The Norfolk 'Pingo' Mapping Project

2007 – 2008

Pingo at NWT Thompson Common, Norfolk *Photo: Rob Yaxley*

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Contents

SUMMARY

Background
Much of Norfolk is characterised by the presence of pits and depressions, many of which are of unexplained origin. Research has shown that, while many may be man-made, some depressions date to the last (Devensian) ice age, and were created by freezing ground-ice in periglacial conditions. Periglacial landforms are believed to occur in various parts of Norfolk, most typically in West Norfolk and Breckland, but with some sites also located in central Norfolk and to the north of Norwich. They usually occur where underlying chalk bedrock is close to the surface, mantled by shallow deposits. These depressions, particularly where water-filled, are commonly referred to as 'pingos', although this term has a specific geological meaning and may not be appropriate in many cases. A range of landform types can result from groundwater freezing in different ways and in different conditions, although the fossil remains of these features may appear superficially similar. In certain circumstances, there may also be striking similarities between depressions which are the result of natural processes, and those which are man-made.

Site importance
While only one or two sites in Norfolk have been the subject of detailed geological investigation, many are known to support a range of important wetland habitats, in particular fen communities which are similar to valley and basin mires. Several are of national importance because of their botanical and faunal interest, often supporting unusually high numbers of nationally rare and scarce species. A few have been notified as SSSIs, while a significant number are designated as County Wildlife Sites (CWS). The potential geological interest at all but a minority of sites has, however, usually gone unrecognised. Furthermore, other, previously unidentified sites within the county are believed to exist.

'Pingo' mapping project
To fill some of these information gaps, the 'pingo' mapping project was set up in 2007 to try to identify and map, for the first time, the distribution of possible ground-ice landforms in Norfolk, and to create a database of sites. This was done using a range of tools, including aerial survey, CWS and SSSI records, and Ordnance Survey (OS) and British Geological Survey (BGS) maps. The expertise of various individuals with an intimate knowledge of Norfolk provided an excellent source of information.

Results
In all, 215 sites were identified and mapped. Of these, over half were in Breckland (58%), nearly one quarter (23%) in West Norfolk and the balance in North Norfolk and Broadland. Nearly one half of sites were within woodland, while approximately one quarter were within a grassland context.

Site condition
One third of all the sites were visited, and their overall condition assessed. The results of the walk-over assessment were fed into the database, and these data were linked to the digital map. Condition assessments showed that one third of sites were in favourable condition, the majority (72%) of which were either CWS or SSSI. A similar proportion were in decline, while a marginally smaller number (27%) were considered unfavourable. The majority of sites within conifer plantations that were visited were considered in unfavourable condition, compared with about one fifth in grassland, and just over one tenth in habitat mosaics.

Threats
The major threat at visited sites was scrub encroachment, affecting about one third of sites. Inappropriate grazing and other forms of inappropriate management were the main threat at a similar number, while cultivation was considered a potential threat at one fifth of the visited sites.

Two thirds of the sites visited were being managed privately, fewer than one fifth by government agencies such as Natural England, the Ministry of Defence or the Forestry Commission, and just over one tenth by conservation organisations.

Further work
Follow-up action has been recommended for 84% of sites, which have been allocated a priority rating based on a range of factors including site quality, site condition, and proximity to other key sites.

1. PERIGLACIAL GROUND-ICE DEPRESSIONS IN NORFOLK

1.1 Introduction

Many parts of Norfolk are characterised by the presence of pits, hollows and depressions. These vary greatly, in size, depth, hydrology and distribution, and may occur in clusters, in isolation, or sometimes spaced quite systematically eg one per field. Hollows include both man-made and natural features, and their origins are often obscure.

Examples of man-made hollows are to be found throughout the county and typically include pits dug to produce marl (used to improve soils); minerals, including flint, lime, sand, gravel and brickearth; and to provide watering holes for livestock. Such excavations vary in age and size, but their inclusion on old estate and Ordnance Survey (OS) maps means that it is often possible to estimate, approximately, their date of origin (Prince, 1962). This is especially true of marlpits, which were being widely dug across the county, particularly in the eighteenth and nineteenth centuries, to produce soil manures to improve crop yields. Although, in its true sense, marl refers to calcareous clay, Prince noted that at least eleven kinds of 'marl' were used to improve different soil types, and marlpits are consequently found all over Norfolk, not just in areas of boulder clay. Many are still highly visible.

Some apparently man-made hollows might have started life as natural depressions. For example, marl pits were frequently dug in chalk, and there is evidence that pits were sometimes excavated in areas already displaying evidence of shallow hollows, or in 'pitted' surfaces (Prince, 1962). The need for standing water in the tannery and hemp retting processes might have led to modification (by dredging) of shallow ponds of potentially natural origin (Bradshaw *et al,* 1981). In addition, many naturally-occurring hollows have been enlarged more recently to create ponds and lakes, for example at Caston Common, Breckland. The origins of heavily modified features may be especially difficult to identify.

It is widely believed, however, that many depressions and hollows that occur in Norfolk are the result of natural processes which occurred at the end of the last glaciation when temperatures were very low. For example, analysis of pollen profiles found in organic sediments in some depressions in West Norfolk (Sparks, Williams and Bell, 1972) has dated them to the last (Devensian) ice age, suggesting that they originated in periglacial conditions, when the expansion of freezing groundwater heaved the ground's surface into ice-cored mounds. When warmer conditions finally returned and the ground ice melted, distinctive landforms, often in the form of circular, water-filled depressions, sometimes with raised ramparts around the rims, were often left behind. Many of these features are still visible today.

Occurring in clusters, sometimes at a density of one hundred per square kilometre, these landforms are widely referred to as "pingos". The term 'pingo' is of Inuit origin and means 'small hill'. It actually describes a very specific landform type, which formed in certain contexts and conditions. Therefore, while many of the relict periglacial features in Norfolk probably are pingo 'scars', or 'fossil' pingos, the term may not accurately describe the full range of periglacial hollows which occur in the county. For this reason, the generic phrase 'ground ice depressions' is used in preference.

In Norfolk, ground ice depressions are typically found in the eastern margins of the Fens and the Breckland valleys, and are characteristic features at sites such as Thompson Common (pictured right), East Walton and Adcock's Common and Foulden Common.

Fig 1: Aerial view of NWT Thompson Common SSSI showing swarms of ground ice depressions, in this case, pingos

Photo: Mike Page

Other sites with similar landforms occur in north, west and central Norfolk; and a few are located to the north of Norwich. Few, if any, of these other sites have been investigated in detail, but similarities in form and landscape context suggest a parallel origin with better-known sites.

Regardless of the processes which formed them, many of these sites support a range of important wetland habitats, in particular fen communities which are similar to valley and basin mires (Wheeler, 1992). Several are considered to be of outstanding national importance because of their assumed geological and obvious biological interest (Lambley, 2005) and have been designated as SSSIs.

Fig 2: A pingo at a site near Foulden Common SSSI, showing characteristic stands of Carex elata
Photo: Robin Stevenson

Others have been notified as County Wildlife Sites (CWS) on the basis of their botanical interest but, in about 90% of cases, their potential geological interest has not previously been recognised. It is likely that other sites in Norfolk have still to be 'discovered' and these may be particularly vulnerable to unsympathetic management, neglect or destruction.

1.2 Rationale and Aims of the 'Pingo' Mapping Project

Although similar landforms occur in Wales, East Anglia and the Thames Basin, and as far north as Cumbria and the Isle of Man (Ballantyne and Harris, 1994), they are relatively rare on a national scale.

Such sites are important for a number of reasons:

a) Fossil landforms associated with particular types of ground ice can provide important evidence for the former extent of perennially frozen ground (Ballantyne and Harris, 1994), so accurate maps showing their distribution are a valuable tool.

b) The Quaternary fossil record in Norfolk can be traced almost continuously to about 1.75 million years ago. In parts of East Anglia, it goes back even further, giving the longest such record in Britain (Birks, 1976; Jones and Keen, 1993). Interpretation of the fossil fragments of plant and animal remains provide vital clues to past environmental and palaeoclimatic conditions, so fossilized remains buried in the organic infill in ponds of periglacial origin can help to build up a picture of periglacial processes. Pollen analysis of organic sediments can be used to determine the upper age limit of the underlying basin, and to reconstruct climatic and seasonal temperature variations, including freeze-thaw episodes (French, 2007). Because some invertebrate populations, particularly beetles and molluscs, have relatively precise habitat tolerances, and respond rapidly to climatic change through migration and dispersal, fossil assemblages can also provide a valuable insight into environmental changes over a given period (Ballantyne and Harris, 1994; French, 2007; Bell and Walker, 1992; Birks, 1976).

c) Sites with relict ground ice depressions frequently also support an important fen vegetation. Fens have declined significantly in the last century, both nationally and across Europe, and are now a UK Priority Biodiversity Action Plan (BAP)[1] habitat. Norfolk is considered to have some of the best fen sites in England, and a number of pingo sites within the county form part of a larger suite of SSSIs and CWS which are notified for the quality of their fen vegetation. Long term damage to fens may be

[1] **UK Fens Biodiversity Action Plan.See http://www.ukbap.org.uk/UKPlans.aspx?ID=18**

caused by a number of factors such as a lack of management, which allows scrub and woodland to develop; inappropriate management, such as drainage and cultivation; water abstraction; and nutrient enrichment, usually through pollution and agricultural run-off. These factors can lead to changes in hydrology, vegetation composition and loss of species.

d) The wetland habitats associated with ground ice depressions may also support a valuable fauna. Sites in Norfolk and elsewhere have been found to contain unusually high populations of nationally scarce and Red Data Book (RDB)[2] invertebrate species (Foster, 1993); while the rich mosaic of terrestrial and aquatic habitats, including pond clusters, is of particular value for amphibians such as Great crested newt *Triturus cristatus.* In addition, the pool frog *Rana lessonae,* now widely believed to be a native relict glacial species (Beebee *et al,* 2005), appears to have a historical association with such sites in eastern England.

Despite the obvious biodiversity and geological value of these sites, until now no detailed, county-wide map showing the overall distribution of sites with ground-ice depressions has been compiled, although a few of the SSSI sites have been mapped in detail and are very well- documented. Furthermore, no overall assessment of site condition and status has been undertaken.

Identifying and restoring sites which support a particularly diverse fen flora and which are at risk of damage through neglect, inappropriate management or development is a key part of the Norfolk Fen BAP[3]. In addition, Government planning policy set out in Planning Policy Statement 9 (Biodiversity and Geological Conservation)[4] specifies that biodiversity and geological conservation must form an integral part of the planning process, and be properly taken into account in preparing local development documents.

To address some of these issues, and as a follow-up to the Norfolk Fen Assessment Project[5] carried out in 2005/6, the 'pingo mapping project' was established in 2007 to:

- map the locations of sites with depressions potentially formed by ground ice
- assess the overall condition of as many as possible, and identify those at particular or immediate risk from damaging activities or succession
- produce a list of sites that would benefit from restoration
- identify previously unknown sites, for future survey/designation as CWS where appropriate
- ensure that appropriate protective measures and conservation strategies are put in place for relevant sites by making the resulting work available to relevant organisations
- identify potentially important sites for great crested newt and other important fauna
- potentially provide a basis for further research into the origins of these features.

1.3 Limitations and Constraints

No attempt has been made during this project to identify or describe in geological terms the features which have been included on the database. The work has focussed on identifying and mapping areas in Norfolk which appear, at least superficially, to contain relict features or landforms of potentially periglacial origin. The resulting inventory of sites can be used as a basis for further investigation by specialists and may help to inform local conservation and planning decisions.

1.4 Project Partners

The project was undertaken by Norfolk Wildlife Trust on behalf of the Wetland BAP Topic Group, and was funded by the Norfolk Biodiversity Partnership, Breckland Council and Natural England.

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2 Red Data Book See http://www.jncc.gov.uk/page-2133

3 Norfolk Fens Biodiversity Action Plan. See http://www.norfolkbiodiversity.org/actionplans/habitat/fens.asp

4 Planning for Biodiversity and Geological Conservation – A Guide to Good Practice. ODPM, 2006

5 Norfolk Fens Assessment Project 2005/6. See http://www.norfolkbiodiversity.org/pdf/REPORT%20SUMMARY1.pdf

2. OVERVIEW OF PERIGLACIAL LANDFORMS IN NORFOLK

2.1 Periglaciation in Norfolk

The most recent glacial stage in Britain, the Devensian, ended approximately 10,000 years ago. This glaciation is divided into three substages, the Early, Middle and Late Devensian (26000 – 10000 years before present, or 26-10 ka BP). Less is known about the Early and Middle substages, which are generally dated at 122-26 ka BP.

