass-heath complexes.

Recommendations:

- Put into effect the recommendations of the Breckland Biodiversity Audit Arable Workshop, via Environmental Stewardship. Update the Breckland Script as necessary with relevant evidence arising from research.
- Research should be conducted to evaluate and compare the relative value of cultivated margins within the arable landscape with the potential to recreate intermittently cultivated ruderal fallows (brecks) from unmodified (unfertilised) soils and intact seedbanks in the Thetford Forest landscape. Research should focus on scarce arable and ruderal plant assemblages and their associated invertebrate assemblages (e.g. beetles particularly carabids, and staphylinids but also other groups of Coleoptera, as well as Hemiptera, Lepidoptera and Hymenoptera).
- Work should examine whether the nutrient status of sandy soils unmodified by agricultural inputs, results in more open vegetation and slower closure, allowing longer intervals between repeat cultivations.
- Work should also investigate whether cultivation every 2-3-4 years is be preferable to some invertebrate and plant species, compared to annual cultivation.
- Examine the relative merits of different cultivation types and timings, together with different herbicide regimes, to manage for priority species of plants and invertebrates on Breckland cultivated margins. Work should include long established non-rotational margins (established under the ESA), together with newer rotational and non-rotational margins.

Ruderal breck seedbanks in Thetford Forest



Much of Thetford Forest was planted on fallow arable brecks not heath and the breck seed-banks persist under plantations on chalky sands. Restoring cultivated habitats may be a more appropriate goal in such locations than attempting to restore grass-heath. Cultivation along forest track-way margins may provide benefits without a need for field-scale reversion. Photographs © P Dolman; historic land-use mapped by Skipper & Williamson.

Key Recommendations for Cultivated Margins of the Breckland Biodiversity Audit Arable Workshop
(Panter, Nichols and Dolman 2010)

1. With HLS agreements, cultivated margins should be included as prescription HF20, not the "more of the same" HF11. This would allow NE to use a tailored prescription to maximise benefit (and also pays the farmer an additional £40/ha)
2. NE should devise a Breckland-specific HF20 prescription (drawing from the workshop discussions) which can be promoted across Breckland by NE. This maximises benefits, increases adviser/farmer confidence, and would be quicker for NE advisers than tailoring individually to farms.
3. Margins should be at least 6m wide to alleviate effects of spray/irrigator drift.
4. Longer 6m margins may be preferable to a shorter length of 12m margins as edge benefits and juxtaposition of the cultivated margin and grass baulk are important, while seed densities are greater near field margins
5. Desirable locations to target for cultivated margins are anywhere on light soils (chalky and acid) but especially alongside old tracks, tussocky verges and grassland areas, on lines of old hedges and pine-lines, near the edge of Thetford Forest, at locations of known rare plant and invertebrate species and at existing well-managed ESA cultivated margins.
6. Undesirable locations are on heavier or peaty soils (unless there is a known rare species which will benefit), in shaded locations (e.g. north sides of woods) and under over-hanging trees.
7. Cultivations should be annual or biennial, since both have benefits, but this must be tied to stronger indicators of success in prescriptions, e.g. spray off once perennial grasses reach >50% cover.
8. Rotational and non-rotational approaches each have benefits, so either approach is appropriate. However a presumption towards non-rotational agreements is compatible with conservation of dispersal-limited invertebrates and may be particularly valuable on ESA non-rotational margins that have accrued value over time.
9. Where existing ESA cultivated margins are being managed well, they are likely to have accrued benefits for biodiversity over time. These should be maintained as non-rotational margins wherever possible under new HLS agreements.
10. Cultivation timing should be varied from September through to March. Different cultivation timings have benefits for different species. Practicalities of management mean it is likely that headlands will be cultivated at the same time as preparing the adjacent field (although this is not always the case), thus there will be inherent variability among headlands and years depending on cropping patterns.
11. Cultivation timing should only be fixed to a specific month/period when conservation priority species are known to be present and the optimal cultivation timing for these is also known. Given the presence of long term seedbanks and the high potential for population increase of invertebrates given appropriate conditions, variability in timing is unlikely to be a serious problem in most cases.

On farmland, a high priority is to ensure that potential accumulated benefits already achieved through public investment in the cultivated margins under ESA agreements be sustained by transition of key sites into Environmental Stewardship (ES).

Recommendations:

- Review the success and apparent value of current ESA field margin agreements and where these appear to have provided benefits make every effort to secure transition to ES. In view of uncertainty over the response of invertebrates to habitats, the presumption should be that any open vegetation with a diversity of annual plants is beneficial.
- ES advisers should recognise the benefits of cultivated margin prescriptions that should be seen as the key mechanism for biodiversity delivery in Breckland farmland.
- Juxtaposition of cultivated margins alongside grass strips, either already in place in permanent grassland, hedge-banks, along pine lines and track-ways, or created through ES options, could bring enhanced benefits.

A crucial feature of ESA implementation in Breckland has been to have static non-rotational cultivated margins, whilst in ES these cultivated margins may be either fixed or rotational. Non-rotational margins seem preferable for scarce invertebrates – that lack a seedbank and therefore require suitable conditions every year. Although it is possible that some more dispersive species (e.g. *Harpalus froelichii*) may be able to readily colonise new areas from healthy source populations, some other species may be much less mobile. It seems sensible therefore to take a precautionary approach and to persist with non-rotational treatments.

Recommendation:

- Implement ES cultivated margin agreements as predominately non- rotational.

Cultivated Margins Compared to Unsprayed Cereal Margins

The potential role or otherwise of the cereal crop in the dynamics of these assemblages, and the relative value of cultivated (uncropped) margins versus unsprayed cereal margins (conservation headlands) is unclear. Work conducted by Robert Marrs on Ropers Heath, an area of cereal agriculture restored to heathland adjacent to Cavenham Heath in the Breckland, suggested that cereal cropping was not effective in reducing nutrient status of soils (Marrs, 1985). Prescriptions involving an unsprayed and essentially weed rich cereal margin are generally not attractive to farmers, as the harvested grain cannot be included with the rest of the cereal crop and subsequent crops in the rotation may be affected by the build up of weeds. In contrast, simple cultivation is an operation that can be applied either together with cultivation of the rest of the field at the same time as normal crop management, or in a single operation on the cultivated margin. Thus for many farmer managers, cultivated margins are preferable.

Evidence accumulating to date, is that both thinly-sown cultivated margins and uncropped (cultivated) margins were equally effective for scarce plants of arable and cereal habitats. In contrast, thickly sown margins (i.e. suitable for subsequent harvesting of a crop) could be detrimental as the crop might grow too densely shading out the conservation priority species. Further evidence that uncropped (cultivated) field margins are more beneficial for arable plants than field-scale unsprayed cereal is confounded by both the fact that vascular weed seed densities are much greater at field margins and that unsprayed cereal treatments may nevertheless receive fertiliser inputs (C. Shellswell *pers. comm.*).

Shallow cultivation is preferable to deeper ploughing. Monitoring of experimental plots showed that "Shallow cultivation tended to result in higher cover of annuals and dicotyledonous species (in May) and lower Ellenberg N values, than deep cultivations. Continual shallow cultivation also resulted in increases in the number of monocotyledonous species under most timing regimes, while number of perennial species increased irrespective of either depth or timing" (ADAS 2001). This is further supported by evidence from Hillborough and Ickburgh in Breckland. Here, heavy harrowing to break up surface soil but not invert it (as would occur in ploughing) has maintained a good balance of open ground and vegetation over long time periods without the loss of open conditions to perennial grasses (B. Nichols *pers. comm.*). This was despite the persistence of perennials in the vegetation. However, the role of light chalky soils in this result is perhaps also important.

However irrespective of depth, repeated annual cultivation generally results in a gradual build up of both annual and perennial grasses (ADAS 2001) that over time reduce the abundance of desired open ground, nectar sources and annual plant species and their associated seed production (e.g. for seed-eating beetles). In contrast, evidence from the arable weed reserve at Weeting suggests that cultivating a low intensity cereal crop prevents such a build-up of grass; this may be at least partly due to dominance and shading of the vegetation by the cereal (although an additional important factor is the lack of inorganic fertiliser inputs to this field).

However a simple and pragmatic solution to grass build-up is to occasionally spray with a broad spectrum herbicide late in the growing season and to then re-cultivate (Panter et al., 2010). This is not a problem for the majority of desired annual plants; even if adults are sprayed off regeneration readily occurs from a healthy seedbank replenished annually through the good growth and suitable above ground conditions. Glyphosate has been shown to be non harmful to larger carabids. However sub-lethal effects have recently been reported for spiders (Benamú, Schneider and Sánchez 2010). The evidence base by which to assess the relative benefits of cultivated margins and unsprayed cereal margins appears incomplete and is strongly slanted towards vascular plants, with the relative benefits of prescriptions to scarce invertebrates poorly known.

Recommendation:

- Research should be conducted to examine whether annual cultivation of arable margins (e.g. as in cultivated margin prescriptions) or other ruderal habitats (e.g. recreated brecks within Forestry Landscape) gives similar outcomes to prescriptions or management with low density unsprayed spring cereal crop. Effects should be studied on the plant and invertebrate species populations and assemblages sustained and the seed bank densities achieved.

Delivering ungrazed, disturbed conditions outside the arable landscape

<u>Targeting large lightly or extensively grazed grass-heath complexes</u>

In extensively grazed sites such as STANTA, rotovation or ploughing of very large areas may provide a volume of ruderal vegetation some of which would remain ungrazed. In other large heathland sites it may be appropriate to fence off and plough areas outside of the grazing regime. Such large scale cultivations would serve two purposes: firstly rejuvenating now species-poor areas of grass-heath (through exposing buried seedbanks and nutrient depletion) and secondly by providing a temporary flush of ruderal vegetation.

The case for this is provided by:

- The large number of conservation priority species in Breckland requiring disturbed but ungrazed conditions (e.g. 144 priority species, including 68 RDB species and 29 Breckland specialists).
- Variable quality and unknown delivery on arable cultivated margins.
- Unimproved soil on grass-heath SSSIs that has not received applications of inorganic nutrients.
- Many grass-heaths represent long term fallows rather than ancient grassland or heathland (e.g. parts of Thetford Heath, much of STANTA and parts of East Wretham).
- Potential for buried seedbanks under some grass-heaths of 20th century origin.
- There are large expanses of grass-heath that currently provide a low value resource for conservation priority species in Breckland (e.g. Brettenham Heath, Bridgham Heath, STANTA, Lakenheath Warren).

Recommendation:

- Examine the feasibility of applying large-scale cultivation treatments to the moribund and ageing grass-heath resource in STANTA, with the aim of rejuvenating brecks that have not been cultivated for 68+ years.

Targeting Ungrazed 'Brownfield' Sites

Some key sites for the assemblage of ungrazed and heavily disturbed conditions are essentially brownfield sites, such as Maidscross Hill and Red Lodge. The conditions that such sites provide is summarised by criteria elaborated by Buglife for "Open Mosaic Habitat on Previously Developed Land". This comprises complex and heterogeneous post-industrial sites providing:

- Nutrient poor, stressed and disturbed environments.
- Loose bare ground with hot microclimates.
- Early successional communities of annuals, mosses, lichens, ruderals.
- Short swards.
- Floristically diverse grassland providing rich nectar sources.
- A structural variety of succession, including scrub.
- Spatial variation forming small-scale mosaics.

***Cheilosia velutina* - Notable**
Diptera – Syrphidae (Hoverfly)

A hoverfly occurring in various habitats, frequently calcareous and waste ground, the larvae are phytophagous on thistle (*Carduus* or *Cirsium*), while the adults feed on *Umbelliferae*. It requires the maintenance of open conditions and flower rich conditions. These conditions are suggested by Falk (1991), to be created by "rotational grazing policies to produce a mosaic of vegetation types", and disturbance "to ensure continuity of pioneer vegetation, perhaps involving rotovation or bulldozing selected parts of a site". However, hogweed (*Heracleum sphondylium*) is suggested to be very important and the removal of this species by spraying or even by the grazing from local deer populations have resulted in the loss of the hoverfly (Ian Rabarts *pers. comm.*).

