Defining and Mapping Pond Irreplaceable Habitat

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Contents

1 Project aims

High quality ponds are a priority habitat (now a 'habitat of principal importance') under Section 41 (S41) of The Natural Environment and Rural Communities (NERC) Act, 2006, with the criteria for identifying them listed in BRIG, 2008.

The purpose of this report is to describe two specific types of priority pond that are considered irreplaceable habitats for biodiversity net gain purposes. These are:

- Ice age ponds.
- Ponds with long established floating vegetation mats including a bryophyte layer and diverse wetland plant community.

Both pond types have been identified as irreplaceable on the basis that they cannot be re-created within 100 years. However, for these pond types to be taken forward as irreplaceable habitat in policy, a description, method of identification and map are required.

2 Methodology

Definitions were drafted by the authors and then circulated for comment to experts in the fields of pond and wetland ecology and Pleistocene geomorphology.

The habitat type 'Ponds with long established floating vegetation mats including a bryophyte layer and diverse wetland plant community' has been exceptionally poorly documented in England, and known sites were compiled through data collected by the authors and through a mail-out to practitioners.

Lists of known sites for 'Ice-Age Ponds' were collated based on pre-exiting published data and grey literature, with additions from authors (WW and GK-S) who were involved in surveys in Herefordshire.

3 Ice age ponds

3.1 Definition

Ice Age Ponds are defined as ponds created as a result of glacial and periglacial activity during the Pleistocene period 2,580,000 to 11,700 years ago. The majority of existing ice age ponds were formed during the last glacial period, the Devensian Glaciation, 115,000 to 11,700 years ago.

They include ponds created by the direct erosional and depositional action of glaciers and their outwash, together with ponds created by periglacial activity in cold regions not always directly affected by glaciers.

Pond types included in this definition are:

(i) Ponds in ground ice depressions, including pingos, palsas and lithalsas

(ii) Kettle hole ponds, including some smaller meres[1]

(iii) Ponds developed from glacial outwash and subglacial channels

(iv) Small tarns, defined *sensu stricto,* as glacial age ponds created by the erosion of ice[2]

(v) Other ice-age ponds

The last category includes a relatively small number of Pleistocene structures that are of more ambiguous origin or not easily classifiable. There are also features, e.g. ponds in solution hollows, where the majority of examples are of Holocene age (i.e. post-glacial), but Pleistocene examples are known or suspected (e.g. Prince 1962). In both cases, the defining characteristic is that features are ice-age associated (e.g. known or highly likely to be of Pleistocene age), rather than concerns over their mode of origin or the mechanisms by which they formed.

3.2 Criteria for defining the pond type

To qualify as an Ice Age Pond a waterbody must be:

- **A Pond:** a standing waterbody between 1 m^2 and 2 ha in area. Ponds can hold water permanently or seasonally: potentially drying for up to 8 months of the year.
- **Created during the Pleistocene period**: i.e. known to have been created, or highly likely to have been created, during the Earth's most recent period of repeated glaciations, 2,580,000 to 11,700 years ago.

Ice age ponds are defined and identified by physical criteria such as their shape and the characteristics of the lithology and landscape that they lie within.

The biological quality of the pond and their species assemblages are not qualifying criteria. However, it is worth noting that England's Ice Age Ponds support some of the UK's most important freshwater assemblages including relict species that are rare and endangered in other habitat types (see Section 4.4).

The main criteria by which the different pond types can be recognised are given below. However, in lowland areas there is often considerable overlap between the characteristics of closed, and semi-closed depressions created as kettle hole, and by ground ice and outwash

[1] Some, but not all meres are of glacial origin. The Breckland meres, although ice-age ponds, are included as irreplaceable habitats under the category 'Aquifer fed naturally fluctuating water bodies ' and are not discussed further in this report.
[2] 'Tarn' is often used in Northern England as a general term to refer to small waterbodies, but in glacial terminology has a specific meaning as defined in this report.

channels. Detailed geological investigation is generally needed to determine the precise type of pond in terms of its formation and even then, the origin(s) may not be completely clear. *However, to qualify as an ice age pond, the key criterion is simply a 'Pleistocene origin', not a clear-cut understanding of the processes which created the original basin feature*. This means that, where a Pleistocene origin has not already been established, topographic and geophysical evidence will usually be sufficient to confirm this.