Table 1: The subdivisions of the Devensian (after Ballantyne & Harris 1994).

Stage	***Substage***	***Stadials/Interstadials***	***Boundary age ('000 years before present, or ka BP)***
Devensian	*Early Devensian*	Brimpton Interstadial Chelford Interstadial	122 - 26
	Middle Devensian	Upton Warren Interstadial Complex	
	Late Devensian	Dimlington Stadial (Full Glacial)	26 - 13
		Windermere Interstadial (Mid Glacial)	13 – 11
		Loch Lomond Stadial (Late Glacial)	11 - 10

The Late Devensian substage is further divided into three units based on the prevailing climatic conditions (see Table 1 above). The last of these represents the final episode of severe periglaciation to have affected Great Britain.

At its maximum extent, the Late Devensian ice sheet covered two thirds of Great Britain as it is today. At its south-easternmost limit, it covered what is now the Lincolnshire coast and a very small area of the coast in north-west Norfolk (see Figure 3, right). To the south and east of this, during the Dimlington Stadial, the land was subject to periglacial conditions.

The term 'periglaciation' refers to conditions around the edge of the ice sheet where the climate is very cold, but temperatures are not low enough to allow glacier ice to persist at the surface. Water in the underlying rocks and soil, however, is typically frozen (a condition known as permafrost), although the surface layers may melt in summer and re-freeze in winter, producing a succession of freeze-thaw cycles.

Fig 3: Map showing maximum extent of Devensian ice sheet across East Anglia and mainland Britain
Diagram adapted from Hart 1995c

Permafrost is used to describe ground in which the temperature remains below 0 deg C for at least two consecutive years. Ice is not necessarily present in the soil, although in moisture-retentive, fine-grained sediments, permafrost may be very rich in ground ice. 'Continuous' permafrost occurs in zones where the climate is very severe, usually at high lattitudes and altitudes. Where there are lateral breaks in the continuity of the permafrost, caused by insulating features such as river valleys, vegetation, etc, the permafrost is described as 'discontinuous', and becomes increasingly so in more southerly latitudes. Seasonal warming thaws the topmost layer of soil (for this reason known as the 'active layer'), so permafrost only occurs at the surface where it is protected by ice from seasonal thaw.

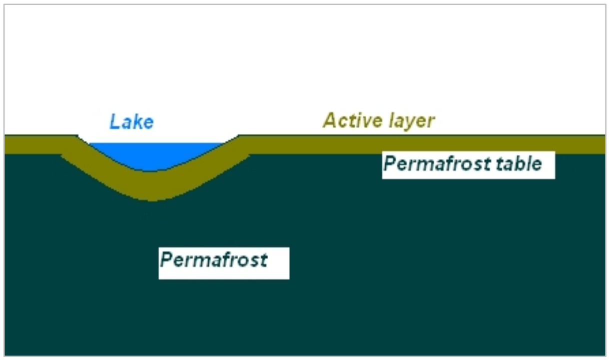

Fig 4: Diagram showing permafrost and the active layer. This layer may melt during the summer months and refreeze in winter

Diagram: Andrina Walmsley

2.2 Landforms Associated with Periglaciation

In a periglacial environment, distinctive landforms and deposits are produced by non-glacial processes, often as a result of ground freezing (Ballantyne and Harris, 1994). By far the most widespread and important periglacial process is frost action, involving repeated cycles of freezing and thawing (Washburn, 1973; Stephens, 1990).

2.2.1 Ground Ice

Groundwater can freeze in different ways, depending on a variety of factors including the landscape and hydrological context. Different types of ground ice result in the development of different landforms, some of which are described below.

There are four main categories of ground ice:

- *Pore ice* - the freezing of the water in the soil and sediment pores, cementing frozen sediment into a hard, rock-like mass. Pore ice can occur in both seasonally frozen ground and in permafrost.

- *Wedge (or vein) ice* - caused by water entering vertical contraction cracks within frozen ground and freezing into a vertical, tapering wedge.

- *Segregation ice* - the gradual freezing of groundwater in saturated, usually fine-grained sediments to produce an ice lens. Water is gradually drawn from the surrounding substrate, via a process known as cryosuction, onto the expanding lens of ice, forming very ice-rich permafrost. A significant volume of ice may accumulate, resulting in upward movement of the ground. On thawing, segregation ice produces a super-saturated active layer, which is subject to flow, even on gentle slopes. The difference between segregation ice and pore ice is determined by soil water content (French, 2007).

- *Injection ice* – this is often formed at sedimentological boundaries, as a result of freezing of water under artesian pressure.

2.2.2 Landform Variations

There are numerous textbook descriptions of periglacial processes and the different landforms they can produce. A brief description of those potentially relevant to Norfolk is given below.

Thermokarst (Cryokarst) Hollows

These are formed as a result of the differential development of ice lenses (segregation ice) in waterlogged soil, causing uneven heaving of the ground's surface. During seasonal thawing of the topmost (or 'active') layer during the summer months, surface material partially melts and is sloughed from the tops of the mounds into the intervening hollows. On re-warming of the climate, the melting ice lenses leave small depressions, while the sloughed material remains in relief, resulting in a 'hills and holes' topography.

Thermokarst depressions have been identified on a wide variety of sediments including Eocene, Cretaceous and Jurassic clays and the Lower, Middle and Upper Chalk. In most cases they are closely associated with overlying deposits which mantle and protect the bedrock from intense periglacial weathering and erosion. By contrast, where the bedrock is exposed, it appears to be rapidly eroded (Boreham and Horne, 2005).

Surface solution dolines

Where the underlying bedrock is calcareous and close to the surface, chemical weathering (or solution) of the calcium carbonate content may occur. Solubility of this mineral increases with a decrease in temperature (subject to precipitation rates), and solution rates may therefore be considerably greater in periglacial and glacial climates, leading to chalk 'denudation' or loss. In areas of permafrost, groundwater and solution may be limited to the active layer, allowing the development of a series of shallow depressions (French, 2007), rather than deeper features, such as sinkholes or limestone karsts.

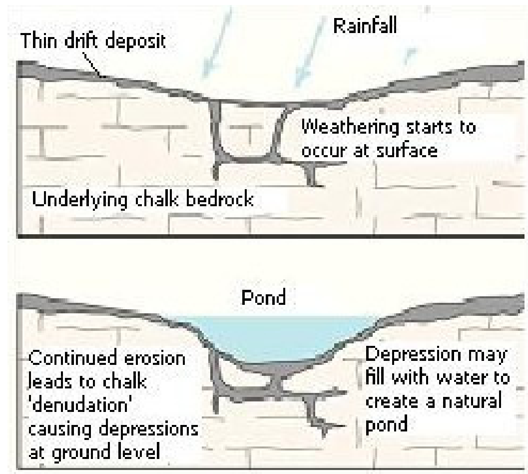

Fig 5: Diagram showing the process of chalk solution by weathering
Diagram adapted from Geohazards Inc, USA

Pingos (Hydrolaccoliths)

Two types of pingo are recognised: closed-system pingos and open-system pingos.

a) Closed-System (Hydrostatic) Pingos

These pingos form by the eventual freezing and expansion of an underground body of water (or talik) expelled in front of advancing ground ice during permafrost development. They typically occur in lake beds or river channels and may involve a significant proportion of segregation ice. As further water freezes, the pingo grows in height and stress cracks in the covering material, or regolith, appear. These dilate to expose the ice core to melting and the mound starts to subside. On eventual re-warming of the climate, the core melts, leaving a depression surrounded by a rampart of shed material, a so-called pingo 'scar'. Closed-system pingos have been found to occur at a density of fewer than eight pingos per km^2 (Pissart, 2000; Stager, 1956)

b) Open-System (Hydraulic) Pingos

This type of pingo is formed by the development of injection ice ie the freezing of groundwater rising under artesian pressure, such as a spring or seepage, usually at the base of slopes. In the surrounding frozen ground, the water is forced upwards as it freezes, pushing up a dome of ice below the surface (see Figure 6).

Surface tension cracks and seasonal thawing of the exposed ice core result in the regolith being sloughed from the top of the dome.

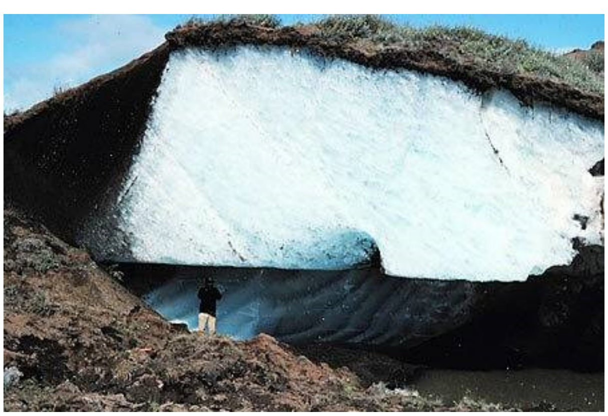

Fig 6: Section through pingo ice in Canada, showing the updomed ice-core
Photo: OUGS Europe

Over time, the shed material forms a ring, or rampart, around the mound, which may be further elevated by compression as the ice core continues to grow. A ridge encircling a shallow depression is left behind when the climate warms and the ice melts.

While the forms are often broadly circular or slightly elongate, superimposition of ground ice mounds developed during a succession of cold stages may result in overlapping ‘vermiform’ patterns with discontinuous and confused ridges. Many fossil pingos in Norfolk, such as those at East Walton Common, display this vermiform rampart formation, and are believed to be the remains of open-system pingos as they are associated with spring activity.

Pingo scars occur in a range of sediment types and are often located on plains, valley floors and lower valley sides where groundwater seepage takes place.

Fig 7: Aerial view of pingos at East Walton Common SSSI, West Norfolk, showing vermiform and overlapping ramparts, suggesting their formation over a succession of cold stages

Palsas

These are similar to closed-system pingos, and are also formed by segregation ice, but they occur in peat bogs. They commonly occur in areas of discontinuous permafrost, and in some areas it may be only the palsas which remain permanently frozen (Gurney, 2001).

Fossil forms of palsas may be difficult to recognise, as the former surface of the peat is largely restored when the ice mound melts and collapses (Washburn, 1973).

Fig 8: Palsas in northern Scandinavia
Photo: Finessi, Italy

Lithalsas (Mineral Palsas)

Like palsas, these are formed by the development of localised segregation ice, but tend to develop in mineral soils on plateaux rather than in low-lying wetlands. With low ramparts, they may have a similar appearance to pingos, but are not formed under artesian pressure. Ballantyne and Harris (1994) note that, as many pingos also contain significant amounts of segregation ice, it is more difficult to differentiate the remnants of true open-system pingos from those of mineral palsas than descriptions of the two forms would suggest. Transitional forms between the two may also exist (Gurney, 2001).

Patterned Ground (Cryoturbation)
Patterned ground is caused by repeated freezing and thawing of the active layer in ice-rich permafrost, which causes fine-grained sediments to migrate downwards, while coarser material rises to the surface. Water movement during summer thawing of the surface creates flow patterns in the surface sediments, typically producing circles, polygons and nets on flatter ground, and stripes on steeper slopes. This patterning may persist to the present day, and often covers large areas.

Patterned ground, especially where differentiated by vegetation cover, is particularly visible from the air. Parts of West Norfolk and Breckland display sizeable areas of patterned ground, known locally as 'Breckland stripes'.

Fig 9: Patterned ground in West Norfolk showing distinctive 'Breckland stripes' caused by variations in vegetation cover
Copyright: Norfolk County Council

2.2.3 Recognition of Landform Types
Despite the apparent distinctiveness of individual landform types, research has shown that ground ice mounds do not always fall neatly into separate categories depending on how the core ice formed. Hybrid or transitional forms, containing a combination of ground-ice types, have also been found, blurring the distinctions between categories (Ross, 2005). Further difficulty is caused by the fact that, on melting, different types of ground ice often leave behind landforms which, although of different origin, may appear superficially very similar (Bryant and Carpenter, 1987); and there is a lack of certainty, even among specialists, concerning key diagnostic criteria for identifying different landform types (Ballantyne and Harris, 1994). Even detailed geological investigations of internal structure and sediments are not always conclusive (West, 1987). It is thus very difficult to identify the individual processes which produced the range of features still visible today.