Maidscross Hill is largely overgrown by closed or rank grassland and encroached by scrub. The remaining open gravel and sand exposures are limited to a small area. The extensive lichen and therophyte communities on the plateau around the margin of these pits have greatly been reduced in recent decades. There is an urgent need to rejuvenate bare ground, broken turf and ruderal plant communities at this site.

Recommendation:

- Ensure that scrub removal, ploughing, turf removal, and creation of steep open exposures within pits is carried out at key sites of former gravel working on Maidscross Hill.
- The status and condition of remaining conservation resource at Red Lodge be examined, and required action be taken to ensure continuing conditions for the valuable species of disturbed ground.

Lightly or Ungrazed, Disturbed Open Space within the Forest Landscape

The large resource of ungrazed (or lightly grazed by deer and hares) and intermittently disturbed ride and track-way verge within the Thetford Forest landscape, combined with the ruderal vegetation in restocked plantations, provide opportunities for some dispersive species including scarce Coleoptera (Lin 2005; Bertoncelj 2010), Aranaea (Pedley unpublished data), Hymenoptera and moths. The potential of these areas as networks for dispersal are discussed further in the Networks for Resilience section.

Grazing Susceptible Perennials

<u>The need to experiment with grazing susceptible perennials and steppe species in the cultivated and arable landscape</u>

In contrast to the clear evidence that annual plants benefit from cultivation, there is less clear evidence that historically intermittently cultivated habitats were also important to the suite of perennial species requiring physically disturbed and ungrazed conditions (e.g. field mugwort *Artemisia campestris,* Spanish catchfly *Silene otites*). However, it is likely that the practice of cultivating outfields for just one or two years and then leaving them fallow for long periods (Bailey 1989) provided ideal conditions for perennials of low competitive ability to regenerate from the seedbank, establish as adults and seed prolifically for a number of years prior to sward closure.

It is therefore likely that populations of short and long- lived perennials may have been dynamic and persisted with prolific regeneration from large seed banks, despite high mortality of adult plants during episodes of ploughing. In 1971 Eric Duffey observed 40 plants of *Silene otites* growing across the northern part of Foxhole heath, despite this part of the heath being ploughed when he worked there during the mid 1950s. Similarly, plant lists made in 1950 and 1953 for Codson Hill include *Silene otites* and this area was thought to have been arable previously (Tansley and Watt, undated).

The relict distribution of some long lived perennial species such as Spanish catchfly *Silene otites*, and grape hyacinth *Muscari neglectum*, which are often restricted to grass strips alongside arable fields (including road verges and banks), is strongly suggestive of them having once been common within the intermittently cultivated arable fields themselves. However, there are a number of alternative

yet plausible explanations for relict distributions along track-ways and road verges of such speciality perennial plants:

- Such species may have been historically dependent on physical disturbance provided by tracks, but excluded by grazing from the heaths and excluded by cultivation from cultivated fields and brecks.
- Such species may have been continually dispersed and redistributed along track-ways and drove roads by movement of livestock, including large sheep flocks, and vehicles and their draught animals.
- If experimental work shows that some of the scarcest and most vulnerable perennial vascular plant species can be managed in intermittently cultivated lightly grazed ground, there is potential for greatly expanding their status through sympathetic management on grass-heath sites that currently have low conservation value.

Recommendation

- Research work should be conducted to examine whether populations of rare vascular plants restricted (or largely restricted) to Breckland, that are stress tolerant perennials intolerant of grazing but requiring occasional disturbance for regeneration (e.g. perennial knawel *Scleranthus perennis,* spanish catchfly *Silene otites,* grape hyacinth *Muscari neglectum,* field mugwort *Artemisia campestris*) can be sustainably managed by a regime of intermittent cultivation on soils of suitably low nutrient status.
- Ideally, a range of cultivation frequency and fallow periods should be examined, across a range of soil types, focusing on the most calcareous sands and most acidic low nutrient status soils. The response of these populations in cultivated situations with and without sowing of cereal crops should be examined.

Ecological Requirements of Wetland Assemblages

Important wetland habitats required by conservation priority species in Breckland include wet woodland, through to open fen, as well as shaded pools, fluctuating water bodies and standing water in open conditions. The diversity of acidic and calcareous water conditions is important in creating diversity in aquatic communities. In Breckland there are many acid-loving species common in bogs and frequently associated with organically rich and mossy conditions, but also some calcareous species common in the relict fen systems and spring flushes.

In the following section, we assess the relative importance of differing wetland habitat types for biodiversity priority species overall, and specifically for Breckland specialists.

Standing Water, Pingos and Fluctuating Meres

Due to the relative paucity of knowledge of ecological requirements many aquatic species could not be placed in specific wetland guilds and were assigned to the broad wetland guild. Differentiating between standing water species that are restricted to fluctuating meres and those restricted to peri-glacial ground-water fed pingos, was beyond the scope of this audit and in many cases beyond the level of available information on species habitat associations. However, the invertebrate communities of both are known have unique elements, and support species not found in other elements of standing water within wetland sites.

Breckland has long been recognised for assemblages of rare invertebrates, particularly water beetles associated with groundwater-fed fluctuating water bodies, including meres and pingos. The importance of groundwater-fed fluctuating water bodies was recognised by the Breckland Natural Area Profile (Rothera 1989). The autecological information collated by the BBA indicted that 21 species were found in fluctuating water bodies. Of these 21 species, 18 are Sciomyzidae, which are marsh flies and predominately prey or parasitize molluscs and include the Breckland specialist fly *Psacadina zernyi*. A further two are small freshwater crustacean species, the water flea *Dunhevedia crassa*, recorded in three 1km squares and Britain's largest freshwater ostracod (2.6mm) the two-spined seed-shrimp *Cypris bispinosa*, known from four 1km squares in Breckland. Both species have no conservation designation, but are possibly entirely restricted to Breckland (although it should be noted that there is a lack of recording in these groups).

LITT/SWARDM
Psacadina zernyi – RDB:VU, Secondary Stronghold
Diptera – Sciomyzidae (marsh flies)
Known from Surrey, Sussex and 5 Norfolk sites, including Thompson, Foulden and East Walton Common (1983). This extremely rare southern species occurs in wetlands especially fens or breckland sites with 'pingo' hollows, as standing water is probably a requirement. The larvae of this species probably develop as parasitoids on aquatic snails. Water levels must be maintained at sites and a range of vegetation types in the margins of ponds and ditches, by rotational management. Furthermore seasonally fluctuating water levels may be important for this species.

Pingos are important and unique standing-water elements. The available ecological information for 47 Breckland conservation priority species mentioned pingos; 30 of these species had Notable conservation statuses and 17 were RDB listed. Seven of these species were Breckland specialists, all with secondary strongholds in the region. A large proportion of the Breckland conservation priority species associated with pingos are water beetles in the Hydrophilidae and Dytiscidae families, which are mostly large predaceous/scavenging water beetles. However, species also include a number of Diptera and the orange-rayed pearl moth (*Nascia cilialis*) that occurs in fen and pingo systems, where it requires mostly saw sedge (*Cladium mariscus*) and greater pond sedge (*Carex riparia*). 15% of priority species for which autecological information mentioned pingos are associated with littoral habitats, such as *Cercyon tristis*, a scavenging water beetle (Hydrophilidae) found in decaying reed litter in shallow margins. A further 64% species are thought to occur in a range of standing-water habitats, including *Prionocera subserricornis*, a RDB cranefly recorded at East Walton and Thompson Common.

Distribution of the open standing-water guild is shown in Figure 30. These species are associated strongly with areas of standing-water and the river valleys clearly shown on the map, but also with smaller unmarked pingo and mere sites, such as East Wretham. The north-east corner of the Breckland NCA is particularly good for species in this guild, with sites in STANTA and SSSIs such as Thompson Common. Foulden Common and East Walton Common are also hotspots for this guild.

The Relative Importance of Shaded and Un-shaded Wetland Habitats

Discussions with entomologists, including those who have surveyed Thompson Common, suggested that whilst open and un-shaded pingos were important for most invertebrate groups, including aquatic Coleoptera, shaded pingos and wet woodland were vital, particularly for rare and scarce Diptera (B. Nichols 2004). This is reflected in the proportions of these groups in the shaded water guilds (shaded littoral, standing water, running water, standing or running water and wetland guilds); these contain 72 species in total, of which 46% are Diptera and 38% Coleoptera.

Wet wooded habitats (pooling assemblages associated with damp woodland, wet woodland, wet woodland with littoral, standing water and running water habitats) support a total of 86 Breckland conservation priority species. The shaded damp/wet woodland assemblages include relatively few RDB species, 18 species, and only 2 Breckland specialists, both of these are associated with damp or wet woodland, rather than shaded standing-water.

180 conservation priority species were associated with un-shaded, open wetland habitats, which could include a variety of habitats from tall reedbeeds to grazed fen and wet meadows. A further 108 priority species associated with open littoral habitats and 96 species with open standing-water habitats. This is a total of 480 priority species in open un-shaded habitats, more than five times the number (86 priority species) in damp/wet woodland. Open wetland habitats provided 74 RDB, with a further 48 RDB species in open littoral habitats and 28 in open standing water, a pooled total of 150 RDB species, approximately eight times as important as the shaded wooded habitats (with 18 RDB).

The Brecks Workshop Report (Perkin and Norden 2007) identified a need to carry out a survey of the wet woodland resource and also to develop an understanding of the importance of wet woodland versus open wetland habitats. Following the analysis of assemblages, we are now able to report that, as described in the preceding section, wet woodland habitats were generally found to support low

numbers of conservation priority species and Breckland specialities compared to open un-shaded fen, littoral margins or standing water in open situations.

Standing water in woodland
Agabus (Gaurodytes) melanarius – Notable: B
Coleoptera - Dytiscidae
This water beetle is associated with shaded shallow pools of standing water within woodland. Generally the pools in which it is found are rich with dead and decaying leaves from the surrounding trees and can include conifer plantations. However, older observations also suggest springs and cold pools in forests, or cold, shaded pools with no mention of dead leaves and detritus.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Littoral Habitats

Littoral habitats were associated with a greater number of conservation priority species than standing water. The open littoral guild has one of the largest proportions of RDB species, with 40% (55 of 136) of the species in this guild designated as RDB. 13 Breckland specialist species require open littoral habitats, with only two of these preferring grazing and eight required open standing water, for which grazing requirements were unknown. Littoral species were dominated by Diptera, Coleoptera, Bryophytes and Charophytes (stoneworts).

Hotspots of littoral biodiversity included Thompson Common and Chippenham Fen, but the distribution of littoral species was considerably less widespread and dispersed than those of standing water guilds (Figure 31).

Standing water with aquatic vegetation
Pisidium pseudosphaerium –Notable:B
Mollusc – Sphaeriidae
This species occurs in marsh drains and ponds. It requires clear clean water but that which is stagnant and choked with a high volume of aquatic plants. It often occurs in waterbodies over a richly organic benthos that verges on becoming anaerobic. The management of ditches for such as species needs to be relaxed more than normal procedures would dictate where the only concern is land drainage. To provide sufficient ditch vegetation, the community must be allowed to reach late stages of the natural succession. However, the ditch still needs to be under management, as with all successional stages, these are temporary and eventual clearance will be needed. The vegetation clearance should be conducted along short stretches of ditches and on long rotations.

Littoral habitats that are disturbed

Omophron limbatum – RDB: EN

Coleoptera – Carabidae (Ground Beetle)

This ground beetle occurs in bare sandy soil at the margins of water in flooded gravel-pits, where it forms burrows in the sand. The species was possible indigenous in the C19th, with the first reliable UK record from 1969 on the Kent/Sussex border (suspected to be a recent re-colonist from Europe). Management recommendations are that some disturbance, on rotation around the pits will help promote early successional stages. The dispersal of this species should be considered extremely high and unlike most carabids it appears to breed all year round.