Ponds in ground ice depressions (including pingos, palsas and lithalsas)

These waterbodies are created when a lens of ice accumulates just beneath the surface in periglacial (i.e. permafrost) areas. This ice may grow to form a mound several metres high. Soil and sediment often slips off the dome towards the edges to create a raised rim. Once the ice melts, water may accumulate in the basin to create a pond, and there may be a characteristic 'rampart' around the pond left by the earth slip. There is considerable research into, and some disagreement about, the differences between pingos, palsas and lithalsas, and how they form (see Appendix 3). However, pond basins created by these features share common defining characteristics.

<u>Criteria:</u>

- *Maps, records and inventories*: these features will usually be present on 1st edition Ordnance Survey maps. However, some examples including seasonal ponds, may be shown as wetland or marsh on these maps rather than marked as ponds. They typically occur in geographical clusters. They are usually found on plains, valley floors and lower valley sides.
- *Geology*: Ground ice ponds will be located on strata shown on geology maps as superficial deposits of Pleistocene age. The exception is where deep depressions formed in the Pleistocene have been subsequently covered by recent river alluvium. Hence, where clusters of ice-age ponds are already known, ponds located on alluvial strata, overlying Pleistocene deposits on geology maps should also be checked for an ice-age origin (Appendix 3). For example, auguring may reveal layers of peat sandwiched between glacial sediments and more recent alluvium showing that the pond was active during the Pleistocene.
- *Topography, shape, size and structure*: Ground ice ponds typically occur in clusters. They have a characteristic basin-shaped structure and often lie in a closed depression[3]. Ground ice ponds are often rather shallow, or seasonal waterbodies, land typically occur in basins with a rounded or elongate shape. The pond basins often have a rather artificial appearance, with evenly-sloping sides and raised, rampart-like bank-tops (Figure 4.1). In Herefordshire (one of the main focal areas for these ponds), ground ice ponds are typically closed systems which do not have an inflow or outflow (except occasionally where ditch drainage has been added). Closed basin structures are unusual for non-glacial ponds, and together with the underling geology, and their occurrence in clusters, this is a strongly indicative feature of this waterbody type (see examples in Appendix 2). In East Anglia, ground ice ponds may also occur in areas specifically associated with spring activity (e.g. East Walton Common) (See Appendix 3). Although typically full of sediment and appearing to be shallow features in the modern day, these structures were usually deep holes when they first filled with water, and they may have sediment depths of 15 m or more (Lewis, and Richards, 2005).

A combination of methods and approaches can be useful to identify ground-ice features. LIDAR can be useful to provide more detailed topographic information about the current surface shape of the basin in which ponds lie. Geophysical surveys may be appropriate to confirm the deep basin shape present *below* the more recent pond sediments. Sediment

[3] Closed depression: a bowl or saucer shaped depression without an inflow or outflow.

cores can be used to definitively date the age of basal pond sediments, and trenches to investigate the stratigraphy of the ramparts and basin. (Appendix 2).

Figure 4.1. A ground ice depression showing a typical rampart-like bank (top right) formed by the collapse of an ice lens (Photo credit Martin Hammond)