Striking, if superficial, similarities also exist between the appearance of naturally-occurring hollows and man-made depressions, and may further complicate the issue, as illustrated below (see also p 20). The naturally occurring hollows caused by chalk solution, shown in Figure 10, bear a strong, if superficial, resemblance to the neolithic flint-mines of Grimes Graves in Norfolk, Figure 11.

Fig 10: Chalk solution hollows, or 'dolines' in limestone, in the Pic du Midi, France
Photo: Frédéric Boulvain, Belgium

Fig 11: Flint mines at Grimes Graves, Norfolk
Photo: Andrina Walmsley

2.3 Which landforms occur in Norfolk?

For reasons described earlier, the interpretation of relict landforms on the basis of surface topography alone is not possible. Accurate classification of individual features requires, at the very least, detailed analysis of its internal structure, including both the organic infill and the structure of the hollow which holds the infill. Aspects such as landscape context and hydrological regime also need to be considered. Fieldwork carried out recently at a range of sites in Wales (Ross, 2005; Ross, Harris and Brabham, 2007) proved that features at a number of sites, long held to be pingos, were formed via a completely different process. Using high-resolution near-surface geophysics (electrical resistivity, seismic refraction) and detailed analysis of sediment layers obtained from boreholes and trenching, the researchers found that many of the features were in fact the result of sub-glacial (ie formed below the ice sheet) rather than periglacial processes. As the ice sheet during the Devensian barely reached into Norfolk, sub-glacial features would not have formed during this period.

Based on research that has taken place to date, it appears likely that Norfolk contains examples of a range of periglacial features, including thermokarst hollows, hydraulic and hydrostatic pingo systems and chalk solution features such as surface solution dolines. Patterned ground, clearly visible from the air, is widespread in Breckland and parts of west Norfolk. Palsas or closed-system pingos may also have occurred in the area now known as Fenland (Ballantyne and Harris, 1994) and in other low-lying peatland areas, although the longevity or visibility of the former as relict features is uncertain (Washburn, 1973; Gurney, 2001).

2.4 Relevant research in Norfolk and Wales

A few sites in the county have been the subject of detailed research, East Walton Common and Thompson Common, in particular, being the most extensively investigated.

In their paper, 'Presumed Ground-Ice Depressions in East Anglia', Sparks, Williams and Bell (1972) considered a number of potential explanations for hollows found in East Anglia, including marl pits, a range of chalk solution features (including collapse dolines and surface solution dolines) and ground-ice depressions. They identified 'subdued' and 'fresh' landforms on the basis of their morphology and current hydrology, and believed the different forms might represent a distinction in age. They analysed rampart cores taken from features at East Walton Common, and found that these contained a reversal of sediment layers, indicative of material shed from 'an updomed form'. They believed this to be consistent with pingo formation and proof, therefore of likely periglacial origin. Chalk solution they considered unlikely as this would have left behind insoluble residues, of which there was no evidence in the deposits they examined.

They also investigated a section that had been exposed by a gas trench cut through a series of dry hollows in the south part of the common. Pollen analysis of organic sediments at different levels in the horizon suggested two superimposed stages of development, the lower depression dating to the Dimlington Stadial (Full Glacial); and the one above it formed during the Loch Lomond Stadial (Late Glacial). They extrapolated from this that there were two main periods of development of ground-ice depressions in Norfolk, namely the Full Glacial (or Dimlington) and the Late Glacial (or Loch Lomond), and that these produced, respectively, the older 'subdued' forms and more recent 'fresh' forms. They found subdued forms to be more widespread, occurring at slightly higher levels, and consistent with the more severe climate and 'more thorough saturation of the ground' associated with the Dimlington. The 'fresh' forms were more limited in their distribution, restricted to areas of springs near the Fenland edge and were thought to have been formed in areas of shallower permafrost than the older forms. A series of pollen studies undertaken at a number of similar sites in Western Europe dated continental landforms to a similar period and appeared to corroborate their findings.

The authors also compared the landscape context of similar, but unramparted depressions near Marham. The lack of springs in this location led them to conclude that these might be thermokarst hollows, formed in waterlogged conditions. They found further evidence of likely periglacial origin at a site in north-west Suffolk which contained Breckland stripes running into the hollow of a subdued form, indicating that the hollow pre-dated the last phase of stripe formation (probably the Full Glacial).

West (1987, 1991) described detailed studies of a series of permanently and seasonally water-filled depressions at Beetley gravel pit, and a site at Wretton. Analysis and configuration of organic sediments contained within two of the hollows at Beetley, and the deep level of the chalk below their bases, led him to conclude that they were the result of chalk collapse as a result of solution. He was unable to determine whether ground-ice had played a role in their formation, but believed that, even if it had, there would have been insufficient volume of ice to produce ramparts around the feature. The origins of a third hollow in the same area were more difficult to determine. The hollow and its margins appeared to be the result of a series of interrelated but separate processes none of which could be proved without further detailed geological survey. The hollow itself he thought might be a thermokarst lake; or possibly a solution feature of the type associated with ice-wedge polygons, a theory supported to some extent by the presence very close by of a wedge-cast (the fossil remains of wedge ice, where a wedge-shaped fissure in the ground created by ice fills with sediment when the ice melts). The hollow at Wretton appeared to have formed as a result of ground-ice freezing under hydrostatic pressure within a channel system to produce a closed-system pingo. West concluded that all of the hollows could be associated with 'processes of Devensian age', and were the result, respectively, of ground ice and chalk collapse. He noted that all except the hollow at Wretton were at sites where springs are still present.

In the past five years, a series of studies has examined the distribution, morphology, structure and origin of ramparted depressions, loosely identified as pingos, at a range of sites in Wales (Ross, 2005; Ross, Harris and Brabham, 2007). The first phase of this work, commissioned by the Countryside Council for Wales (CCW), was undertaken largely in response to the destruction of a number of features by drainage, excavation and levelling for agricultural use. Using high-resolution near-surface geophysics and drilling, the project investigated the composition of features and the hydro-geological regimes at selected sites to try to determine whether the depressions could have been formed in permafrost conditions as the result of ground-ice development, and could be classified as pingos. In a subsequent study, narrow trenches were cut through ramparts to determine their composition. The aim of the work was partly to identify relationships between the surface topography and internal structure of these features, and has resulted in a clearer understanding of which sites are likely to be pingos in origin and which, although superficially similar, are attributable to some other process. The result of this work will enable the most important sites to be protected.

Prince (1962) attempted to identify the origins of depressions found across Norfolk by comparing and interpreting maps of different ages, and looking at the historical evidence for practices, such as marling, which produced pits on a widespread scale. He counted over 27,000 hollows on 1:25k Ordnance Survey maps; and noted that most occurred in areas where glacial drift deposits exceeded three feet in depth, and were generally more numerous on heavy soils. Mineral workings appeared to be almost ubiquitous (with the exception of the Fens and the Broads), providing local supplies of gravel for roads and building materials. He cited evidence, however, that many such hollows might have pre-existed, as pits were sometimes dug at sites already containing shallow depressions. Prince suggests that some of these might have been formed 'under glacial or periglacial conditions', and goes on to examine a range of processes, including chalk solution and thaw sinks, which might explain some of these features. He concludes that many natural depressions might have originated under periglacial conditions and been enlarged by chemical weathering.

Other research has been conducted on the vegetation of the pingos of Thompson Common (Watts and Petch, 1986; Yaxley, 2003), the invertebrate fauna in pingos and other water-filled ground ice depressions at various locations in Norfolk (Foster, 1993; Nobes, 2005, 2007, 2008); pollen analysis revealing evidence of hemp processing at Thompson (Bradshaw *et al,* 1981) and a range of detailed faunal and plant surveys at Thompson Common[6].

[6] For example, see *Transactions of the Norfolk and Norwich Naturalists' Society, 27, 5 (1987)*

3. IMPORTANCE OF GROUND-ICE DEPRESSIONS FOR BIODIVERSITY

Ground-ice depressions are important habitats in their own right, and sites with these features have been found to support a remarkable array of species. Habitats associated with these sites include open water, dry chalky banks, damp grassland, wet heath, fen, scrub and woodland, a diversity that supports a very wide range of plants and animals, making them of immense conservation value. Many of the intact pingo systems in Norfolk appear to be especially important for invertebrates, particularly water beetles (Foster, 1993; Nobes, *pers. comm.)*; and are excellent breeding sites for amphibians, especially notable for great crested newt, smooth newt, common frogs and toads.

Flora

The present day character of ground ice depressions is highly variable and includes permanent spring-fed basins, temporary pools, seasonally wet/damp hollows, and depressions which are dry all year round. This variety gives rise to a wide-ranging vegetation, which may itself be more or

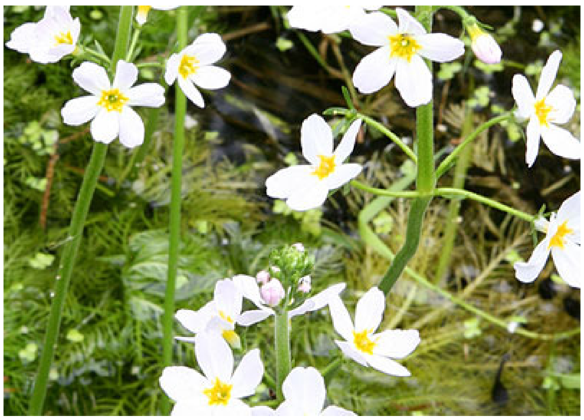

Fig 12: Water violet Hottonia palustris, *above left, frequently colonises pingos and other water-filled ground ice depressions where water quality is good. Pingos in less favourable situations, such as the one above right, on a roadside at Thompson, may be significantly less diverse*
Photos: Geoff Nobes/Andrina Walmsley

less diverse depending on the degree to which the site is actively managed. Very many sites are now located in woodland, and may support little vegetation other than woody emergent species, such as sallow or alder scrub. Where depressions occur in a more open context, however, in a well-buffered site, and particularly where management helps to retain a habitat mosaic, they can be extremely diverse, with a wide range of aquatic, emergent, marginal, fen and grassland species.

Much of the overall floristic value of these systems arises from variations in substrate and hydrology, and the habitat mosaic which they support. Even the pH value of the water contained in different hollows may vary quite significantly (G. Nobes, *pers. comm.;* Watts and Petch, 1986*),* providing a range of different aquatic habitats. The raised chalk rims on some ramparted depressions can support a species-rich calcareous flora, often abundant in cowslips *Primula veris,* particularly where the site is kept open and competitive species are controlled through regular management such as grazing. Neutral grassland and scrub may also develop in and around the depressions. Where water levels within the hollows fluctuate, vegetation may be unable to establish for long periods, and bare mud on the drawdown zones can provide opportunities for species which 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. Characteristic species include blunt-flowered rush *Juncus subnodulosus*, black bog rush *Schoenus nigricans*, fibrous tussock sedge *Carex appropinquata*, lesser tussock sedge *Carex elata*, marsh helleborine

Epipactis palustris, fen fragrant orchid *Gymnadenia conopsea*, southern marsh orchid *Dactylorhiza praetermissa*, grass of Parnassus *Parnassia palustris*, butterwort *Pinguicula vulgaris* and marsh lousewort *Pedicularis palustris* (Lambley, 2005). At Thompson, Watts and Petch (1986) found abundant populations of water violet *Hottonia palustris,* bogbean *Menyanthes trifoliata,* water forget-me-nots *Myosotis laxa* and *M. scorpioides,* lesser and greater spearwort *Ranunculus flammula /Ranunculus lingua* with species such as cuckooo-flower *Cardamine pratensis,* marsh bedstraw *Galium palustre,* marsh pennywort *Hydrocotyle vulgaris* and water-mint *Mentha aquatica* at the slightly drier margins. Permanent pools are important for species such as water plantain *Alisma plantago-aquatica*, water dropwort *Oenanthe fistulosa* and water-cress *Nasturtium officinale*.