The Breckland Natural Area Profile (Rothera 1989) quantified two RDB plants and approximately 60 RDB invertebrates, with 23 plant and invertebrate BAP species in groundwater-fed wetlands (pingos, meres and valley-head fens), of which only one species was regarded as a Breckland speciality. The results of the Biodiversity Audit largely confirm this, with 76 RDB species associated with standing water or littoral margins.

From the autecological information available, it was not possible to distinguish between species associated with fen habitats in pingo systems, species associated with fen habitats in calcareous flushed valley-head mires and species associated with fen habitats in other parts of the landscape, such as fen remnants along river valley margins or at the Breckland / Fen margin. Further analysis is recommended in order to prioritise restoration and conservation efforts.

Recommendation

- Requirements of wetland species are less well understood and frequently more complex, with more elements and habitat variables to be considered. Improvements are needed in the knowledge of the species and in the assessment of guilds.
- The relative importance of wetland assemblages that occur in different landscape elements should be investigated, e.g. associations with pingo systems, calcareous flushed valley-head mires, fen remnants along river valley margins, fens at the Breckland / Fen margin.

Open wetland and aquatic habitats were more important for Breckland conservation priority species than damp/wet wooded habitats.

Similar numbers of Breckland specialists required wetland, littoral margin and standing water habitats. Similar numbers also occurred between requirement for grazing, physical disturbance, and ungrazed conditions.

Wetland restoration

Tree removal over 16 ha of Cranberry Rough (Goodwin's 'Hockham Mere') to restore peat fen. Photographs © N. Armour-Chelu

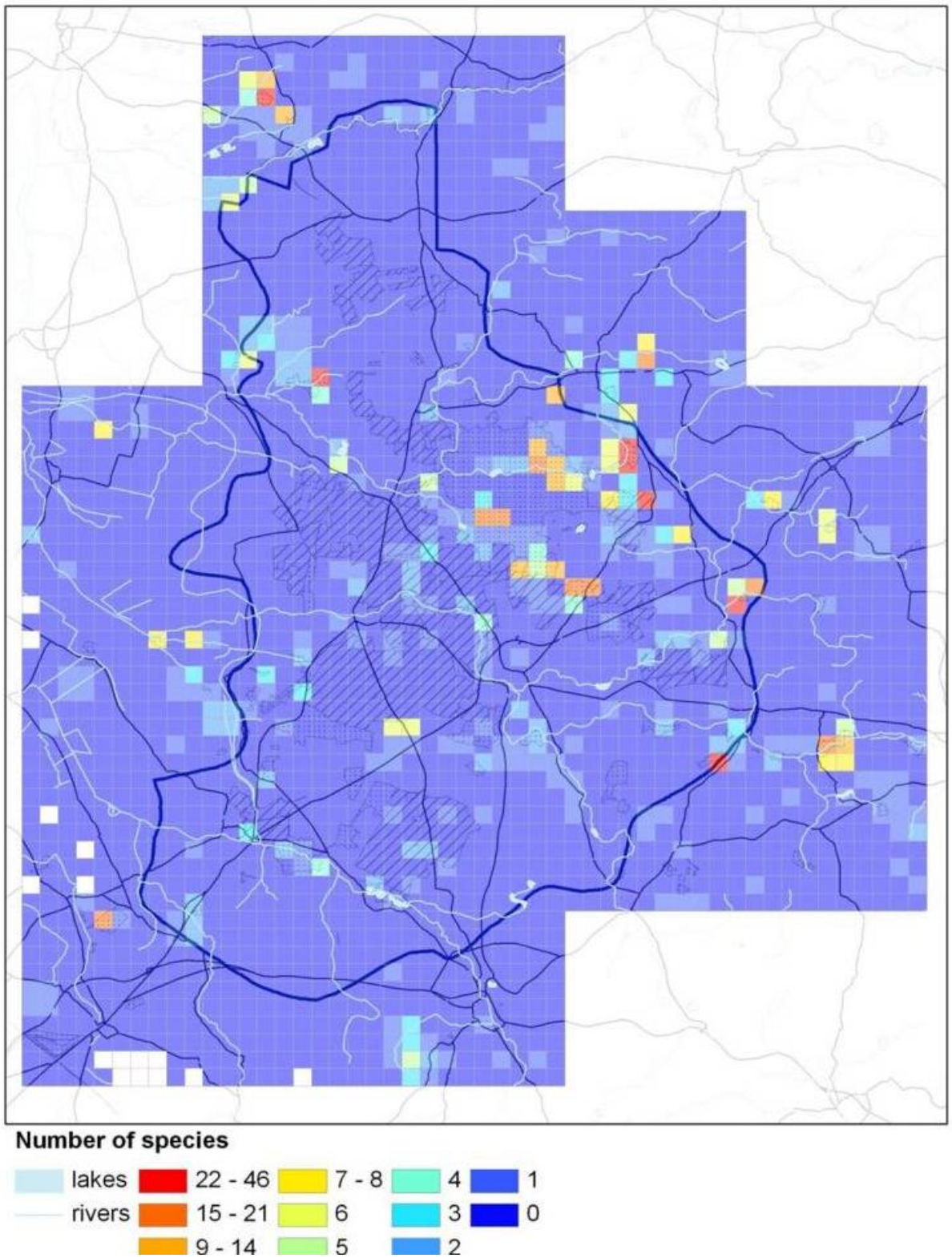


Figure 30. Number of Breckland conservation priority species from open, un-shaded standing-water guilds in each of the 1 km grid squares in the Breckland region. White indicates areas for which no records were obtained.

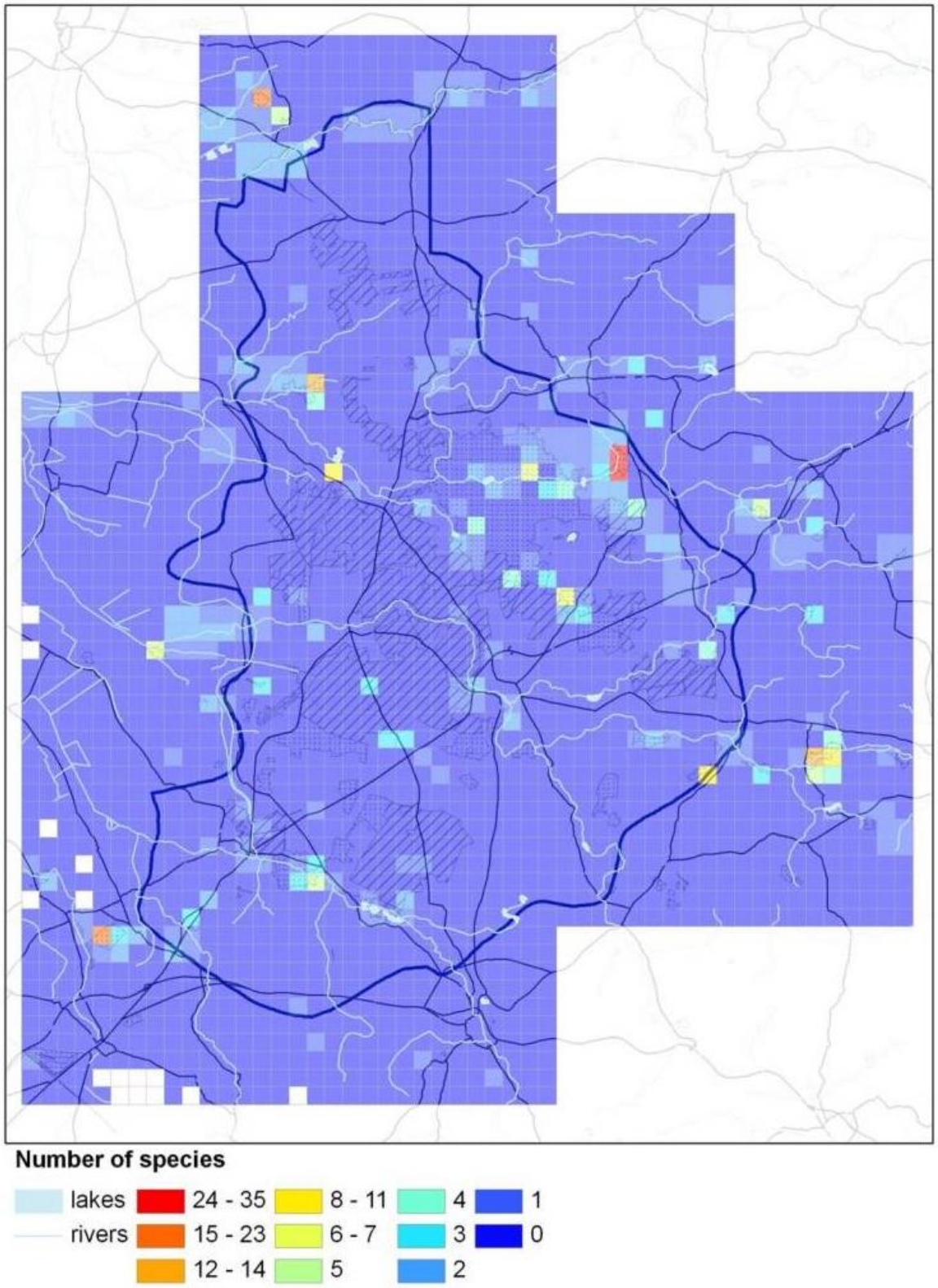


Figure 31. Number of Breckland conservation priority species from littoral guilds in each of the 1 km grid squares in the Breckland region. White indicates areas for which no records were obtained.

Grazing of Wetlands and Fluctuating Water Bodies

Wetland assemblages have been identified that require:

- Short vegetation such as provided by grazing or that require trampling and poaching within the wetland or at littoral margins.
- Other species require less disturbed tall vegetation, tall stems or litter accumulation, which would best be provided by very low or no grazing.

For assemblages of wetland species broadly similar numbers were identified that require grazed conditions (41 priority species) compared to ungrazed (44). However, grazing sensitivity of a slightly greater number was unknown (94). For priority species associated with littoral conditions, a similar pattern was apparent (34 species requiring grazed, 21 ungrazed, 28 unknown). The pattern for Breckland specialists was broadly similar.

Wetlands with no or light grazing
Cryptonevra consimilis – RDB:VU, primary stronghold
Diptera – Chloropidae (Grass fly)
This species occurs in the wetland without grazing guild. The species within this guild occur in wetlands, but open standing or running water is not essential, but obviously an environmental element in determining wetlands. This rare species is recorded from southern England. The larvae of this are inquilines of another species of grass fly (*Lipara similis* RDB: VU, BAP) galls on Common Reed (*Phragmites*). Grazed wet grassland or heavily grazed fen would therefore, not be suitable for this species. However, low density extensive grazing or rotational biomass harvesting by reed cutting would be appropriate.

Research by RSPB examining the effects of introducing highland cattle to wet fen in the mid-Yare, showed that grazing significantly reduced densities of three snail species, common Desmoulin's whorl snail *Vertigo moulinsiana,* marsh whorl snail *V. antivertigo* and the land snail *Euconulus alderi*. However, because of the patchy nature of grazing, high densities of these species still persisted in less heavily grazed parts of the grazing unit. *V. moulinsiana* was particularly associated with vegetation dominated by greater pond sedge *Carex riparia* (RSPB 2002).

Similarly at Thompson common Desmoulin's whorl snail (*Vertigo moulinsiana*), whilst present in grazed pingos, achieves higher populations in ungrazed situations (based on survey data from 2001; B Nichols *pers. comm.*) due to a requirement for a combination of low and tall vegetation structure. The same may also be true for other invertebrate groups including for aquatic Coleoptera, for which pingos are an important resource (Martin Collier, Geoff Nobes, *pers. comm.*).