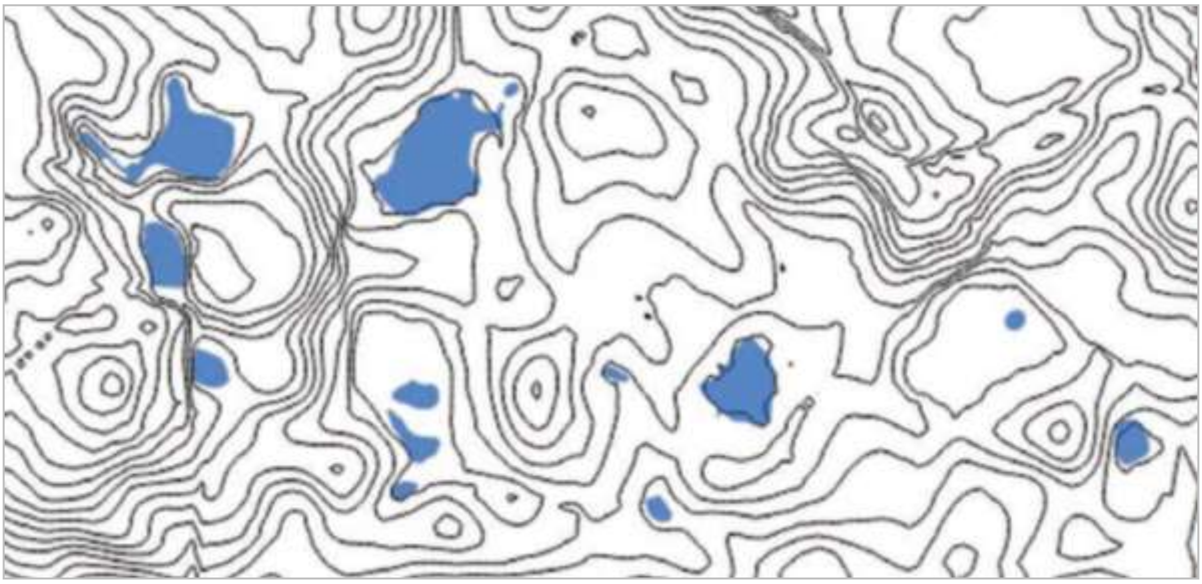

Figure 4.2 LIDAR image of a cluster of ground-ice ponds in Herefordshire. Contours at 1 m intervals show ponds each lying in their own closed depression. Credit: Herefordshire Wildlife Trust

Kettle Hole Ponds

Kettle hole ponds are created by the melting of a mass of ice. The ice generally represents stagnant glacial ice, or ice calving from the end of a glacier, although other modes of formation are also possible. These ice blocks can become embedded in, or surrounded by, glacial sediment, so that when the ice eventually melts a kettle hole is created which may retain water to create a pond or lake.

Criteria:

- *Maps, records and inventories*: these features will usually be present on 1st edition Ordnance Survey maps. However, some examples including seasonal ponds, may be shown as wetland or marsh, rather than marked as ponds. Because they are directly associated with the presence of glaciers, in England they do not occur south of the area of glacial cover shown in Figure 4.4.
- *Geology*: typically located on glacial tills, in some areas particularly associated with hummocky moraine (e.g. Herefordshire). In some areas deep depressions formed in the Pleistocene may have been subsequently covered by recent river alluvium. Hence, particularly where *clusters* of ice-age ponds are known, ponds located on alluvial strata should also be investigated for an earlier ice-age origin (Appendix 3). Auguring may reveal layers of peat sandwiched between glacial sediments and more recent alluvium showing that the pond was active during the Pleistocene.
- *Topography, shape, size and structure*: Kettle hole ponds are located in closed depressions within their own catchment area. They do not naturally have outflows. The size of the kettle holes can be as small as 5 m in diameter, their maximum size far exceeds the 2 ha limit for a pond. Kettle hole structures can occur singly, but are characteristically found together in clusters, often in association with other ice-age features.

A combination of methods and approaches can be useful to identify these features. LIDAR can be useful to provide more detailed topographic information about the current shape of the basin in which ponds lie. Geophysical surveys may be appropriate to confirm the closed-depression basin shape present *below* the more recent pond sediments. Dating of core samples can be used to determine the age at which ice age ponds began accumulating sediments (Appendix 2).

Glacial Outwash and Subglacial Channels

Glacial channels are created by streams and rivers emerging from or flowing underneath glaciers. Because of the considerable volume of water that can be disgorged, these channels may be of considerable size. Although originally created as linear features, ponds can be created either contemporaneously when channels switch (e.g. to create cut-off channels), or at a later date when abandoned channels fill with more recent sediments.