Fig 13: Greater spearwort (Ranunculus lingua)
Photo: Geoff Nobes

Bryophytes
Although no moss species in Norfolk appear to be specifically confined to such sites, they may often retain pockets of bryophyte species which are generally poorly distributed across the county, (R Stevenson, *pers. comm.*). Typical moss species include *Plagiomnium elatum, Campylium stellatum* and *Calliergonella cuspidata.*

Invertebrates
Water beetles (Coleoptera)
The outstanding invertebrate fauna associated with many water-filled ground ice depressions is attributed to the stability of these habitats over very long periods, and the range and mosaic of habitats frequently present (Lambley, 2005).

In particular, there are unusually high populations of Red Data Book (RDB) species in pingo systems. Foster (1993) observed that the pingo systems of Norfolk are dominated by nationally rare water beetle species, 'the remnants of early postglacial biota', probably because they are often still fed by the same groundwater source that created them. He found that the four best-known pingo systems in Norfolk, at Thompson Common, Foulden Common, East Walton Common and East Harling Common, support 125 species of water beetle in total, of which 104 occur at Thompson alone (Foster, 1993).

Fig 14: The diving beetles Hydroporus glabriusculus (RDB3) *and* H. scalesianus (RDB2), *both of which are associated with pingo sites in Norfolk*
Photos: Geoff Nobes

Because many of the ponds are dry in the summer months, early spring breeding species dominate, while those which require permanent water tend to be scarce. More recently, a survey (2007) of the pingos at The Wilderness, north of Norwich, identified three RDB3 (Nationally Rare) species and seven Nationally Scarce species (Nobes, *pers. comm);* while at East Harling Common, 94 species of water beetle have been recorded from the site between 1983 and 2005, although repeat surveys have shown a decline in the number of RDB species present over the same period (Nobes, 2005).

Dragonflies (Odonata)

Water-filled ground ice depressions may not have a specific importance for dragonflies and damselflies for any reason other than their inherent value as ponds and pools which are shallow, and therefore able to warm up quickly. However, species such as the rare and local Scarce emerald damselfly *(Lestes dryas)* favour temporary pools, and this characteristic of some pingo sites may make them of particular value for this species, which is regularly associated with pingos (P. Taylor, *pers. comm*). One of the greatest threats to *L. dryas* is over-abstraction resulting in lowering of the water table, specially at sites where they breed in temporary pools[7], suggesting that some pingo sites may be at particular risk. In 1987, Thompson Common was ranked as one of the top sites in the county for dragonflies, with seventeen species recorded from the site (Irwin, 1987).

Fig 15: Scarce emerald damselfly (male) Lestes dryas, *a species associated with pingo ponds*
Photo: Geoff Nobes

Snail-Killing Flies (Sciomyzidae)

The larvae of these species are parasitic on freshwater and terrestrial snails, eventually killing them. Snail-killing flies are an outstanding feature at many pingo sites, particularly Thompson Common, where 25 of the 65 British species (several of them Nationally Scarce) were found to occur in 1987 (Irwin, 1987). Irwin assumed that the remarkable richness of the sciomyzid fauna was attributable either to the 'antiquity of the habitat'; or to the particular combination of basic grassland alongside pools of varying character. Another key factor may be the fluctuating water levels, which expose snails to a greater degree to predation by the flies (Irwin, 1987).

Fig 16: Pingo in woodland at a site near Foulden Common SSSI, showing extensive draw-down zone
Photo: Robin Stevenson

[7] British Dragonfly Society. *Lestes dryas* Management Fact File. 2004 http://www.dragonflysoc.org.uk/mffledryfull.htm#status

Molluscs (Mollusca)
Pingo systems at two sites in Norfolk are amongst a limited number of sites nationally, and only a handful of sites within the county, which support the nationally rare Desmoulin's whorl snail *Vertigo moulinsiana* (Killeen, 2003). Listed as a Red Data Book (RDB3, or 'rare') species, the snail has its Norfolk stronghold in the Broads, but also lives in fen habitat in and around the pingos at East Walton Common and Thompson Common, and is known from sites in the Nar Valley and at Guist and Hempton, all of which are areas believed to contain relict periglacial features. Desmoulin's whorl snail was more widely distributed in Britain in early postglacial times than it is now, its retreat possibly due to climatic cooling over the past 5000 years (Killeen, 2003).

Thompson Common also supports the rare Shining ram's-horn snail *Segmentina nitida,* now classified as Endangered. The snail's stronghold in Norfolk is in the Broads[8].

Irwin (1987) noted that, while a relatively small number of freshwater and terrestrial snails had been recorded from Thompson Common, including *S nitida,* different species tended to have colonised different pingos, with a limited range in each pool (Irwin, 1987).

Herpetofauna
Northern-clade pool frog (Rana lessonae)
Fossilized bone material found in deposits dating to the Hoxnian period, before the Devensian ice age, suggest that the northern-clade pool frog is native to East Anglia (Gent, 1996), having possibly colonised Britain from Scandinavia via the land bridge which linked Britain to the continent until about 8500 years ago.

It is believed that pool frogs may have existed at a number of sites in East Anglia, although it is unclear whether they were present, or widely distributed outside of the region. Drainage of the Fens, loss of breeding ponds, lowering of water tables as a result of water abstraction and loss of habitat through lack of management are thought to have been the major factors in the collapse of the native population (Beebee and Wycherley, 2001). Thompson Common supported the last population of pool frog which became extinct in the 1990s (Irwin, 1987; Beebee and Wycherley, 2001), although it is not known whether these were descendents of a native population or the result of more recent introductions as they were only rediscovered at the site during the 1960s (Gent, 1996). The pool frog was reintroduced to a pingo site in Norfolk in 2005, using northern-clade frogs from Sweden.

Great crested newt (Triturus cristatus)
Great crested newts require water (typically, but not always, ponds) for breeding and feeding; while terrestrial habitat, such as undisturbed grassland, scrub, woodland and hedgerows, is essential for feeding, refuge, dispersal and hibernation. A range of pond types may be used, provided they are well-vegetated, not too shaded, and have areas of shallow water. Pond clusters with good connectivity between them provide the best habitat, and will support the largest populations (Foster, 2001). Many pingo sites in Norfolk offer ideal conditions for great crested newts and other newt species, and great crested newt records[9] for the county show them to be present at a large number of sites, particularly within the Stanford Training Area (STANTA).

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[8] Norfolk BAP Shining Ram's-horn Snail http://www.norfolkbiodiversity.org/actionplans/species/shiningsnail.asp#Status
[9] Norfolk Biological Information Service (NBIS), 2009

4. METHODOLOGY

4.1 Desk Study

4.1.1 Data Sources

Because pingos and other similar periglacial features are formed where porous bedrock, frequently chalk, lies close to the surface mantled by only shallow drift deposits, the search for sites in Norfolk was focussed on areas where this is the case, and particularly in those areas where depressions are already known to occur, eg

- parts of West Norfolk, (including Gayton, Walton, Hiborough, Boughton, Methwold);
- large areas of Breckland (including Thompson, Stanford, Stow Bedon, Merton, Harling);
- parts of western North Norfolk (particularly the Fakenham and Helhoughton areas)
- A small area north of Norwich (particularly Horsford, Horsham, Hevingham)

The following data sources were used to identify potential sites.

a) Aerial Surveys

Aerial photography allows rapid coverage of large areas and, in some cases, is ideal for a county-wide survey. Unusual formations and soil marks can show up clearly when seen from the air, and pingos and other depressions in open sites are easily visible (see Figure 17).

Adjacent to these sites, ploughed (but uncropped) land frequently displays very distinct, chalky white 'swarms' of marbling patterns, which merge into the semi-natural areas (see Figure 18), suggesting that the ploughed land might once have contained similar landforms.

Fig 17: Pingos at Gayton Thorpe Common, West Norfolk, seen from the air

Semi-natural sites within these swarms may contain relevant landforms and are worth closer investigation. Use of aerial photographs makes it possible to track the full extent of these swarms of soil marks over large areas, something which it would be impossible to do on the ground, not least because soil marks are only clearly visible from the air.

The 1946[10] and 1999[11] aerial surveys of Norfolk were analysed to identify areas with heavily marked ground. Areas of 'patterned ground' (ie cryoturbated or frost-sorted ground) were also noted as evidence of localised periglacial activity, although these were not digitally mapped because of their extensive nature.

Fig 18: In aerial photos, swarms of chalky marbling patterns show up clearly in cultivated land and may be a useful indicator of the extent of periglacial activity.

[10] The Royal Air Force National Air Survey, 1945-6. Norfolk Rural Life Museum, Gressenhall, Norfolk

[11] GetMapping plc

Areas with known ground ice depressions were also identified on the aerial survey so that their appearance could be compared with unknown sites and used as a benchmark. Using this method, it was possible to identify a number of semi-natural sites with potentially relevant features. Wooded and other sites which lay within the patterned 'swarms', but which were not visible from the air because of canopy cover or shadow, were also captured.

There are limitations to using aerial survey, including:

- poor visibility of the terrain within wooded and heavily scrubbed sites

Fig 19: Swarms of shallow depressions at Grimes Graves, the site of a neolithic flint mine in Breckland, seen from the air.
Photo: Derek Edwards
Copyright: Norfolk Museums & Archaeology Service

- the potential for misinterpreting crop and soil marks and unusual land formations eg archaeological remains, impact craters and other features may appear very similar from the air (compare Figure 19, above right, and Figure 20, below)

- the potential for significant changes in land-use (especially cultivation) since the survey was carried out

e

Fig 20: Aerial view showing landscape scale hollowing of the land's surface as a result of chalk or limestone solution
Photo: National Caves Association, USA

The 1946 survey was used because it shows:

- sites with ground ice depressions which have since been ploughed out
- once-open sites with ground ice depressions which now have a canopy cover

The 1999 survey was used alongside the earlier one to provide more recent land-use data, and because the use of two surveys helps to overcome visibility problems caused by low cloud, shadow and mature crops, all of which can conceal soil marks. Locations with soil-marks or hummocky terrain which appeared relevant were marked onto OS maps.

b) County Wildlife Site System
The Norfolk County Wildlife Site[12] database was used to compile a list of sites both known to contain ground-ice depressions or with reference to potentially relevant (but unidentified) features eg clusters of depressions, hollows or ponds. Sites were correlated with zones identified via aerial survey.

[12] Survey records, citations and database of the CWS system are held at Norfolk Wildlife Trust head office, Norwich

c) Ordnance Survey Maps
OS maps (1:25,000 Explorer Series) were used in conjunction with aerial photographs to mark areas with relevant soil marks, differentiating between cultivated and non-cultivated sites. Cartographical marks showing closely-grouped water bodies (unless obviously of man-made origin) and contour lines indicating clusters of dry depressions were also used as indicators for potential sites.

d) Geological Maps
A digital layer showing the underlying geology and drift deposits against which identified sites could be directly compared was not available. Instead, British Geological Survey (BGS) solid and drift geology maps were used, where available, to provide geological data for many sites. (Maps of two key areas, in Breckland and north of Norwich, are currently out of print.)

e) Soil Map
Underlying soils for all sites were collated using the soil map of Norfolk[13]. A list of codes and descriptions for each soil type is at Appendix 1.

4.2 Field Work

4.2.1 Ground Truthing

To try to assess the reliability of the information obtained from the aerial photographs, a large number of sites were 'ground-truthed'. This was also necessary to ascertain current land-use where this was not clear from current maps, or where maps and photographs did not agree. For speed, ground-truthing was generally confined to areas accessible from adjacent roads or footpaths, but was also used wherever possible for sites where interpretation of the aerial photographs was difficult.

4.2.2 Site Assessment

Prioritising sites
Identified sites were prioritised for visit based on the likely presence of ground-ice depressions. In no particular order, this was assessed on

- likely interest, based on existing site descriptions (mostly available only for sites)
- likely interest, suggested by aerial photography
- proximity to other well-known GID sites
- size (ie sites of less than one hectare were not prioritised, although small sites were visited if adjacent to a road)
- ease of access (eg availability of ownership information or public accessibility)

SSSI sites were not prioritised because many of these sites are already well-researched and documented, and their condition and management is under ongoing review.