Restored pingo complex

At Great Hockham Hills and Holes removal of tree cover and restoration of extensive grazing has provided a wide variety of complex vegetation structures, shaded and unshaded pools with differing pH and plant communities.
Photographs © P Dolman

River Valley Assemblages

River valley habitats include wet alluvial woodlands, valley fen and valley-head fen and river channels with diverse within-river habitats and micro-habitats.

The biodiversity value of riverine habitats

The Natural England Natural Area Profile recognised the value of riverine habitats to species such as bats, water vole and otter, but the resources were not available at that time to conduct a fully systematic audit across all landscape elements in Breckland.

Compared to wetlands, littoral margins and standing water, many fewer species were found to be associated with running water habitats. Species did however; include 39 RDB species that require either standing or running water, 16 only occurring in running water in open conditions and 2 requiring running water in shaded conditions. It is notable that the mapped distribution of Breckland conservation priority species picks out the River Nar as a linear hotspot (Figure 32).

There were no Breckland specialities associated with running water. However, it is important to realise the importance of littoral, wet meadow, reedbed, carr and isolated trees along river margins in providing conditions suitable for species in the wetland and littoral guilds.

Wet woodland

Aromia moschata - Notable: B
Coleoptera – Cerambycidae (Longhorn Beetle)

This beetle is one of a number of invertebrates within the wet woodland guild which can be regarded as carr and woodland close to water, e.g. riverine, species. It requires mature poplars (*Populus*) and willows (*Salix*). Oviposition occurs on the trunk or the base of healthy branches, larvae then bore into the sapwood and when at the heartwood tunnel vertically for 30-40cm. Adults are recorded from May to September and occur on a variety of flowers particularly *Umbelliferae* (e.g. angelica, cow parsley and chervil). Formerly it was much more widespread and it is threatened by the clear-felling of wet woodland and riverside trees. Furthermore the cessation of pollarding may threaten this species, but it is important that pollarding should be carried out on rotation as large populations of the beetles can occur in lines of pollards.

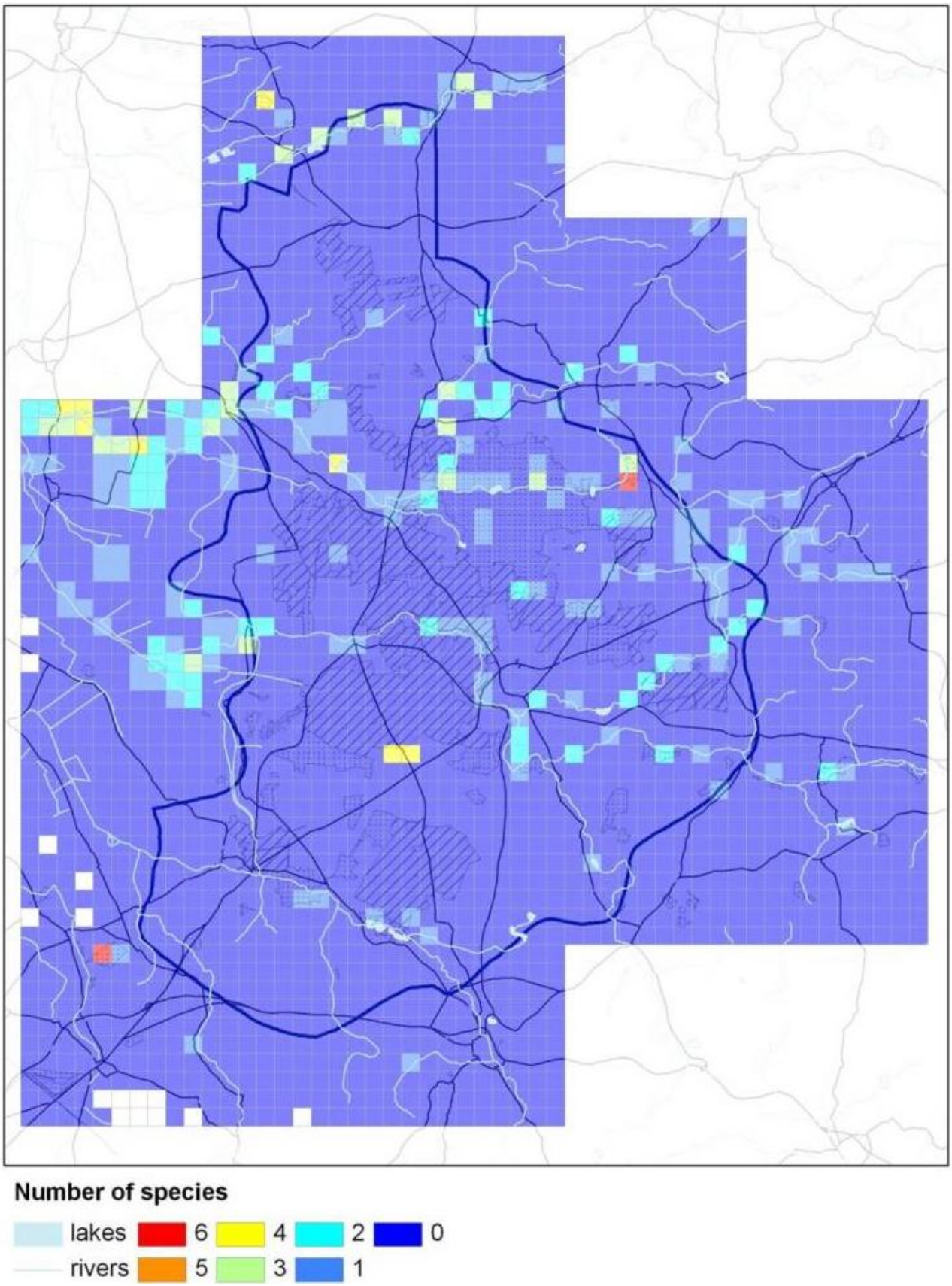


Figure 32. Number of Breckland conservation priority species from the running water and running or standing water guilds in each of the 1 km grid squares in the Breckland region. White indicates areas for which no records were obtained.

Management to Sustain Wetland Assemblages

Fens and Fluctuating Water Bodies

The results of the Biodiversity Audit clearly show that, although there are priority species associated with damp and wet woodland, larger numbers of priority species, RDB and specialists are associated with open conditions.

Furthermore, a range of grazed and ungrazed, disturbed (e.g. poached) and undisturbed (e.g. tall vegetation, dead stems, litter) conditions are important, with fen vegetation, littoral margins and standing waterbodies each having distinct value. Scattered scrub, of a variety of plant species, at relatively low cover (e.g. less than 10%) and retained in a range of situations is valuable structure for invertebrates, with a number of conservation priority species dependent on wetland/scrub ecotones.

Recommendation:

- Resources permitting, the majority of each significant fen, wetland, pingo and mere site should be predominantly cleared of woody vegetation, while retaining some wet woodland resource. The ratio of RDB species between the open and shaded habitats suggests that perhaps a maximum of 10% - 20% of a site should be wooded.

The full range of structures required by different wetland, fen and standing water assemblages is best achieved by extensive grazing (e.g. of hardy cattle and or ponies) across large integrated wetland sites with both open fen (and pingos where present) and some elements of retained wet woodland and scrub; this is currently implemented at Thompson Common and Cranberry Rough. Fen cutting may also be appropriate on some sites, either where grazing is impractical or if there is the potential to harvest sedge or reed in an economically viable way.

<u>The pingos</u>

Within pingo complexes a range of diverse conditions should be maintained, with much of the site open but retaining some shaded pingos. A range of vegetation structures should be maintained around the margins and within the water body. Ideally, some areas should be maintained as open but without grazing and in close proximity to grazed areas. Evidence from surveys of aquatic Coleoptera and Hemiptera at Frosts Common showed that a range of conditions and structural complexity is key to invertebrate diversity (Nobes 2008).

However, pingo sites pose particular challenges in maintaining the range of vegetation structures necessary. Whilst grazing can achieve much of this, a single, static approach to grazing management, e.g. with fixed numbers of animals of whatever type, is unlikely to yield satisfactory results. Some grazing animals (depending on stock type) may be more adventurous than others in wading into pingos to graze and browse, but as the water draws down (often in late summer) more of the vegetation becomes accessible, with the potential for greater uniformity in vegetation structures.

Grazing intensities that successfully control scrub within pingo basins, and indeed the surrounding drier land, may well be too intense to support the range of vegetative structures required by priority species. In contrast, too low an intensity would lead to the re-establishment of scrub and trees. This poses a dilemma for site management and certainly practises at Thompson Common have revealed

the difficulties of achieving this balance. Where grazing extensively, it is likely that cattle, ponies and/or sheep can all be used as part of a grazing regime, but that scrub will need to be mechanically removed, at least occasionally.

Management of pingo sites where grazing is the principal management tool needs to be flexible and responsive to how the site itself is responding, to ensure the range of structures is maintained across sites.

Recommendation:

- The appropriate management and restoration of pingo sites should remain a priority for the targeting of funding of Environmental Stewardship, on both SSSIs and County Wildlife Sites. Consideration should be given to notifying as a CWS any significant pingo sites that are currently undesignated, in order to aid this targeting.
- A range of vegetation structures should be maintained around margins and within the water body of pingos. Grazing regimes, and the use of mechanical means, needs to be flexible to achieve this.

The restoration of pingo sites from woodland, especially on a large scale, can be especially challenging because clearance tends to be followed by vigorous re-growth of scrub and tree seedlings. Intensive management (grazing, mechanical and chemical means) may need to be employed for a period, before this can be relaxed to allow the full range of vegetation structures to develop. The restoration of sites from arable land generally does not pose the same challenges, although the distinctive 'hills and holes' relief is usually subdued. Restoring arable sites where some relief is present may be valuable, especially to extend, connect or buffer more intact sites.

There is also clear evidence of the need to retain areas of pingos and wetlands in ungrazed situations. This runs counter perhaps to the desire to establish 'sustainable' grazing regimes, but certainly on smaller, wooded sites, where large-scale restoration is beyond current resources, this may be the only option. Simply clearing pingos, creating glades between them and managing these mechanically maintains ungrazed vegetation structures not present on extensively grazed sites, and without the inherent risks of overgrazing. This approach should not be seen merely as a 'second best' option to grazing, or a step towards it, but as a positive enhancement of a site.

Recommendation:

- Some pingo sites, and units of sites within larger grazed complexes, should be maintained without grazing, or with only very light grazing.
- A strategic review should be conducted to examine the status and management of wetland complexes across Breckland, particularly at fen sites and fluctuating water bodies.

<u>The Fluctuating Meres</u>

Of the five principal meres, all but one is under extensive grazing management. Langmere and Ringmere lie within East Wretham Heath, Fowlmere and Home Mere within STANTA. The Devil's Punchbowl lies outside of any grazing unit and is surrounded by deciduous woodland. Grazing of the meres at East Wretham began within the last decade on the supposition that grazing (by sheep) would reduce the nutrient accumulation from vegetation growing in the basins and help control scrub. Other than a brief period of the 20th Century the meres have always been grazed, by wild animals and by domestic livestock seeking water in an otherwise largely arid part of Breckland.

The relative pros and cons of grazing the meres, pertinent for both the principal meres and the many smaller meres, are largely unknown. The BBA does not distinguish between the wetland assemblages of the pingos and the meres, but key species known to be associated with the meres generally require re-flooding of exposed sediment following periods of draw down and vegetation removal (e.g. by grazing).

Management of River Valleys

Many fewer species were found to be associated with running water habitats, though these did include conservation priority species.

The value of within-channel habitats depends on water quality, maintaining flows and on the complexity of macro and micro habitats, such as weed-beds, riffles, meanders and coarse woody debris. It was beyond the scope of this Audit to collate information on river channel management or habitat quality.