Assessment
Site assessments were carried out at 73 sites, using a specially compiled survey form (see Appendix 2). The form was designed to be simple and quick to complete during a walk-over survey, while providing useful comparative information for each site, including the approximate number and distribution of hollows/ponds, presence of features such as ramparts/drains, vegetation type, hydrology and matrix. Site condition, management status and apparent threats were also noted for each site. Condition was assessed using standard condition categories ie:

- Favourable
- Recovering
- Declining
- Unfavourable
- Destroyed
- Variable

[13] Soil Survey of England and Wales, 1:100K 1973, Rothamsted Experimental Station, Harpenden, Herts

The main threats to each site were identified, and broadly categorised as follows:

- Scrub encroachment
- Siltation
- Pollution
- Poaching
- Modification
- Drainage
- Enrichment
- Disturbance
- Over-grazing
- Neglect
- Cultivation
- Dredging
- Unknown

Management status of sites was noted using broad categories including:

- Grazed (livestock type noted where possible)
- Mown, not cleared
- Mown/cleared
- Forestry operations
- Unmanaged
- Unknown

5. Outputs

5.1 Access Database

A database of sites was compiled using Access 2003. Twenty-six fields of data were entered for each site, giving a range of information including a generic landform type (eg pond, damp depression), type of distribution within site (closely grouped, scattered), number, matrix, current management, etc. A full list of the data fields is included at Appendix 3.

5.2 Digital Map

Sites were digitally mapped (MapInfo 5.5) showing their known or likely extent. Contiguous but differently-designated sites were mapped and listed separately. Separate pingo 'zones' within the same large site (particularly extensive SSSIs) were mapped and listed separately to distinguish between them.

Sites were also differentiated by colour according to whether they were known ('extant') or believed ('unverified') to contain ground-ice depressions.

The map is linked to the database so that all datafields are shown for each site on the GIS layer. A copy of the map is at Appendix 4.

6. FIELD OBSERVATIONS

6.1 Overview

A total of 215 sites were listed and mapped. Of these:

- 124 sites (58%) are in Breckland District
- 49 (23%) are in West Norfolk
- 29 (13%) are in North Norfolk
- 11 (5%) are in Broadland

Of the total list, 39% (84) of the sites are known to contain depressions which might be of periglacial origin, with the balance of the sites unvisited.

Of all the sites in the database, 13 are SSSI or part of SSSIs; 41 are designated CWS, and one of these is also a registered common; and one is a potential CWS. The remaining 160 sites are currently unprotected, including 29 sites where hollows/depressions are known to occur.

6.2 Site Character

a) Height about sea level

Sites on the database occur at a relatively wide range of altitudes, although the majority fall within a gradient of 11-40m. Of the 84 sites known to have extant features, 49% (41) are within a range of 21-40m, with the majority of these (26 sites) falling within the 31-40m contour.

This range compares with data for eight 'known pingo sites', including five SSSIs and three CWS, which also occur at widely varying altitudes ie two sites are at 0-10m, three at 11-20m, one at 21-30m and two at 31-40m.

b) Matrix

The sites were broadly categorised according to 'matrix' type, and sub-categorised where information was available. Approximately half of sites are within a mainly wooded context; one quarter of sites are within grassland; approximately one fifth are within a habitat mosaic; and only 4% within fen.

A breakdown of sites by matrix is shown in Table 1 below.

Table 1: Breakdown of sites by matrix type

Matrix Type	Sub-Category	% Within Category	Totals (of all sites)
Woodland	*Dry, broad-leaved*	22%	47% (102)
	Wet woodland	13%	
	Conifer plantation	9%	
	Mixed woodland	11%	
	Unknown	45%	
Grassland	*Damp grassland*	43%	26% (56)
	Dry grassland	5%	
	Pasture	36%	
	Improved pasture	<1%	
	Unknown	15%	
Fen		4%	4% (8)
Mosaic		18%	18% (39)
Scrub		<1%	<1% (1 site)
Unknown		4%	4% (9)

6.3 Site condition and management

a) Overview
Site condition for visited sites was analysed according to management type, who the site is managed by, and level of site protection.

Condition was determined at a total of 73 sites, on the basis of factors such as vegetation quality, levels of scrub encroachment, nutrient levels, appropriateness of management such as grazing, damaging activities such as drainage, cultivation, keepering etc

Where the site overall was considered in acceptable condition, but the ‘pingos’ or hollows were not, the site was classified as declining or unfavourable. A breakdown of sites by condition alone in shown in Table 2 below.

Table 2: Breakdown of sites by condition category

Condition Category	*% of Visited Sites*	*Of these, % within a SSSI or CWS*
Favourable	34% (25 sites)	72% (18)
Declining	30% (22)	82% (18) (of which one also a registered common)
Unfavourable	27% (20)	35% (7)
Variable/Recovering	7%	
Destroyed	<1% (1)	<1% (1 CWS)

b) Site management responsibility
Site management was noted for each site visited, where possible, and the category of those responsible for management (eg conservation body, private estate, etc) recorded for all sites where information was available (48% of sites).

A breakdown of this information is shown in Table 3:

Table 3: Breakdown of sites by manager category (information available for approximately half of all sites)

Manager Type	**Sub-Category**	**% Within Category**	**Totals (of all sites)**
Private	*Farms/estates*	48%	66%
	Private individuals	18%	
Government Agencies	*Forestry Commission*	11%	17%
	Ministry of Defence	4%	
	Natural England	2% combined	
	National Trust		
Conservation Bodies		12% combined	12%
Parish / Charitable Trusts			
Corporations		3%	3%

There are 17 SSSI sites (or 'pingo zones' within SSSIs) within this group. Of these, one third are managed by private estates, a quarter by the FC, one eighth by the MoD, and the same proportion by conservation organisations/parish charities.

Within the same group there are 62 CWS. Of these, 66% were managed privately (roughly evenly divided between farms, estates and private individuals); 15% were managed by conservation organisations/parish charities, 13% were managed by the FC/MoD, 2% were managed by a corporation, and 11% were unknown.

The single registered common within the sample was managed by the local authority.

For the remaining 133 unprotected sites, information relating to management responsibility was not available for 104 sites (78%). Of the balance, 17% were managed privately (farms, estates and private individuals); 2% were managed by the FC; 2% were divided evenly between conservation organisations, the NT and a business corporation.

c) Site condition by management responsibility
The condition of sites was analysed by manager type, and is shown below in Table 4 below.

Table 4: Comparison of site condition by broad category of site manager type

Manager Category	**Site Condition Category**					
	Favourable	*Recovering*	*Declining*	*Unfavourable*	*Destroyed*	*Condition Variable*
Private (farms, estates, individuals)	15 (60%)	-	14 (64%)	10 (50%)	1 (100%)	1 (33%)
Government Agency (FC, MoD, NE, NT)	2 (8%)	-	1 (4%)	4 (20%)	-	1 (33%)
Conservation Body	4 (16%)	1 (50%)	1 (4%)	1 (5%)	-	-
Local Authority (district / local / parish council)	-	-	2 (8%)	-	-	-
Parish Trust/Charity	-	-	1 (4%)	1 (5%)	-	-
Corporation	-	-	-	1 (5%)	-	-
Unknown	4 (16%)	1 (50%)	3 (14%)	3 (15%)	-	1 (33%)
TOTALS	*25*	*2*	*22*	*20*	*1*	*3*
	Total assessed sites: 73					

d) Site condition by management type
The type of management in place was correlated with the site condition to determine the effectiveness of the management activity. This information is shown in Table 5 below.

Table 5: Site condition shown by type of management

Management Type	**Site Condition Category**						
	Favourable	*Recovering*	*Declining*	*Unfavourable*	*Destroyed*	*Condition variable or unknown*	*Totals*
Grazed / part grazed	17 sites	1	8	2		10	*38 (18%)*
Mown /part mown	1	-	-	-	-	-	*1 (<1%)*
Part mown / part grazed	-	-	-	-	-	2	*2 (<1%)*
Forestry operations	-	-	1	5	-	11	*17 (8%)*
Keepered	-	-	-	4	-	2	*6 (3%)*
Fishery	-	-	-	-	-	1	*1 (<1%)*
Minimum /non intervention or unmanaged	5	1	8	4	1	3	*22 (10%)*
Recreation/ amenity	-	-	1	-	-	-	*1 (<1%)*
Unknown	2	-	4	5	-	116	*127 (59%)*
TOTALS	*25*	*2*	*22*	*20*	*1*	*145*	*215 (100%)*

e) Site condition by matrix type

Site condition of visited sites was analysed by matrix type. These data are presented in Table 6 below.

Table 6: Site condition by matrix category

Matrix Catetory	*Favourable*	*Recovering*	*Declining*	*Unfavourable*	*Destroyed*	*Condition variable*
Grassland	53%	-	26%	21%	<1%	-
Conifer plantation	-	-	5%	95%	-	-
Habitat mosaics	41%	6%	35%	12%	-	6%
Fen	-	25%	75%	-	-	-

6.4 Great crested newt

The sites listed in the database were correlated with all currently held Norfolk records[14] for Great crested newt (GCN), using GIS layers. Positive newt records were entered into the database where relevant.

Sites with no formal records, but with apparently suitable habitat for great crested newt were noted in the database as being of 'high', 'moderate' or 'low' potential for GCN.

Fig 21: Great crested newt (male) Triturus cristatus
Photo: Geoff Nobes

6.5 Threats to Sites

Threats (or perceived threats) to individual sites fell into eight broad categories, listed below in order of threat magnitude (number of sites in brackets):

- Scrub encroachment (33)
- Cultivation (19)
- Inappropriate management (16)
- Inappropriate grazing (13)
- Disturbance (5)
- Neglect (3)
- Development (2)
- Siltation (2) (Total sites: 93)

Water abstraction is cited as a significant, or the major threat at many sites, with ponds now drying up during minor droughts and taking longer to recharge (Nobes, *pers. comm.).* This is consistent with findings from the Fen Assessment Project survey but was difficult to establish on the basis of single visits undertaken during the course of this project.

Based on visits undertaken during this survey:

Scrub encroachment threatens the highest number of sites, although 11 of these are unmanaged and type of management (if any) was unclear in a further six cases. Nine of the sites were grazed, four by cattle (3) or sheep (1), and the balance by unspecified livestock. Nineteen of the sites are designated CWS (including one registered common), and seven are part of SSSIs. The balance are undesignated.

Nineteen sites appeared to be most at threat from *cultivation*, although this is difficult to assess based purely on observation. Two of the sites within this group are CWS.

Inappropriate management threatens 17% of sites, of which management primarily for shooting and fishing affect six. Three are managed for forestry.

In cases where *inappropriate grazing* was considered the most serious threat, only two sites appeared under-grazed, while more than half were over-grazed or heavily poached. Livestock in 46% of cases were horses, in 38% of cases were cattle, and in 15% of cases, sheep. Five of the sites are CWS.

Disturbance at sites was attributed in all five cases to forestry operations, and in one of three of the '*neglected'* sites. The remaining two sites suffering from neglect were unmanaged.

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[14] Records held by Norfolk Biological Information Service (NBIS), Norfolk County Council, Norwich.

Development was considered a major threat at just two sites, one at Roudham where planning permission was recently refused for a site containing a small pingo. This site has since been designated as a CWS, so is hopefully more secure. Another site at Hainford, although not visited, appeared from aerial photographs to be potentially at risk from encroaching development.

Siltation was frequent in wooded sites, but was noted as the main threat at two woodland sites.

7. FURTHER ACTION

7.1 Prioritising Sites for Action

a) Allocating priorities
180 sites have been targeted for further action, and allocated a priority rating from 1-5 (where 1 is the highest priority). A few sites have been allocated a score of 1*, to indicate those of particularly high quality or extensive sites in a state of rapid decline or suffering from inappropriate management, where action to restore the site is highly desirable and becoming urgent.

The actions recommended for individual sites are generic and applied to sites by category, depending on site quality, designation, matrix etc.

An outline of how priority ratings have been determined and allocated is at Appendix 4.

b) Site priorities
The number of sites within each category is given below.

a) **Priority 1*** - 9 sites (4%), all of which were classified as either declining or unfavourable. All sites have been earmarked as suitable candidates for restoration, and include:

CWS 654	Breckles Wood/Hockham Common (tenanted)
CWS 836	Caston Common (privately owned)
CWS 1289	Part of Kettlestone Fen (privately owned)
CWS 838	North-east of Thompson (privately owned -restoration programme already underway)
CWS 1394	The Wilderness (FC + privately owned)
CWS 847	North of Lower Stow Bedon (privately owned)
SSSI	Queen’s Close (part of Breckland Forest SSSI) (FC)
Undesignated	Eccles Common (privately owned)
Undesignated	Spring Covert (FC)

b) **Priority 1** – 26 sites (12%), of which 12 are CWS, one is part of a SSSI and the balance are undesignated. Of these, approximately one third (9 sites) require condition assessments, 27% (7 sites) require survey, 23% (6 sites) are of unknown ownership and need following up, and four sites require management plans or management advice.

c) The remaining sites have been earmarked for specific action as shown below in Table 7:

Table 7: Recommended actions and priority ratings for lower priority sites

Priority rating	***Number of Sites Requiring:***						
	Management plan	*Management advice*	*Survey / resurvey*	*Condition Assessment*	*Ascertain presence of features*	*Establish Ownership /follow up*	*Other*
2	2	5	4	5	31	9	1
3	-	5	3	12	35	5	1
4	-	3	-	1	11	1	-
5	-	-	-	-	11	-	-
Totals	***2***	***13***	***7***	***18***	***88***	***15***	***2***

8. DISCUSSION

8.1 Survival of Ground-Ice Depressions

It is probably correct to assume that many of the extant relict pingo sites in Norfolk have never been cultivated because the topography and, more importantly, the presence of active springs and water bodies would have made draining of the land too difficult and uneconomic. Wheeler and Shaw (1992) observed that a number of botanically rich fen sites in East Anglia had escaped cultivation precisely because the land was nutrient-poor with strong spring activity. In many parishes these marginal sites, regarded as unfit for any other purpose, were given over to the poor who were allowed to graze animals, and cut peat and wood for fuel. This low level of management fortuitously helped to protect and shape many sites, enabling them to survive largely intact to the present day (although loss of traditional 'management' means that many are now in decline).

Sites with pingos and other water-filled depressions would have been even more challenging to drain and cultivate, and the best-preserved pingo sites in Norfolk today are those which occur on common (or former common) land. Several are notified as SSSIs or SACs, namely East Walton Common, Foulden Common, Thompson Common and East Harling Common. A great many others are used for pasture, some designated as County Wildlife Sites. A large number have been planted with conifers in the last 80 years, and are managed by the Forestry Commission. Notable 'pingo' sites in afforested land include Hills and Holes, Frost's Common and Fox Covert in Breckland; Spring Covert in West Norfolk; and The Wilderness in Broadland. The pingos at many of these sites are not managed in their own right, and many are in unfavourable condition, shaded or blocked with encroaching scrub and fallen trees.

Aerial surveys show that, where there is underlying chalk, there are extensive areas, now cropped, which once also contained periglacial landforms of some kind. The 'ghosts' of these largely-destroyed features show up very clearly as swarms of soil-marks in ploughed land, although they are more difficult to detect, both from the air and on the ground, with standing crops. At ground level, these features often appear as subdued, gently-contoured depressions, often bowl- or saucer-like, without ramparts, but often damp or wet in the bottom. Whether these depressions were once more pronounced, or habitually held water, is not generally known. However, as land would presumably have been cultivated only where drainage was viable and cost-effective, it seems unlikely that the majority of these depressions represent the remains of spring-fed pingos, and are more likely to be attributable to other processes not dependent on the presence of springs, such as chalk solution or thermokarst activity. Alternatively, if water tables increasingly lowered by abstraction gradually reduced the flow of springs, previously wet hollows might have dried to the point where cultivation was deemed feasible. It would be necessary to excavate a trench across some of these features to test this theory.

Fig 22: Different views of a cultivated field at Thompson showing the ploughed-out remains of pingos. Water levels in these features are frequently high enough to prevent harvest, and in wet periods form significant standing pools.
Photos: Andrina Walmsley

Cropped fields at sites in Thompson (see Figure 22 above), Hockham and Northwold contain the remains of what were clearly once water-filled depressions, and remain very wet in the bottom to the extent that harvesting of crops in some years has not been possible (K Stone, *pers. comm).* In some cases, the ploughed features are known to have been pingos and after heavy rainfall and in the winter months may habitually be water-filled.

9. RECOMMENDATIONS

As a result of the work carried out during this project, it is recommended that:

- The database, map and report resulting from this project be distributed to other relevant organisations in Norfolk, including land managers, conservation organisations responsible for giving land management advice, relevant planning authorities, specialist recorders and geological groups

  Target groups: Natural England (NE), Norfolk County Council, Local Authorities, Environment Agency (EA), Forestry Commission (FC), Ministry of Defence (MoD), Norfolk Biological Information Service (NBIS), Farming and Wildlife Advisory Group (FWAG), Internal Drainage Boards (IDBs), countryside projects, land agents, relevant county recorders and geological groups (Geological Society of Norfolk,

- All sites with ground-ice depressions, particularly where these are water-filled and of high biodiversity and geodiversity value, are recognised and protected by local authorities
- Further funding be sought to undertake follow-up work including
  - site survey and notification where relevant
  - site restoration in the case of high quality sites in a state of rapid decline because of lack of management or inappropriate management
  - follow-up of other sites identified as high priority
  - completion of remaining information gaps in the database and digital map

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11. REFERENCES

BALLANTYNE CK and HARRIS C (1994). *The Periglaciation of Great Britain*. (Cambridge University Press)

BEEBEE, TJC, BUCKLEY, J, EVANS, I, FOSTER, JP, GENT, AH, GLEED-OWEN, CP, KELLY G, ROWE, G., SNELL, C, WYCHERLEY, JT, and ZEISSET, I (2005). Neglected native or undesirable alien? Resolution of a conservation dilemma concerning the pool frog *Rana lessonae*. *Biodiversity and Conservation,* 14, 1607-1626

BEEBEE TJC and WYCHERLEY J. (2001). An assessment of pool frog habitat and reintroduction prospects in Britain. (University of Sussex)

BELL, M and Walker, MJC (1992). *Late Quaternary Environmental Change: Physical and Human Perspectives.* (Longman)

BIRKS HH (1976). The history of the flora and fauna of East Anglia. In *Nature in Norfolk – A Heritage in Trust.* (Jarrold Press)

BOREHAM S and HORNE DC. (2005) The role of thermokarst and solution in the formation of Quidenham Mere, Norfolk, compared with some other Breckland meres. (Cambridge University)

BRADSHAW RHW, COXON P, GREIG JRA, HALL AR (1981). New fossil evidence for the past cultivation and processing of hemp *Cannabis sativa* in Eastern England. *New Phytologist,* 89, 503-510

BRYANT RH and CARPENTER CP (1987). Ramparted ground-ice depressions in Britain and Ireland. In *Periglacial Processes and Landforms in Britain and Ireland.* Ed. J Boardman, 183-190

FOSTER GN (1993) Pingo fens, water beetles and site evaluation. *Antenna*, 17, 184-190

FOSTER J (2001). Great crested newt mitigation guidelines. (English Nature)

FRENCH H (2007). *The Periglacial Environment* (Wiley Press)

GENT A (1996). The pool frog: Britain's seventh species of amphibian? Species Conservation Handbook (English Nature).

GURNEY SD (2001). Aspects of the genesis, geomorphology and terminology of palsas: perennial cryogenic mounds. In *Progress in Physical Geography* 25, 2, 249-260

HART JK (1995c). An investigation of the deforming layer/debris-rich ice continuum, illustrated from three Alaskan glaciers. *Journal of Glaciology,* 41, 619-633

HORNBY RJ (1976). Heaths, bogs and fens. In *Nature in Norfolk – a Heritage in Trust.* (Jarrold Press)

IRWIN AG (1987). The fauna of Thompson Common. *Transactions of the Norfolk and Norwich Naturalists' Society*, 27, Part 5, 375-380

JONES, R.L. and KEEN, D.H. (1993) Pleistocene environments in the British Isles. (Chapman & Hall)

KILLEEN IJ (2003). Ecology of Desmoulin's Whorl Snail. *Conserving Natura 2000 Rivers Ecology Series No 6.* (English Nature)

LAMBLEY PW (2005). Natural Area Profile for North Norfolk (English Nature)

NOBES G (2006). A survey of the aquatic Coleoptera of East Harling Common 2005 (English Nature)

PISSART A (2000). Remnants of lithalsas of the Hautes Fagnes, Belgium: a summary of present-day knowledge. In *Permafrost and Periglacial Processes,* 11, 327-355 (Wiley Press)

PRINCE HC (1962). Pits and ponds in Norfolk. In *Erkunde*, 16, 10-31

ROSS N, HARRIS C and BRABHAM PJ (2007) Internal structure and origins of late Devensian 'ramparted depressions', Llanio Fawr, Ceredigion. *Quaternary Newsletter*, 112, 6-21

ROSS N. A re-evaluation of the origins of late Quaternary ramparted depressions in Wales. (Cardiff University)

SPARKS BW, WILLIAMS RBG and BELL FG (1972*).* Presumed ground-ice depressions in East Anglia. In *Proceedings of the Royal Society of London,* Series A, 327, 329-343.

STAGER JK (1956). Progress report on the analysis of the characteristics and distribution of pingos east of the Mackenzie Delta. In *Canadian Geographer,* 7, 13-20

STEPHENS N (Ed). (1990) *Natural Landscapes of Britain from the Air*. (Cambridge University Press).

WASHBURN AL (1973). *Periglacial processes and environments*. (Edward Arnold).

WATTS GD and PETCH CP (1986). Vegetation of the depressions of Thompson Common North. In *Annual Report, Norfolk and Norwich Naturalists' Society.*

WEST RG (1987). Origin of small hollows in Norfolk. In *Periglacial Processes and Landforms in Britain and Ireland* Ed. J Boardman. 191-194

WEST RG (1991). *Pleistocene Palaeoecoloy of Central Norfolk.* (Cambridge University Press)

WHEELER BD and SHAW SC (1992). Biological indicators of the dehydration and changes to East Anglian fens past and present. *Valley Fens of East Anglia* (Report to English Nature)

YAXLEY R (2003). NVC surveys of selected areas at East Walton and Adcock's Common SSSI and Thompson Common SSSI. (Report for Entec UK)

12. APPENDICES

- Appendix 1 Key to Soil Codes
- Appendix 2 Site Assessment Form
- Appendix 3 List of 'Pingo' Database Data Fields
- Appendix 4 Map of Norfolk showing site distribution
- Appendix 5 List of Sites
- Appendix 6 Site Priority Categories

Key to Soil Codes

Soil Type	Key Soil Sub-Group	Lithology	Landscape
343a	Brown rendzinas	Loamy and sandy; chalky drift	Gentle/moderate slopes
343b		Coarse loam and sand; coversand over chalksand and glaciofluvial drift	
511b	Typical brown calcareous earths	Loamy; chalk drift	Gentle lower slopes
551a	Typical brown sands	Sandy and coarse loamy over sandy; glaciofluvial drift and coverloam	Level terraces and valley floors
551c		Sandy, glaciofluvial drift	Level to moderately sloping crests, slopes and terraces
551d			Level and gently sloping lowland
551e		Sandy and loamy; glaciofluvial and non-calcareous drift	Level and gently sloping interfluves
552a	Gleyic brown sands	Sandy and loamy; glaciofluvial and chalky drift	Gentle slopes and plateaux
554a	Argillic brown sands	Sandy; coversand over chalk-sand drift	Level plateaux
554b		Sandy; coversand over chalk-sand and glaciofluvial drift	
555a	Gleyic argillic brown sands	Sandy and coarse loamy; glaciofluvial drift, locally ferruginous over Lower Cretaceous sands	Level and gently sloping interfluves
572a	Stagnogleyic argillic brown earths	Loamy, coarse loamy over sandy and sandy; chalky till, non-calcareous and glaciofluvial drift	Level and gently sloping interfluves
572c		Loamy and sandy; chalky till, non-calcareous drift and coversand over over chalk-sand drift	Level and gently sloping interfluves
572d		Loamy and sandy; chalky till, non-calcareous and glaciofluvial drift	Level and gently sloping interfluves
572e		Loamy and sandy; chalky till, non-calcareous and glaciofluvial drift	Level and gently sloping interfluves
711b	Typical stagnogley soils	Loamy and clayey; drift over chalky till (Chalky Boulder Clay)	Level and gently sloping plateaux
821b	Typical sandy gley soils	Sandy and fine loamy over clayey; glaciofluvial drift over Jurassic clay and chalky till (Chalky Boulder Clay)	Level lowland
821c		Sandy and loamy; glaciofluvial drift and coverloam over till (Norwich Brickearth)	Level and gently sloping interfluves
831a	Typical cambic gley soils	Fine loamy; head and alluvium over gravel	Level, minor valley floors
861a	Typical humic-sandy gley soils	Sandy and peaty; glaciofluvial drift and fen peat	Level valley floors
861b		Sandy, peaty and loamy; glaciofluvial drift, fen peat and chalky drift	Level valley floors
861d		Sandy, peaty and fine loamy over clayey; glaciofluvial drift, fen peat and drift over Jurassic clay	Level lowland