The Brecks Workshop Report (Perkin and Norden 2007) identified a number of strategic challenges and priorities for work in the river valleys and wetlands of Breckland, including the need to:

- Complete the Review of Consents process.
- Implement the Cam and Ely/Ouse Catchment Area Management Schemes (CAMS).
- Ensure that the water requirements of the Thetford Growth Point are sustainable.
- Implement the Water Framework Directive and produce River Basin Management Plans seeking “good ecological status”.
- Ensure the Catchment Sensitive Farming initiative delivers environmental benefits by reducing nutrient, pesticide and sediment run-off.

Recommendation:

- Progress towards the strategic priorities for river valleys and wetlands of Breckland, identified by the Brecks Workshop Report (Perkin and Norden 2007) should be reviewed.

Strategic Challenges to Biodiversity Implementation in Breckland

In this section strategic challenges facing conservation management in Breckland are identified.

Congruence of SSSI designation with priority sites

The Biodiversity Audit is not able to examine whether the designated sites are concurrent with the distribution of priority species, as monitoring and survey has been biased strongly towards designated sites. However, it is likely that important localities exist on farmland and waysides.

SSSIs and Common Standards Monitoring
There are cases where the requirements for measurable targets have produced institutional mechanisms that could potentially damage, rather than assist, the original nature conservation values for which a site may have been designated. Natural England has developed a system of setting conservation objectives and condition monitoring to maintain a focus on appropriate management for the SSSI notified features.
However, it is clear that:

a) The notified features need to properly represent the conservation interest of a site.
b) The conservation objectives need to properly represent the requirements of priority species known or assumed to be present, or capable of being present with changes in management.
c) The system of condition monitoring needs to be adequately tailored to detect change against those revised conservation objectives.

It is likely that early approaches to the notification of SSSIs was carried out with regard to a holistic and integrative sense of the nature value of species assemblages present at sites, with the presence and subjective quality of the habitats present being taken as a proxy for the likely biodiversity they would support. This is apparent in the site descriptions presented in the Nature Conservation Review (Ratcliffe 1977), that underpinned much of the initial prioritisation of sites for notification. Biological criteria for selection of SSSIs were made clearer and explicit with the introduction of the 1981 Wildlife and Countryside Act, with existing sites subsequently re-notified. However, it is likely that notifiable features listed in the criteria sheet that formed part of the notification package often served as a justification for the wider nature value recognised at a site and may have been used implicitly as proxies for a wider suite of important biodiversity that was otherwise difficult to quantify, or where data was lacking at the time of notification.

Of the priority species for Breckland conservation identified by this Audit:

- 208 are flowering plants, of which 140 are RDB.
- 1,636 are invertebrates, of which 287 are RDB.

Of the 55 SSSIs that lie within the Breckland NCA, and excluding two woodland sites, one river and two sites designated primarily for their aggregations of breeding or non-breeding birds, we have analysed the notified features of the remaining 50 SSSI (see Table 4):

- 49 (98%) have been designated for a vascular plant attribute.
  Of these:
    - 44 have plant community as a notified feature.
    - 20 have a plant species assemblage as a notified feature.
    - 9 have named RDB or Schedule 8 plant species as a notified feature.

In stark contrast to their relative importance amongst the biodiversity, only

- 13 (26%) have been designated for an invertebrate feature.
  Of these:
    - 12 have an invertebrate assemblage as a notified feature.
    - 2 have a RDB or schedule 8 invertebrate species as a notified feature.

Plant communities do provide readily recognisable indicators of ecological processes and conditions. If key plant indicator species or features of site condition (e.g. sward height, bare ground) could be readily found during a site visit, an intrinsic assumption may be that protecting the site can also deliver a suite of associated conservation priority species (mostly invertebrates) for which exhaustive survey was not possible or practical, due to constraints of taxonomic expertise, time and cost.

Potential problems arise, however, when the objective of management becomes the delivery of condition criteria based on the narrow presence of the notified features, rather than the delivery of priority biodiversity that implicitly formed the reason for notification in the first place.

For example, a site notified for a plant community may still retain the notified feature in some form, even though the structure and ecological processes have dramatically altered, due to a change in grazing intensity, nutrient supply and the extent of small scale disturbance. Many of the conservation priority species that were the implicit focus of conservation efforts and designation may actually disappear, even though the notified feature is still present.

Within Natural England's Common Standards Monitoring (CSM), the Condition Assessment Criteria for vegetation communities (e.g. CG7, U1 or H1) were drawn up as broad guidelines. Attention was given to ecological and management processes such as disturbance and grazing, with sward height, extent of bare ground or frequency of 'undesirable' species (e.g. ragwort, bracken) as proxies for condition. Advisers are encouraged to revise these broad guidelines in order to develop criteria tables that can be site-specific or at least guided by local or regional priorities. However, due to constraints of time and a lack of any clear and explicit bio-geographic objectives, this has not always happened, even on key sites.

As a result, the condition of at least some key Breckland SSSIs is assessed by criteria that, if then used to guide and determine management objectives, would result in damage to the potential biodiversity interest of the site. These problems are listed in Table 22.

Table 22. Problems arising from poorly refined or inappropriate criteria used in condition assessment of designated sites, and as indicators of success for Environmental Stewardship delivered through Higher Level Stewardship (HLS) lowland heathland and species-rich grassland prescription

NVC	CSM generic condition assessment criteria HLS Indicator of success	Problem	Recommended revision
H1	CSM: minimum 25%% heather HLS: H01 (Maintenance of Lowland Heathland): 25%-95% heather cover.	This condition criteria encourages low grazing intensity (so that annual heather growth increment is not entirely removed), that in turns favours grassy swards and nutrient accumulation and eutrophication.	Allow heather cover to decline below 25%, accepting that the community may consequently be reclassified as a grass-heath community type.
H1	CSM: undisturbed bare ground 1% - 10% HLS: H01 Cover of bare ground 1% - 10%.	Far too conservative. Limited extent of bare ground directly conflicts with the requirements of large numbers of priority Breckland species.	25% - 70% bare ground.
H1	CSM: heavily disturbed bare ground <1%.	Far too conservative. Limited extent of heavily disturbed bare ground directly conflicts with the requirements of numerous Breckland conservation priority species, reduces opportunities for early successional lichen heath, reduces opportunities for heather regeneration.	10-30% heavily disturbed ground.
H1	HLS: SH01 Wide range of age classes of dwarf shrubs present.	Not relevant to Breckland biodiversity. Retention of building and mature stages requires limited grazing intensity, encouraging grassing up and eutrophication.	30-80% of heather present should be in pioneer condition, i.e. indicating recent disturbance.
CG7 / U1	Rabbit grazing and localised bare ground around warrens should be no more than 0.25 ha extent (50m x 50m).	Not scaled with area of management unit! Rabbit disturbed and bare ground is beneficial for key assemblages of priority Breckland biodiversity.	Active rabbit warrens should be present over 15-80% of the site. If not, management to re-establish and enhance rabbit population should be in place, particularly predator control. Alternatively, or as well, physical disturbance should be identified as a management priority.

In a nutshell, it is the assemblages of priority species for Breckland conservation known or assumed to be present that should be the objective of conservation efforts, not the vegetation community in which they are believed to live. Vegetation is a fundamental vehicle for biodiversity delivery, but it is the priority species, including priority plant species, that should be the objective. There has been too much preoccupation with the presence of NVC types as an end point, rather than either their quality or value as an indicator of ecological condition and the potential of a site to support key species.

Both Common Standards Monitoring (condition assessment) and Higher Level Stewardship prescriptions can encourage a static approach to management. This is counter to the known dynamic history of Breckland historic land-use, habitats, vegetation and species assemblages. It is also counter to the management interventions that are required to create suitable conditions for priority assemblages, which cannot be provided by a status quo, attempting to hold conditions static or to arrest succession.

Recommendations:

- Consideration should be given to revisit notification criteria for designated sites, particularly those now known to hold significant invertebrate assemblages. It would be useful to explicitly relate these interest features to the conditions and processes required to sustain them.
- Conservation objectives should be specifically tailored to reflect the requirements of priority species known or assumed to be present, or capable of being present with changes in management, in light of what is now known about the requirements for priority species in Breckland.
- For Common Standards Monitoring, condition assessment criteria for NVC plant communities should be revised, and localised, to reflect the conditions and processes required by key assemblages of priority Breckland species.
- A small percentage of heather, including seedlings and pioneer heather or the appropriate conditions for their regeneration should be considered sufficient qualification of the European feature (i.e. heather heathland, or H1 community of NVC) to be in appropriate condition.

Ground Disturbance Regimes

A further set of institutional challenges arise through the management of uncertainty and change, for example, where the potential outcomes of disturbance treatments are unknown. Objectives and criteria for measuring success need to be rigorous, but flexible enough to allow a range of contrasting results.

Conflicts between conservation and archaeological interests

Potential conflicts between conservation land management and archaeological interests need to be resolved without requiring a separate impact assessment for each operation and site.

Recommendation:

- Natural England and the County Archaeological Services meet to agree generic guidelines that can be used to decide which sub-set of physical disturbance operations require further consultation and where. One example may be to allow rotovation or shallow ploughing on any site on previously arable soils.

Cross-county partnerships

The Norfolk/Suffolk border has long operated as a barrier to effective and coordinated delivery of biodiversity in Breckland. Most organisations and initiatives operate either north or south of the county boundary, including biological recording and monitoring schemes, management advice and practice. In recent years this has begun to change, through increased partnership fostered by the close liaison of the Norfolk and Suffolk Biodiversity Partnerships and through structural changes in NE.

Recommendation:

- Organisations should operate to maintain and enhance cross-border integration and joint working, both within and between organisations, to ensure collaborative working at the landscape scale, to co-ordinate efforts and understanding and to share best practice.
- It is important that both Local County Records Centres continue to liaise and maintain the Breckland Biodiversity Audit database as an updated and live resource, available to managers for strategic planning.

Agri-environment schemes

It is self-evident from the findings of the Audit that the priority species in Breckland are far from confined to the designated sites, both statutory and non-statutory (Figure 26). Indeed, some key ecological processes that support priority species may be most readily achieved within the wider arable landscape. For the guild of species requiring disturbed and ungrazed conditions in particular, the establishment of cultivated margins under the ESA, maintained and extended under Environmental Stewardship, is a key mechanism for supporting this biodiversity in the area. Environmental Stewardship is also likely to be a key mechanism in promoting connectivity on farmland (discussed below) and between designated sites, in order to create more resilient ecological networks.

Recommendation:

- Ensure Natural England continues to target Breckland for agri-environment funding, with an emphasis on options and initiatives which support priority species and create and maintain resilient ecological networks.

Integrated landscape-scale strategies

Rationale

At a national scale, the importance of landscape-scale connectivity to long term biodiversity resilience has been emphasised by the recent Lawton report (Lawton et al. 2010). In a Breckland context, landscape-scale restoration of connectivity can help achieve biodiversity resilience in an economically productive landscape with high aesthetic and recreational value. In this section, approaches to providing connectivity and linkage are discussed, and a local worked example is presented.

However, connectivity should not be the sole guiding principle of integrated landscape planning. The importance of a strategic and unified approach to setting priorities for individual sites is emphasised below.

The potential for dispersal

The history of species records, notably those of rare plants, may indicate the importance of dynamic processes operating on a landscape scale. It is tempting to interpret varying locations of plant records as evidence for shifting population dynamics and dispersal processes in the landscape. However, the scale of movement and the amount of dynamism are uncertain. It is often assumed that species requiring early successional conditions can readily disperse to exploit suitable habitats. However, this is not necessarily true over short time periods. Rather, many species appear to respond to a long term presence of dynamic conditions that provide a continuity of small scale disturbance and regeneration; this could operate at a very small scale within a locality or site. This appears to be true of many dune species. In contrast some ruderal plant species are more mobile, as are some invertebrates. For example, the brush-thighed seed-eater beetle *Harpalus froelichii* has been recorded at moth traps and in locations well away from any breeding habitat, and is therefore, likely to be mobile over distances of at least 100s of metres (Telfer 2009).