Reproduced from the Soil Survey of England and Wales (Soils of Norfolk), 1973

APPENDIX 2

Site Assessment Form Date of visit:

Site No/Name			
Grid Ref		**Parish**	
District	**Breckland**		**West Norfolk**
	North Norfolk		**Broadland**

Feature Type	**Ponds**	**Dry Hollows**
	Shallow depressions	**Wet silted hollows (woodland)**
	Other (specify)	

Feature characters	**Closely grouped clusters**	**Linear series**
	Loosely scattered	**Dry Wet Variable**
	Varied sizes	**Uniform size**
	No in group 1-10 11-20 over 20 unknown	
	Other (specify)	

Geomorphology	**Obvious ramparts**	**No obvious ramparts**
	Partial ramparts	**Drains**
	Signs of damage	

Overall condition	**Favourable**	**Unfavourable**
	Declining	**Recovering**
	Destroyed	**Variable**
	Other (specify)	

Vegetation	**Aquatic**	**Emergent**
	Marginal	**Fen good poor**
	Woody	**Algae/Lemna sp**
	Grassy Dry Damp Rushy	**Other**

Matrix	**Open grassland**	**Wet woodland**
	Dry woodland	**Woodland type: BL C MXD**
	Scrub	**Mosaic**
	Fen	**Other**

Main threats	**Scrub encroachment**	**Siltation**
	Pollution	**Poaching**
	Modification	**Drainage**
	Enrichment	**Disturbance**
	Over-grazing	**Neglect**
	Cultivation	**Dredging**

Current management	**Grazed Hrs Ctl Shp ?**	**Mown and cleared**	
	Mown not cleared	**Forestry**	
	Unmanaged	**Unknown**	
	Other		
Managed by	**Conservation body**	**FC MOD NE**	
	Corporation	**Private individual**	
	Local authority	**Unknown**	
Recommended Action		Priority	

List of Pingo Database Data Fields

Field Name	Description
GIS ID	*Unique identifier to match database record to map polygon*
Site designation	*Details whether site is a SSSI, CWS, registered common, or undesignated*
Site name	*Either the given name, or a descriptive term for unnamed sites*
District	*The local authority area within which the site is located*
Parish	*The county parish within which the site is located*
Grid reference	*The grid reference given in standard format (eg TG 222152)*
Grid square	*The grid square, or hectad, reference (eg TG)*
Easting / Northing	*Two fields providing the east and north Cartesian coordinates of the site (eg 622200 and 315000)*
Site status	*Indicates whether depressions are extant at the site, or if this is unknown ('unverified')*
Feature type	*Indicates nature of depressions eg ponds, shallow depressions, damp hollows, etc*
Formation	*Indicates whether features within a site are closely grouped, scattered, etc*
Number of features	*Provides broad estimate of number of depressions within the site (ie 1-10,11-20 etc)*
Feature size	*Indicates whether features within a site are broadly uniform or of a variable size*
Hydrology	*Indicates water retention within features eg wet all year, damp, winter wet, variable etc*
Landscape context	*Gives location of site at landscape scale ie valley bottom, mid-slope, top of slope etc*
Metres AOD	*Gives approximate height above sea level (Ordnance Datum)*
Vegetative status	*Describes vegetation within features in broad terms eg woody emergent, poor fen, damp grassland etc*
Geomorphology	*Describes whether features have obvious ramparts, partial ramparts, no obvious ramparts, etc*
Soil type	*Provides soil code for site, based on Soil Association descriptions (see Appendix 1 of this report)*
Matrix	*Provides broad description of landscape context in which site is located eg woodland, grassland, etc*
Potential for great crested newt	*Estimates likely value of site as suitable habitat for GCN, and notes existing records for this species*
Protected status	*Indicates whether site is protected via a designation such as SSSI, or (to a lesser extent) CWS, whether it is a registered common, or whether it is unprotected*
Geology	*Based on the British Geological Survey maps of Norfolk, this field provides the bedrock and drift deposit type for each site. Information unavailable for some sites*
Joint Character Area	*The JCAs are NE categories which define different regions of the UK based on landscape character*
Overall condition	*This field uses the standard condition categories: Favourable, Declining, Recovering, Unfavourable, Destroyed, with the addition of Variable and Unknown*
Main threats	*Indicates the primary* perceived *threat eg scrub encroachment, over-grazing, cultivation etc*
Current management	*Indicates the way in which a site is currently being managed, where known, or where there are non-deliberate factors influencing the condition of the site, such as rabbit-grazing*
Managed by	*Provides generic information about 'who' manages a site eg Ministry of Defence, farmer, private estate*
Recommended action	*Suggests the next, most appropriate course of action for individual sites based on site quality, site requirements, proximity to other sites, etc. Further details are in Appendix 6*
Priority for action	*Sites are prioritised for further action based on a range of factors. Further explained in Appendix 6*

List of Sites with Presumed Periglacial Ground-Ice Depressions

Site Designation	Site Name	District	Grid Ref	Site Status*
CWS	Adj Disused Railway	North Norfolk	TF 938288	Extant
CWS	Adj River Wissey	Breckland	TF 909085	Extant
Undesignated	Adj to CWS 905	Breckland	TF 896004	Unverified
Undesignated	Adj to Doctor's Plantation	West Norfolk	TF 743190	Unverified
Undesignated	Adj to Sugar Fen	West Norfolk	TF 687206	Unverified
Undesignated	Adjacent to CWS 839	Breckland	TL 926978	Unverified
CWS	Babingley Meadow	West Norfolk	TF 705261	Extant
Undesignated	Barton Leys	West Norfolk	TF 696047	Unverified
CWS	Blackmill Meadow	Breckland	TL 963897	Extant
SSSI	Boughton Fen	West Norfolk	TF 718013	Unverified
CWS	Boughton Fen	West Norfolk	TF 717010	Extant
SSSI	Breckland Forest	Breckland	TL 923929	Unverified
SSSI	Breckland Forest	Breckland	TL 939919	Extant
SSSI	Breckland Forest (West Harling Common)	Breckland	TL 963854	Unverified
Undesignated	Breckles Plantation	Breckland	TL 925937	Unverified
CWS	Breckles Wood/Hockham Common	Breckland	TL 956938	Extant
Undesignated	Brick Field	Breckland	TL 910969	Unverified
CWS	Brick Kiln Covert	Breckland	TL 841923	Extant
Undesignated	Brick Kiln Covert/Hospital Hill	Breckland	TL 922918	Extant
Undesignated	Broom Plantation	Breckland	TL 958893	Unverified
Undesignated	Butler's Barn and Butler's Carr	Breckland	TF 745122	Unverified
Undesignated	Buxton Plantation	West Norfolk	TL 730973	Unverified
CWS	Caston Common	Breckland	TL 945967	Extant
Undesignated	Caston Plantation	Breckland	TL 942974	Unverified
CWS	Common Plantation	Breckland	TM 035885	Unverified
Undesignated	Common Plantation and adjacent land	Breckland	TF 733122	Unverified
CWS	Copince's Fen	Breckland	TM 049883	Unverified
Undesignated	Copse south of Starmoor Plantation	North Norfolk	TF 943286	Unverified
Undesignated	Doctor's Plantation	West Norfolk	TF 741189	Unverified
Undesignated	Eartholes Plantation	Breckland	TL 915971	Extant
CWS	East Harling Fen	Breckland	TM 000874	Unverified
SSSI	East Harling Fen	Breckland	TL 998878	Extant
Undesignated	East of Boughton Fen SSSI	Breckland	TF 722013	Unverified
Undesignated	East of Foulden Common	Breckland	TF 776007	Unverified
Undesignated	East of Lamb's Holes	Broadland	TG 224177	Unverified
CWS	Eastwood Farm Meadow and adjacent land	West Norfolk	TL 761960	Extant
Undesignated	Eccles Common	Breckland	TM 030886	Extant
Undesignated	Engine Carr	North Norfolk	TF 873262	Unverified
CWS	Furze Allotment	Breckland	TL 949935	Extant
CWS	Gayton Thorpe Common	West Norfolk	TF 732178	Extant
CWS	Gayton Thorpe Wood	West Norfolk	TF 738187	Extant
CWS	Hargham Estate	Breckland	TM 024907	Unverified
CWS	Heater Plantation	Breckland	TL 965903	Unverified
CWS	Helhoughton Common (East)	North Norfolk	TF 870274	Unverified
CWS	Helhoughton Common (North)	North Norfolk	TF 861276	Extant
CWS	Hills and Holes	Breckland	TL 960910	Extant
Undesignated	Holt Plantation	West Norfolk	TF 717162	Unverified
CWS	Hopton Carr	Breckland	TL 866977	Unverified
CWS	Illington Carr/Fen Carr	Breckland	TL 951902	Unverified
Undesignated	Jarrod's Belt	West Norfolk	TL 729977	Unverified
SSSI	Kettlestone Common (River Wensum)	North Norfolk	TF 962296	Unverified
Undesignated	Kingston's Plantation	West Norfolk	TF 612045	Unverified
CWS	Lakes and River	Breckland	TL 992914	Unverified
CWS	Lamb's Common & the Narboroughs	West Norfolk	TF 730172	Extant
Undesignated	Lamb's Holes	Broadland	TG 217180	Extant
Undesignated	Land adj to Leziate Church	West Norfolk	TF 698186	Unverified
Undesignated	Land adj to Starmoor Plantation	North Norfolk	TF 942287	Unverified
Undesignated	Land adjacent to Boughton Fen	Breckland	TF 719010	Unverified
Undesignated	Land adjacent to Bradcar Farm	Breckland	TL 990913	Unverified
Undesignated	Land adjacent to Nook Farm	West Norfolk	TF 708224	Unverified
Undesignated	Land adjacent to Wood Lane	Breckland	TF 909069	Unverified
Undesignated	Land adjacent to Wood Lane	Breckland	TF 906068	Unverified
Undesignated	Land at Bintree	Breckland	TG 019241	Unverified
Undesignated	Land at Coppins Farm	Breckland	TM 047884	Unverified