An astounding diversity of priority and rare species has been recorded at the Elveden Center Parc site. The area was essentially a highly disturbed building site with extensive bare chalk, sandy banks, pathways and regenerating scrub and young pines. This shows that creating conditions and processes opportunistically can give valuable biodiversity benefits as some species readily arrive, including species of wasp, moth and beetles.

The importance of refugia and local continuity of conditions

Many species are unlikely to be mobile in terms of colonising new locations in the short-term (i.e. years), for example, very small Brachypterous beetles that lack wings and must disperse by crawling. Similarly, although spiders may balloon and disperse by fine threads in the wind, the dynamics of supply and random dispersal mean this may not be effective when source populations are small or restricted to small sites and target habitats are scattered or distant. The same may be true of many plant species that rely on vectors to move them around and colonise new sites. With declines in traditional practices such as extensive stock droving, such species may be considerably less mobile than they used to be. This is a problem when they need to re-colonise sites which, having become temporarily unsuitable, are once again in suitable condition for them.

It is therefore vital to carefully manage and sustain those locations containing high quality conditions for different guilds, and focusing management on what particular sites are important for currently. Managers should consider what conditions have been prevalent at a site in recent years, as this is likely to indicate what species are extant at a site. Although management could seek to add other new elements (e.g. to provide new areas of bare or disturbed ground, or diversify sward structure) it is wise to retain a large element of existing micro-habitats or structures for those species currently present and supported, particularly emphasising those habitats and structures that are likely to be valuable to any priority species assemblages. For example, Weeting Heath has a long history of management by rabbit grazing and supports an important assemblage of invertebrates characteristic of physically disturbed sand and intensive grazing, including coastal species. Management at Weeting could diversify sward structures, add nectar elements and ungrazed margins, but this should not be at the expense of maintaining a large extent of closely grazed and physically disturbed conditions. This could be by encouraging rabbit populations and supplementing this with mechanical disturbance where appropriate.

A strategic and integrated approach to local and site priorities

It is not appropriate to attempt to provide for every assemblage within every site.
Sites should no longer be considered in isolation, but management priorities should be considered strategically integrating across multiple sites in the landscape.

A strategic and integrated approach should be taken, that considers suites of sites across the landscape, and considers the resource within the region without the distraction of the County, district or other artificial boundaries. Strategically explicit and planned approaches are required to produce an optimised and coherent assemblage of sites each with a different emphasis. Key sites, localities and regions for different processes and assemblages should be identified, and this should guide management priorities for restoration and enhancement at a strategic scale, synthesising and analysing across sites. Without this approach, differences in individual or institutional objectives for sites will be unlikely to result in a coherent and focussed regional strategy.

Spatial targeting can be guided by an understanding of the historic and recent past distribution of certain conditions and processes. For example, the mobile dune and windblown sand resource that is now virtually lost from Breckland was most recently active in the Icklingham plains area (e.g. Avenue Farm Breck) and at Wangford Warren, and less recently at Foxhole Heath (Figure 25). Initiatives to rejuvenate areas of windblown sand, or at least locally disturbed sand in these areas might benefit relict populations of invertebrates dependent on these conditions. For example, the beetle *Broscus cephalotes* that requires wind-blown sand as it burrows into the ground, preying on small crustaceans and the sulphur beetle *Cteniopus sulphureus*, a coastal specialist which requires wind blown sand and flower rich areas, particularly plants in the carrot family, Umbelliferae.

Local and site priorities can also be strategically guided by the mapped hotspots for assemblages, targeting management according to the parts of the landscape that are important for particular guilds. Maps of assemblage distribution should not be interpreted too literally due to the known limitations of survey effort and incomplete coverage – both spatially and taxonomically. Rather, maps should be interpreted intelligently. For example, a high value for specialist moths at accessible locations such as forest gate-ways, can be taken to indicate high value of moths across the adjoining forest landscape - including areas lacking records on current maps. A high value for specialist beetle fauna associated with cultivated arable margins at Gallows Hill, Thetford, can be extrapolated only by

considering the distribution of similar calcareous soil and freely draining slopes, and even then remains uncertain given the variation in soil, management history and local site conditions. Validation and survey would be highly desirable and an ideal, but implementing appropriate measures on best evidence should not be delayed.

Networks for resilience

The remaining high-quality wildlife habitat in Breckland is fragmented (see Figure 33). Species are isolated in small sites and the landscape is hostile to species dispersal between such sites.

The Lawton Report "Making Space for Nature" (Lawton et al. 2010) has emphasised the importance of networks and connectivity for biodiversity. Regional Ecological Networks projects have been implemented in both Suffolk and Norfolk, and the Brecks Workshop (Perkin and Norden 2007) called for a detailed ecological network to be planned for the Breckland.

The benefits of ecological networks are unproven, but different approaches (corridors, stepping stones, increased permeability) are all likely to be bring some benefits to some groups.

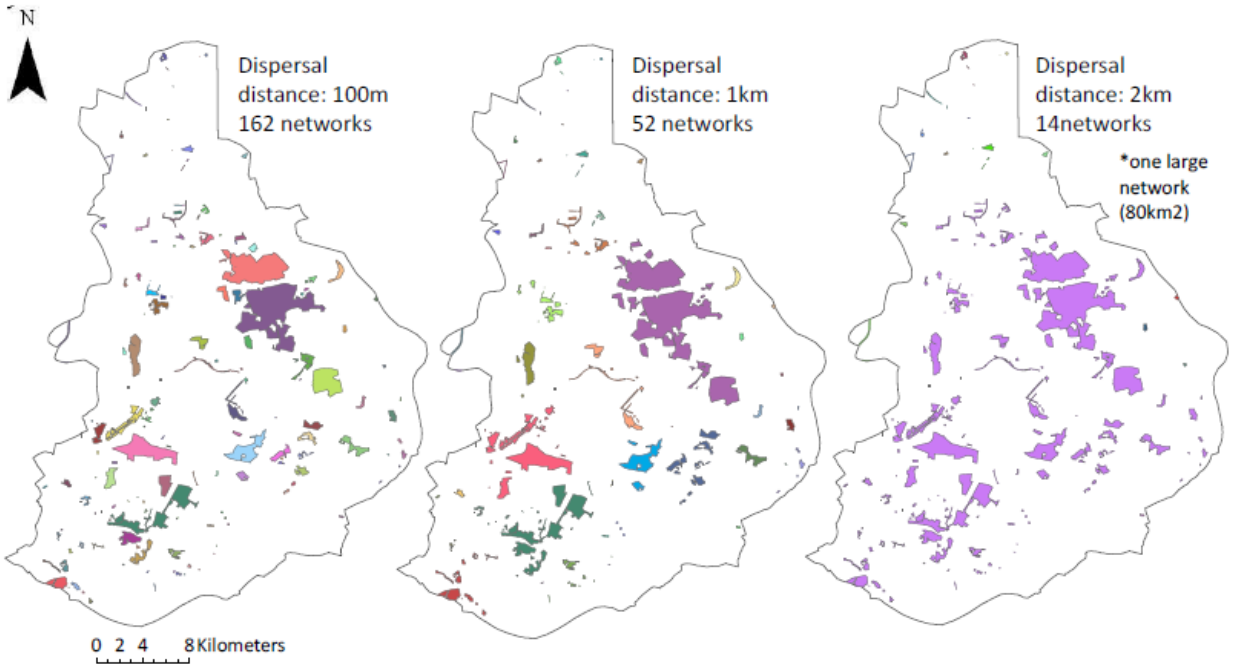


Figure 33. Network analysis of the 87.1km^2 of dry grass-heaths resource across Breckland, showing potential networks for hypothetical taxa with differing dispersal abilities (100m meters, giving 162 networks each isolated from the next; 1km giving 52 networks, and 2km giving a single connected network). From Hardman (2010).

Creating networks for resilience

To reduce biodiversity losses from existing sites and to allow restoration and resilience of populations for the longer term, opportunities should be taken to

- **Restore and ensure continuity of appropriate conditions within remaining sites.**
- **Consolidate adjacent sites into larger contiguous integrated units** for management across land-ownership boundaries. This will increase the potential size and resilience of species populations, particularly of highly specialist species.
- **Buffer and expand existing sites**, where possible, so that conditions and populations are more likely to be sustained within them. Buffering of some heathland sites has been achieved, for example at Weeting and Cranwich and this approach should be extended where possible.
- **Develop connectivity networks** to enhance the resilience of sites and of the biodiversity they protect and to provide opportunities for dispersal and recolonisation.

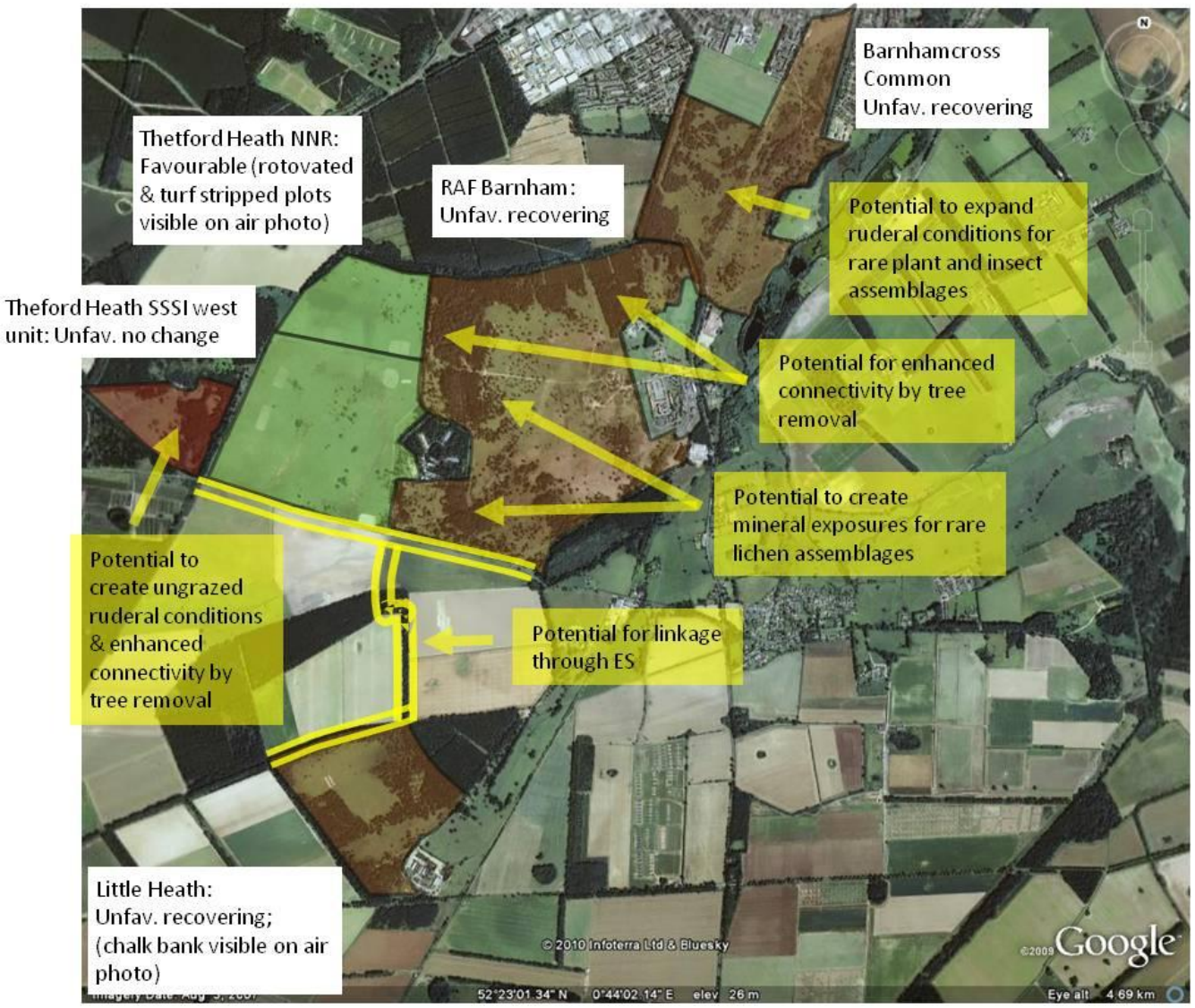
This needs a coordinated and integrated strategic approach to conservation planning across sites, rather than just within. It is the latter, intra-site scale which currently dominates conservation activity.

Suggestions are made below on re-uniting fragments that are either immediately adjacent, or located nearby, and that could potentially be joined into larger contiguous complex units.

Example of a potential network

Thetford Heath once covered a wide sweep of landscape to the west, south-west and south of Thetford. It is now reduced in extent to Thetford Heaths SSSI, which exists as three potentially contiguous units that are under separate ownership and are currently fragmented and isolated by intervening woodland belts (see next page). The units include the unfavourable western unit 1 (condition unfavourable no change), the core NNR (the only part currently in favourable condition), and the Eastern unit 3 (Barnham MOD camp in unfavourable recovering condition). By removal of parts of the screening woodlands, there is potential to integrate these into a single suite of contiguous habitat, physically continuous with Barnham Cross Common SSSI (also unfavourable recovering). Taking advantage of the hard barriers and lack of single grazing regime, areas of ungrazed physically disturbed habitat could be created as linking elements along boundaries. The need to retain screening for breeding stone curlew will impose constraints on some boundaries, but it appears that current approaches to management of these sites are considered in isolation and without integration.

Potential connectivity networks



Consolidation of contiguous units and enhanced connectivity can only be achieved by a strategic over-view of sites at a landscape-scale.

Thetford Heath once covered a vast area to the west, south-west and south of Thetford. The few remaining fragments are managed in isolation even though some are physically contiguous. A strategic approach could provide a range of grazed disturbed conditions, ungrazed ruderal disturbed conditions, chalk and mineral exposures, and landscape scale contiguity and connectivity to sustain and recover rare invertebrate, vascular plant and lichen assemblages.

More ambitious possibilities that could be explored include the potential to provide unite and link Eriswell Low Warren SSSI through to Foxhole Heath SSSI. With goodwill and appropriate agri-environment agreements it may also be possible to link these to Codson Hill via existing arable reversion sites.

At a larger scale, there is potential to provide corridors to connect more widely dispersed and separated units. It is important that any corridor or dispersal network provides suitable habitat for reproduction and sustaining populations within the corridor, so that over longer time periods gradual percolation may allow population spread among remnant sites. A simplistic approach that merely aims to create some kind of grassland between sites is unlikely to reflect the complexity of ecological processes required for the mobility and interchange of priority species.

To create connectivity networks among sites, instead of focusing on creating linear strips of grass-heath habitat, strategic planning should focus on:

- Buffering existing track-ways and track verges with cultivated margins and agri-environment agreements in the arable landscape, to provide complexes of juxtaposed habitats in long bands (Figure 35).
- On creating broad ruderal and disturbed highways for invertebrate and plant dispersal (by percolation) through the forest landscape.

In the forest landscape, fire-routes and ride (track-way) verges already provide a widely dispersed network. Work by the Conservation Ecology Research Group at the University of East Anglia shows this can support considerable diversity of specialist heathland carabids and spiders including nationally notable and scarce species (Lin 2005; Bertoncelj 2010; Pedley unpublished data). However this network is spatially interrupted and incomplete due to shading of track elements when adjacent tree crops pass thicket stage. We therefore recommend focusing on creating wide permanently un-shaded invertebrate superhighways, flanked by disturbed strips of ground (e.g. with ploughing or turf stripping treatments to create bare disturbed sand and chalk). This could provide suitable conditions for resident populations that could slowly percolate providing connectivity:

- Within the forest landscape (linking existing open areas, providing enhanced dispersal into clear-felled and restocked areas)
- Across the forest landscape (potentially linking key heathland SSSIs, for example linking Weeting Heath to Cranwich and Grimes Graves (Figure 34); Lakenheath Warren to Wangford Warren; Lakenheath Warren to Thetford Golf Course and Marshes via High Lodge; and linking West Stow and Ramparts Field to Berners Heath).

All corridors will inevitably be opportunistic, but should be planned in relation to soil types, with preference to the extremes of the chalkiest, most sandy and acid soil types.

Ultimately an ideal would be to overlay the connectivity networks with patterns of revitalised stock movements to encourage dispersal of plants and seeds, but some dispersal of seeds and movement of invertebrates can nevertheless occur without this.

Recommendations:

- Opportunities should be taken to strategically buffer and link existing SSSI units into large contiguous networks wherever possible, allowing integrated grazing management and enhanced populations of specialist assemblages.

- Connectivity among dispersed sites could be achieved by providing juxtaposition of grass strips, disturbed ground, and cultivated field margins along existing track-ways.
- Connectivity both within and across the forest landscape may be achieved by creating wide, physically disturbed ‘invertebrate super-highways’, that would provide opportunities for spatially continuous un-shaded conditions, population percolation and flanked by nectar rich ungrazed flower rich verges.
- Connectivity elements may be provided by revitalising stock droving activity to provide cross links with these ‘super-highways’.

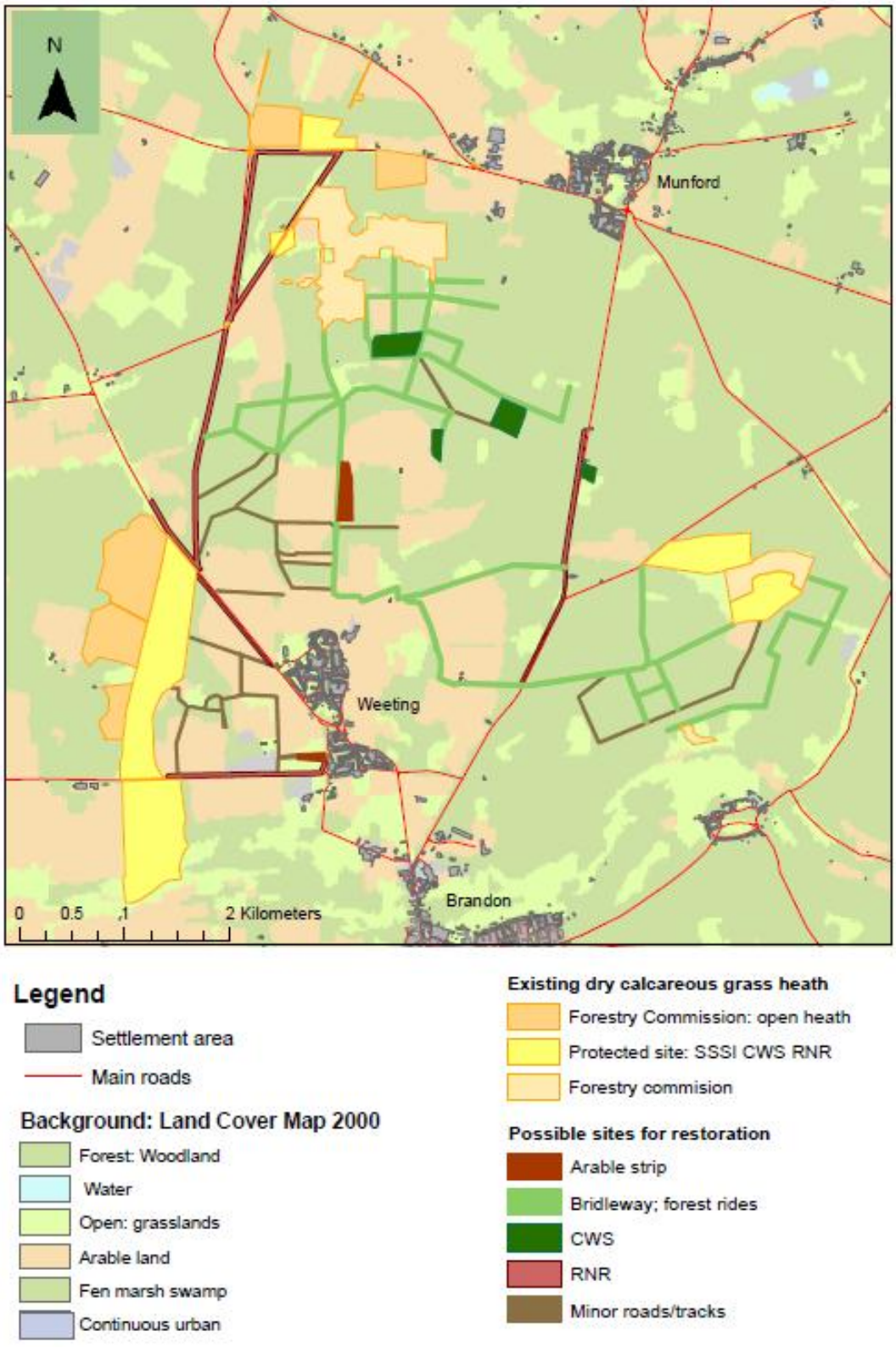
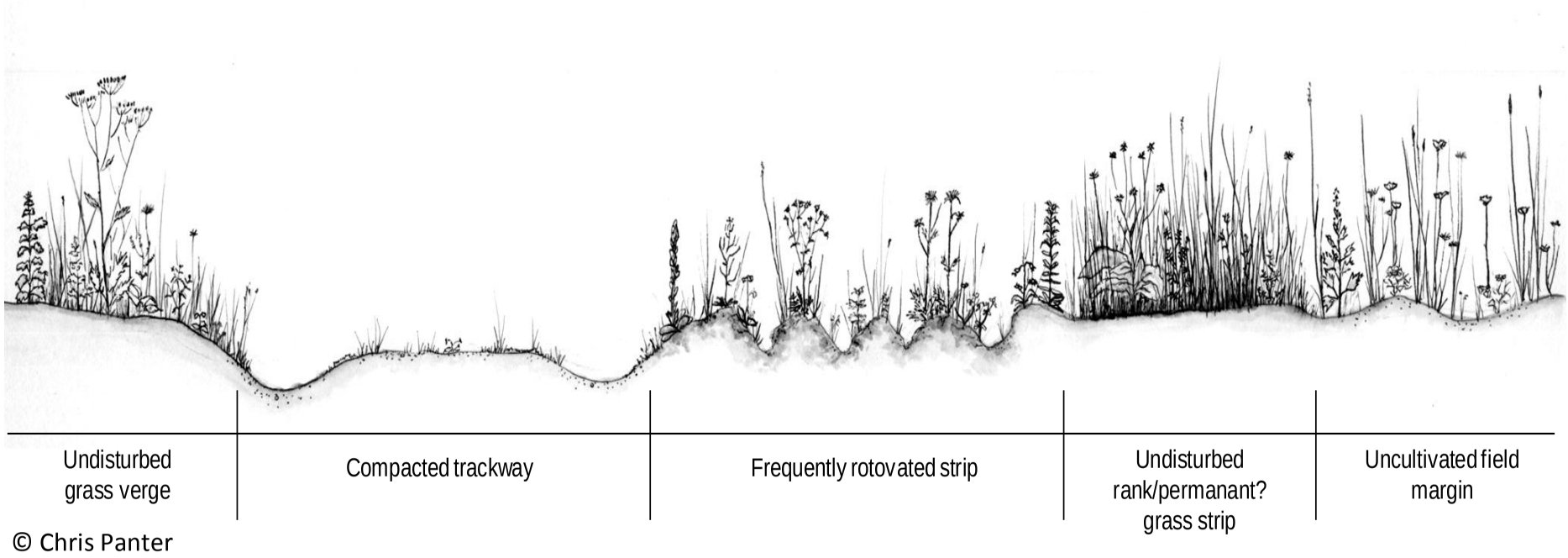


Figure 34. Example of a potential connectivity network, incorporating track-ways and field margins in the arable landscape, and forestry track-ways, to link remnant and restored grass heath sites at Weeting, Cranwich and Grimes Graves. From Hardman (2010)

Figure 35. Schematic figure suggesting how how to achieve sward mosaics and juxtapositions of structure



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Connectivity networks

Creation of wide 'invertebrate super-highways' based on existing track-way networks has potential to provide connectivity both within, and across, the forest landscape. Corridors should be wide enough to escape shading when adjacent crops are mature, and should provide a continuity of bare sand or soil, disturbed margins and early successional vegetation.