Undesignated	Land at Coppins Farm	Breckland	TM 044883	Unverified
Undesignated	Land at Drayton	Broadland	TG 181129	Unverified
Undesignated	Land at Drayton	Broadland	TG 179129	Unverified
Undesignated	Land at Foulsham	North Norfolk	TG 025243	Unverified
Undesignated	Land at Guist	Breckland	TG 010249	Unverified
Undesignated	Land at Twyford	Breckland	TG 010245	Unverified
Undesignated	Land at West End	Breckland	TF 912089	Unverified
Potential CWS	Land east of Guist	Breckland	TG 004254	Extant
CWS	Land Near Linger Hill	Breckland	TL 967919	Unverified
Undesignated	Land near Stonehouse Farm	Breckland	TL 960853	Extant
Undesignated	Land north of Boughton Fen SSSI	West Norfolk	TF 719024	Unverified
Undesignated	Land north of Congham House	West Norfolk	TF 721234	Unverified
Undesignated	Land north of CWS 731	Breckland	TL 898999	Unverified
Undesignated	Land north of Hockham Belt	Breckland	TL 926922	Extant
Undesignated	Land south of Crow's Farm	Breckland	TL 905990	Unverified
Undesignated	Land south of East Farm	Broadland	TG 232161	Unverified
CWS	Land South of Hills and Holes	Breckland	TL 969908	Unverified
Undesignated	Land south of Manor Farm	Breckland	TF 918089	Unverified
Undesignated	Land west of Mildrift Cottage	Breckland	TL 965919	Believed extant
CWS	Lane Meadow	Breckland	TL 916910	Extant
CWS	Larling Fen	Breckland	TL 983898	Extant
Undesignated	Ling Hills	West Norfolk	TF 667101	Unverified
SSSI	Little Ryburgh Common (River Wensum)	North Norfolk	TF 964297	Unverified
Undesignated	Long Plantation	West Norfolk	TF 722163	Unverified
Undesignated	Low Common	Broadland	TG 208203	Unverified
CWS	Lower Stow Bedon	Breckland	TL 982949	Unverified
Undesignated	Mansom Plantation	Broadland	TG 204202	Unverified
CWS	Marham Fen	West Norfolk	TF 724113	Extant
CWS	Mauley's Carr (adj Middle Harling Fen SSSI)	Breckland	TL 991858	Unverified
Undesignated	Meadows at High House Farm	North Norfolk	TG 034240	Unverified
Undesignated	Meadows at Westfield Farm	North Norfolk	TG 027239	Unverified
CWS	Merton Common	Breckland	TL 894994	Extant
SSSI	Middle Harling Fen SSSI	Breckland	TL 989852	Extant
CWS	Moor's Common	West Norfolk	TF 725176	Extant
Undesignated	Narborough Common	Breckland	TF 734116	Unverified
Undesignated	Narborough House	West Norfolk	TF 744134	Unverified
Undesignated	NE of Sandpit Plantation	Breckland	TL 938947	Extant
CWS	New Decoy	Breckland	TL 922908	Unverified
CWS	North of Barker's Farm	Breckland	TL 976906	Extant
Undesignated	North of Great Ryburgh Common	North Norfolk	TF 939293	Unverified
Undesignated	North of Hempton Green	North Norfolk	TF 913293	Extant
Undesignated	North of Lady's Lane	Broadland	TG 226182	Unverified
Undesignated	North of Leziate Church	West Norfolk	TF 699190	Unverified
CWS	North of Lower Stow Bedon	Breckland	TL 976954	Extant
CWS	North of Northacre	Breckland	TL 959990	Unverified
Undesignated	North of RAF Marham	Breckland	TF 744105	Unverified
Undesignated	North-east of Feltwell	West Norfolk	TL 727918	Unverified
CWS	North-east of Thompson	Breckland	TL 930974	Extant
Undesignated	Northwest of Long Plantation	Breckland	TF 751099	Unverified
Undesignated	Old Pasture Plantation & Young Wood	West Norfolk	TF 732183	Unverified
CWS	Part of Bones Barn	Breckland	TL 774998	Extant
SSSI	Part of Boughton Fen	West Norfolk	TF 719017	Extant
SSSI	Part of Breckland Forest	Breckland	TL 929924	Unverified
SSSI	Part of Breckland Forest	Breckland	TL 929911	Unverified
SSSI	Part of Breckland Forest (Fox Covert/Frosts's Comm	Breckland	TL 945931	Extant
SSSI	Part of Breckland Forest (Queen's Close)	Breckland	TL 937907	Extant
CWS	Part of Cockley Cley Meadows and Stream	Breckland	TF 777032	Unverified
SSSI	Part of East Walton & Adcock's Common	West Norfolk	TF 748150	Extant
SSSI	Part of Foulden Common	Breckland	TF 765003	Extant
CWS	Part of Griston Road Meadow	Breckland	TL 925976	Extant
National Trust	Part of Home Covert	Breckland	TF 741005	Unverified
CWS	Part of Kettlestone Fen	North Norfolk	TF 964302	Extant
Undesignated	Part of Larch Wood	Breckland	TF 767061	Unverified
Undesignated	Part of Moor Plantation	Breckland	TL 786973	Unverified
CWS	Part of Necton Common	Breckland	TF 898087	Extant
CWS	Part of Pentney Common	West Norfolk	TF 743135	Extant
CWS	Part of Sculthorpe Mill and Meadows	North Norfolk	TF 908301	Unverified
CWS	Part of Sculthorpe Moor and Meadows	North Norfolk	TF 893299	Extant
CWS	Part of Sculthorpe Moor and Meadows	North Norfolk	TF 903296	Unverified
Undesignated	Part of Spring Covert	Breckland	TL 789964	Unverified

SSSI	Part of STANTA	Breckland	TL 906949	Extant
SSSI	Part of STANTA	Breckland	TL 846930	Extant
Undesignated	Part of Starmoor Plantation	North Norfolk	TF 942287	Extant
Undesignated	Pasture adjacent to CWS 819	Breckland	TL 918910	Unverified
Undesignated	Pasture adjacent to Dawkin's Covert	West Norfolk	TL 757962	Extant
Undesignated	Pasture adjacent to Moor's Plantation	West Norfolk	TF 727176	Extant
Undesignated	Pasture adjacent to Queen's Close	Breckland	TL 944904	Extant
Undesignated	Pasture adjacent to Starmoor Wood	North Norfolk	TF 942286	Extant
Undesignated	Pasture at Gooderstone	Breckland	TF 763024	Extant
Undesignated	Pasture at Helhoughton	North Norfolk	TF 870266	Extant
Undesginated	Pasture at Horsham	Broadland	TG 222152	Unverified
Undesignated	Pasture at Horsham St Faith	Broadland	TG 215155	Extant
Undesignated	Pasture at Manor Farm	Breckland	TL 916907	Extant
CWS	Pasture in Wretham	Breckland	TL 924904	Extant
Undesignated	Pasture south of Congham village	West Norfolk	TF 713232	Unverified
Undesignated	Pasture South of Gayton Thorpe Wood	West Norfolk	TF 738184	Extant
Undesignated	Pasture South of Manor House	West Norfolk	TF 741183	Extant
Undesignated	Pingos within ploughed field	Breckland	TL 925939	Extant
Undesignated	Romer Plantation	West Norfolk	TF 713001	Unverified
Undesignated	Sandpit Plantation	Breckland	TL 934942	Extant
Undesignated	Sandpit Plantation	Breckland	TL 971863	Unverified
CWS	Sandy Bottom	Breckland	TL 974877	Extant
Undesignated	Scotgate Plantation	Breckland	TL 953935	Extant
Undesignated	Shadwell's Plantation	Breckland	TL 784892	Extant
Undesignated	Site west of Narborough	Breckland	TF 741126	Unverified
Undesignated	South of Contract Plantation	Breckland	TF 752105	Unverified
Undesignated	South of Cowle's Drove	West Norfolk	TL 710870	Unverified
Undesignated	South of Helhoughton Common	North Norfolk	TF 869271	Unverified
Undesignated	South of Hempton Moor	North Norfolk	TF 902295	Unverified
CWS	South of Hills and Holes	Breckland	TL 964904	Extant
SSSI	South of Langor Bridge (River Wensum)	North Norfolk	TF 959289	Unverified
Undesignated	South of Sugar Fen	West Norfolk	TF 692204	Unverified
Undesignated	South of Thompson Common	Breckland	TL 933953	Unverified
CWS	South of Wissey Tributary	Breckland	TF 894004	Unverified
Undesignated	South-east of Cockley Cley Clumps	Breckland	TF 837037	Unverified
Undesignated	South-East of West Rudham Common	West Norfolk	TF 825277	Unverified
CWS	South-east of Whitehouse Farm	Breckland	TF 730001	Extant
Undesignated	South-West of Coxford	West Norfolk	TF 842288	Unverified
CWS	Sparrow Hill Meadow	Breckland	TL 911967	Unverified
Undesignated	Spring Covert	Breckland	TL 792960	Extant
CWS	Starmoor Belt	North Norfolk	TF 951284	Extant
SSSI	Starmoor Plantation (part of River Wensum SSSI)		North Norfolk	TF
938289	Extant			
Undesignated	Starmoor Wood	North Norfolk	TF 938287	Extant
CWS	Stow Bedon Meadow	Breckland	TL 939967	Extant
SSSI	Sturston Carr	Breckland	TL 880952	Unverified
Undesignated	Tennis Plantation	West Norfolk	TL 719932	Unverified
Undesignated	The Anchorage and adjacent land	West Norfolk	TF 839287	Unverified
Undesignated	The Carr	North Norfolk	TF 930282	Unverified
Undesignated	The Clumps	Breckland	TL 963887	Unverified
Undesignated	The Lodge	Breckland	TF 903027	Unverified
CWS	The Spinney	Breckland	TL 962938	Unverified
CWS	The Wilderness	Broadland	TG 214164	Extant
SSSI	Thompson Water, Carr and Common	Breckland	TL 930955	Extant
CWS	Thompsonhall Meadow	Breckland	TL 923954	Extant
CWS	Tuzzy Muzzy	Breckland	TL 976908	Extant
SSSI	Walton Common	West Norfolk	TF 734164	Extant
CWS	Walton Woods and Osierbed Plantation	West Norfolk	TF 740156	Extant
Undesignated	West of My Lord's Wood	Breckland	TL 738997	Unverified
Undesignated	West of Starmoor Wood	North Norfolk	TF 931285	Unverified
CWS	West of Walton Common and Oldlands Wood	West Norfolk	TF 730165	Extant
CWS	West Rudham Common	West Norfolk	TF 823279	Extant
Undesignated	Whin Carr	North Norfolk	TF 842288	Extant
Undesignated	Whin Carr and adjacent land	West Norfolk	TF 850286	Extant
SSSI	Whitwell Common	Broadland	TG 086204	Extant
Undesignated	Woodland adjacent to Babingley River	West Norfolk	TF 702256	Unverified
Undesignated	Woodland adjacent to Breckles Grange	Breckland	TL 944942	Unverified
Undesignated	Woodland adjacent to CWS 819	Breckland	TL 918907	Unverified
Undesignated	Woodland at Colkirk Hill	North Norfolk	TF 916271	Unverified
Undesignated	Woodland at Guist	Breckland	TG 008250	Unverified

Undesignated	Woodland in Hilborough	Breckland	TL 848996	Unverified
Undesignated	Woodland near Flint Farm	Breckland	TL 986870	Unverified
Undesignated	Woodland north of Congham Hall	West Norfolk	TF 713230	Unverified
Undesignated	Woodland north of Four Score	Breckland	TF 779015	Unverified
Undesignated	Woodland south of Flint Farm	Breckland	TL 982865	Unverified
Undesignated	Woodland south of Holme Hale Hall	Breckland	TF 904071	Unverified
Undesignated	Woodland south of Pentney Common	Breckland	TF 736128	Unverified
Undesignated	Woodland south of Queen's Close	Breckland	TL 934903	Unverified
Undesignated	Woodland south of Roudham Hall	Breckland	TL 963869	Unverified
Undesignated	Woodland south of Roudham Hall	Breckland	TL 960867	Unverified
Undesignated	Woodland south of Shadwell's Plantation	Breckland	TL 783886	Extant
Undesignated	Woodland south of Walton Common Woodland	West Norfolk	TF 727153	Unverified

** Site Status has been allocated as ‘unverified’ where hollows that are presumed to be periglacial are thought to occur, based on desk study; and as ‘extant’ where the site has been visited*

APPENDIX 6

Breakdown of Priority Categories Awarded to Individual Sites

Recommended Action	Site Category	Site Type	Priority Rating
Facilitate restoration	Good quality CWS in rapid decline		= 1* / 1
Management plan	a) Sites being restored b) Sites in management but requiring guidance/changes		= 1 = 2
Management advice	Less complex and lower quality sites where management could be improved		= 2
Survey as pCWS	Sites >2ha where depressions are believed/known to occur	• Open and mosaic sites • Wooded sites	= 1 = 2
Re-survey	CWS not surveyed for 15 years or more	• Open/mosaic sites • Wooded sites	= 2 = 3
Assess condition and potential for restoration	a) CWS with known pingos not visited for 10+ years b) CWS with unverified pingos	• Open and mosaic sites / wooded • Open and mosaic sites / wooded	= 1 / 2 = 2 / 3
Establish ownership/ follow up	a) High quality sites without public access “ “ b) Sites of lower interest	• Large open / mosaic sites • Wooded sites in key areas • Open / wooded	= 1 = 2 = 3 / 4
Verify presence of ground ice depressions	All unverified sites	• In open heavily marked • In wooded heavily marked areas • Elsewhere	= 2 = 3 = 4
No action	Very small sites, those already in good care, or those of poor inherent quality		= 0