Recommendations

Historical land use

- Further investigation of the long term patterns of land-use between heath and arable, linking land-use archaeology and ecology, will benefit understanding of habitat and species requirements.
- Relating the current and recent past distribution of speciality Breckland vascular plants to historical land-use will provide insights to past ecology.

Coverage of species records

- BTO be commissioned to analyse Atlas data, BBS data and other survey coverage from Breckland, in relation to East Anglia and lowland England, to identify which species have regionally or nationally important populations.
- Encourage further survey and recording effort of under-represented groups, particularly true bugs (hemiptera), flies (diptera) and non-carabid coleopteran (beetles), and regionally important under-recorded groups such as freshwater aquatic invertebrates and spiders.
- Consider ways to aid digitisation of historic records.
- Encourage recording of multiple taxa in under-recorded areas, particularly within the Breckland Forest and Farmland SSSIs.
- Further investigation is needed to understand the distributions of coastal Breckland specialists and to fully quantify the number of species that have their only inland population in Breckland.
- Work is needed to understand the importance of inland populations and the potential as refuges of primarily coastal species. This may be increasingly important in context of sea level rise and threats to coastal habitats.
- Further investigate the UK distribution of Breckland specialists without conservation statuses. Encourage further recording of these species.
- Survey work should be encouraged or commissioned to improve understanding of the status abundance and distribution of those species considered to be Extinct in the UK according to the Natural England Lost Life report, but for which the Audit has collated recent records.
- Surveillance and monitoring of created chalk exposures should be repeated intermittently to examine whether rare terricolous lichen species re-colonise by long-distance spore transport.

Threats: Climate change and nutrient deposition

- Ground water scenarios should be explored by models that combine temperature and precipitation in equations for potential evapo-transpiration.
- Attempt to mitigate increased vegetation productivity from milder and wetter winters by greater use of soil disturbance transpiration and adjustments in grazing regimes to remove excess biomass.
- Nitrogen deposition is a significant pressure for Breckland grass-heath eco-systems. Management tools to mitigate nitrogen accumulation impacts are imperfectly understood, but the use of soil disturbance, turf stripping and encouraging high density rabbit populations are possible approaches.
- Soil nutrient properties of annually rotovated plots should be assessed, in comparison with adjacent untreated control areas of similar basic soil type. Managers should examine results

and consider whether these repeatedly rotovated plots should be continued further, or left to fallow and develop oligotrophic grass-heath while beginning soil disturbance management on new plots.

- The relative effects of ploughing, rotovating and turf stripping on soil nutrient properties should be investigated, across a range of soil types differing in pH and organic content. This could first be explored by systematic review of available studies, but if insufficient information is available, it will be necessary to undertake experimental research and monitor soil and leachate in replicated experimental trials.
- Current research commissioned by Natural England aimed at examining whether intensive livestock and poultry units have had or are having localised impacts on nearby grass-heath sites is not sufficient in design or sensitivity to show whether there is an effect. Further research is required, but this should include direct measurements of nitrogen deposition rates as well as vegetation dynamics in both existing and experimentally manipulated swards (i.e. with manipulated *Festuca-Deschampsia* composition on mineral and organic soils).

Concerns and uncertainties regarding the condition of remaining grass-heaths

- Available quantitative data for vegetation species composition at known sites could be collated and analysed to examine trends in species composition.
- A field based survey and audit of the acidic grass-heath could be conducted to examine the extent and successional status of the remaining resource, in order to guide priorities for management.
- The relative extent of lichen rich and ephemeral / therophyte rich NVC sub-communities compared to grass and herb-rich NVC sub-communities (including mesic vegetation with *Holcus*, *Anthoxanthum* and *Trisetum*), compared to *Deschampsia* dominated sub-communities be assessed across a suite of Breckland grass-heaths, considering both the acidiphilous and calcareous resource. This may be possible using data held by Natural England, or may require commissioning of field based survey.
- Spatial analysis should be conducted to examine whether, within species-rich assemblages, sites known to support one or more of the BAP representatives for the guild are also the sites that are overall richest in the guild. If so, targeting management resource at sites known to hold BAP species will be an effective strategy for conserving the overall guild. If not, then it may be better to target guild-based prescriptions at sites known to support guild members.

Conservation value of cultivated arable

- There is an urgent need to conduct extensive survey work, examining a wider range of invertebrate taxonomic groups, in order to improve understanding of the conservation value of cultivated arable margins and other elements of the (poorly known) farmland landscape.
- Work should seek to improve understanding of how species and assemblage responses differ in relation to: soil type, aspect, exposure, crop rotation, boundary features (e.g. grass banks, hedges, shelter belts) and geographical location within Breckland, and what are their management needs (e.g. cultivation frequency, timing and type.
- Research should be conducted to evaluate and compare the relative value of cultivated margins within the arable landscape with the potential to recreate intermittently cultivated ruderal fallows (brecks) from unmodified (unfertilised) soils and intact seedbanks in the Thetford Forest landscape. Research should focus on scarce arable and ruderal plant assemblages and their associated invertebrate assemblages (e.g. beetles particularly carabids,

and staphylinids but also other groups of Coleoptera, as well as Hemiptera, Lepidoptera and Hymenoptera)

- Work should investigate whether cultivation every 2-3-4 years is preferable to some invertebrate and plant species, compared to annual cultivation.
- Examine the relative merits of different cultivation types and timings, together with different herbicide regimes, to manage for priority species of plants and invertebrates on Breckland cultivated margins. Work should include long established non-rotational margins (established under the ESA), together with newer rotational and non-rotational margins
- Review the success and apparent value of current ESA field margin agreements and where these appear to have provided benefits make every effort to secure transition to ES. In view of uncertainty over the response of invertebrates to habitats, the presumption should be that any open vegetation with a diversity of annual plants is beneficial.
- ES advisers should recognise the benefits of cultivated margin prescriptions that should be seen as the key mechanism for biodiversity delivery in Breckland farmland.
- Implement ES cultivated margin agreements as predominately non- rotational.
- Research should be conducted to examine whether annual cultivation of arable margins (e.g. as in cultivated margin prescriptions) or other ruderal habitats (e.g. recreated brecks within Forestry Landscape) gives similar outcomes to prescriptions or management with low density unsprayed spring cereal crop. Effects should be studied on the plant and invertebrate species populations and assemblages sustained and the seed bank densities achieved.
- Examine the feasibility of applying large-scale cultivation treatments to the ageing grass-heath resource in STANTA, with the aim of rejuvenating brecks that have not been cultivated for 68+ years.

Management of the heaths

- Juxtaposition of cultivated margins alongside grass strips, either already in place in permanent grassland, hedge-banks, along pine lines and track-ways, or created through ES options, could bring enhanced benefits.
- Graze hard.
- Grazing should not be constrained by the presence of heather
- The overwhelming importance of physical disturbance to very large numbers of Breckland conservation priority species must be recognised and acted upon if this biodiversity is to thrive.
- Survey and monitoring be urgently undertaken at as many mechanically disturbed plots as possible, to cover key invertebrate groups as well as vascular plants. This will provide evidence to guide and inform future management.
- Ensure database of disturbance plots is kept up to date
- Work should examine whether the nutrient status of sandy soils unmodified by agricultural inputs, results in more open vegetation and slower closure, allowing longer intervals between repeat cultivations.
- Research work should be conducted to examine whether populations of rare vascular plants restricted (or largely restricted) to Breckland can be sustainably managed by a regime of intermittent cultivation on soils of suitably low nutrient status. Ideally, a range of cultivation frequency and fallow periods should be examined, across a range of soil types, focusing on the most calcareous sands and most acidic low nutrient status soils. The response of these populations in cultivated situations with and without sowing of cereal crops should be examined.

- Ensure that scrub removal, ploughing, turf removal, and creation of steep open exposures within pits is carried out at key sites of former gravel working on Maidscross Hill.
- The status and condition of remaining conservation resource at Red Lodge be examined, and required action be taken to ensure continuing conditions for the valuable species of disturbed ground.

Wetland management

- Requirements of wetland species are less well understood and frequently more complex, with more ecological processes and habitat variables to be considered. Improvements are needed in the knowledge of the species and in the assessment of guilds.
- The relative importance of wetland assemblages that occur in different landscape elements should be investigated, e.g. associations with pingo systems, calcareous flushed valley-head mires, fen remnants along river valley margins, fens at the Breckland/Fen margin.
- Resources permitting, the majority of each significant fen, wetland, pingo and mere site should be predominantly cleared of woody vegetation, while retaining some wet woodland resource. The ratio of RDB species between the open and shaded habitats suggests that perhaps a maximum of 10% - 20% of a site should be wooded.
- The appropriate management and restoration of pingo sites should remain a priority for the targeting of funding of Environmental Stewardship, on both SSSIs and County Wildlife Sites. Consideration should be given to notifying as CWS any significant pingo sites that are currently undesignated in order to aid this targeting.
- A range of vegetation structures should be maintained around margins and within the water body of pingos. Grazing regimes, and the use of mechanical means, need to be flexible to achieve this.
- Some pingo sites, and units of sites within larger grazed complexes, should be maintained without grazing, or with only very light grazing.
- A strategic review should be conducted to examine the status and management of wetland complexes across Breckland, particularly at fen sites and fluctuating water bodies.
- Progress towards the strategic priorities for river valleys and wetlands of Breckland, identified by the Brecks Workshop Report (Perkin and Norden 2007) should be reviewed.

SSSI condition assessment mechanisms

- Consideration should be given to revisit notification criteria for designated sites, particularly those now known to hold significant invertebrate assemblages. It would be useful to explicitly relate these interest features to the conditions and processes required to sustain them.
- Conservation objectives should be specifically tailored to reflect the requirements of priority species known or assumed to be present, or capable of being present with changes in management, in light of what is now known about the requirements for priority species in Breckland.
- For Common Standards Monitoring, condition assessment criteria for NVC plant communities should be revised, and localised, to reflect the conditions and processes required by key assemblages of priority Breckland species.
- A small percentage of heather, including seedlings and pioneer heather or the appropriate conditions for their regeneration should be considered sufficient qualification of the European feature (i.e. heather heathland, or H1 community of NVC) to be in appropriate condition.

Strategic planning and creation of networks

- The Biodiversity Audit Commissioning Group should continue to coordinate an integrated approach to biodiversity delivery.
- Organisations should operate to maintain and enhance cross-border integration and joint working, both within and between organisations, to ensure collaborative working at the landscape scale, to co-ordinate efforts and understanding and to share best practice.
- It is important that both Local County Records Centres continue to liaise and maintain the Breckland Biodiversity Audit database as an updated and live resource, available to managers for strategic planning.
- Ensure Natural England continues to target Breckland for agri-environment funding, with an emphasis on options and initiatives which support priority species and create and maintain resilient ecological networks.
- Opportunities should be taken to strategically buffer and link existing SSSI units into large contiguous networks wherever possible, allowing integrated grazing management and enhanced populations of specialist assemblages.
- Connectivity among dispersed sites could be achieved by providing juxtaposition of grass strips, disturbed ground, and cultivated field margins along existing track-ways.
- Connectivity both within and across the forest landscape may be achieved by creating wide, physically disturbed ‘invertebrate super-highways’, that would provide opportunities for spatially continuous un-shaded conditions, population percolation and flanked by nectar rich ungrazed flower rich verges.
- Connectivity elements may be provided by revitalising stock droving activity to provide cross links with these ‘super-highways’.

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