- *Maps and records/inventories*: e.g. usually present on historic maps and typically associated with river valleys. May be fed by springs emerging from higher ground.
- *Geology*: created in sediments of Pleistocene age, however the channels and surrounding area may be covered by more recent alluvium.
- *Topography, shape, size and structure*: typically showing evidence of having been created by river channel erosion: for example a waterbody with a broadly linear structure, or a linear chain of pools within a longer depression.

LIDAR and aerial photography can be particularly useful to provide evidence of the presence of ponds located within a broader linear depression created by the partially infilled river channel. Geophysical surveys may be appropriate to confirm this shape below the more recent pond sediments. Sediment cores can be used to definitively date the age of basal pond sediments (Appendix 2).

Figure 4.3. The Lawn Pool at Moccas Park NNR. The Lawn Pool and other ponds form a chain that may represent a subglacial channel. Photo credit: Will Watson

Tarns

Tarns are small mountain waterbodies located at the base of a steep-walled amphitheatre-shaped feature typically termed a coombe, or coomb in England (cwm in Wales, corrie in Scotland and Ireland, cirque in France). Coombes form at the mouth of a valley glacier where ice masses and associated processes gouge out a, usually over-deepened, basin. Water accumulates in the depression after the glacier has retreated.

Criteria:

- *Maps, records and inventories*. Tarns will be evident as waterbodies on historic maps; occurring in upland areas that have been directly covered by glaciers during the Pleistocene[4].
- *Geology*. Geology maps show that tarns are partially or wholly located on bedrock, and typically associated with glacial moraines or talus in their surrounds.
- *Topography, shape, size and structure*: tarns lie in hollows, eroded by, and often over-deepened by, ice scour. They often have steep headwalls, typically on three sides, with a lower bank on the downhill side. The downhill end of the tarn may be blocked by moraine, glacial till, or be created by a lip of the underlying bedrock. Most tarns have an outflow.

Geophysical surveys may be appropriate, if necessary, to confirm the basin shape prior to sediment deposition. Sediment cores can be used to date the age of the oldest pond sediment (Appendix 2).

[4] Waterbodies named as a 'tarn' on maps will not always be of glacial origin and other criteria are required to identify them. Equally many glacial tarns are not named as tarns on Ordnance Survey maps.

3.3 Distribution

It has been estimated that around 1% of Britain's ponds are of ice age origin (Herefordshire Wildlife Trust 2022). However, the majority of these will inevitably be located in the more heavily glaciated areas of Scotland and Wales. In England their distribution is not uniform, with concentrations in counties such as Herefordshire, Norfolk, Northumberland and Cumbria.

Broad distribution:

- Tarns, kettle holes and most ponds created in glacial outwash channels have a distribution restricted to areas directly covered by glacial activity (Figure 4.4). Hence they are not found south of the area covered by the Anglian glaciation.
- Pingos, palsas and lithalsas: can potentially be found anywhere in England because they can be created in periglacial areas south of the maximum glacial extent, as well as in previously glaciated areas that become subject to periglaciation as glaciers retreated. Clusters of these ponds are known in East Anglia and Herefordshire/the Welsh borders, but they are also recorded from the Thames basin, Cumbria and Isle of Man (Ballantyne and Harris 1994).

Specific distribution:

Although there is the potential for ice age ponds to occur across England, the majority of sites have been identified from four areas:

- Norfolk, including Breckland
- Herefordshire, Shropshire, Cheshire and west Staffordshire
- Cumbria
- NE England, particularly Northumberland

Within these regions, ice age ponds are further limited to areas of Pleistocene superficial deposits, with the exceptions of: (i) locations where river alluvium has recently covered the older Pleistocene sediments and (ii) mountainous areas where glacier ice has gouged hollows directly into bedrock. In the latter case, ponds are always in areas also associated with glacial sediments.

Figure 4.4. Maximum southern limit of glacial ice in Britain during the Devensian glaciation 115,000 to 11,700 years ago. South of this line, only ponds created in periglacial landscapes are expected.
Note that glacial ice spread further south than this line in the Anglican glaciation which ended 424,000 years ago, however ponds created directly by glacial ice in this more southerly zone are likely to have been filled in by natural processes during subsequent periods.
Modified from Elhers and Gibbard 2004

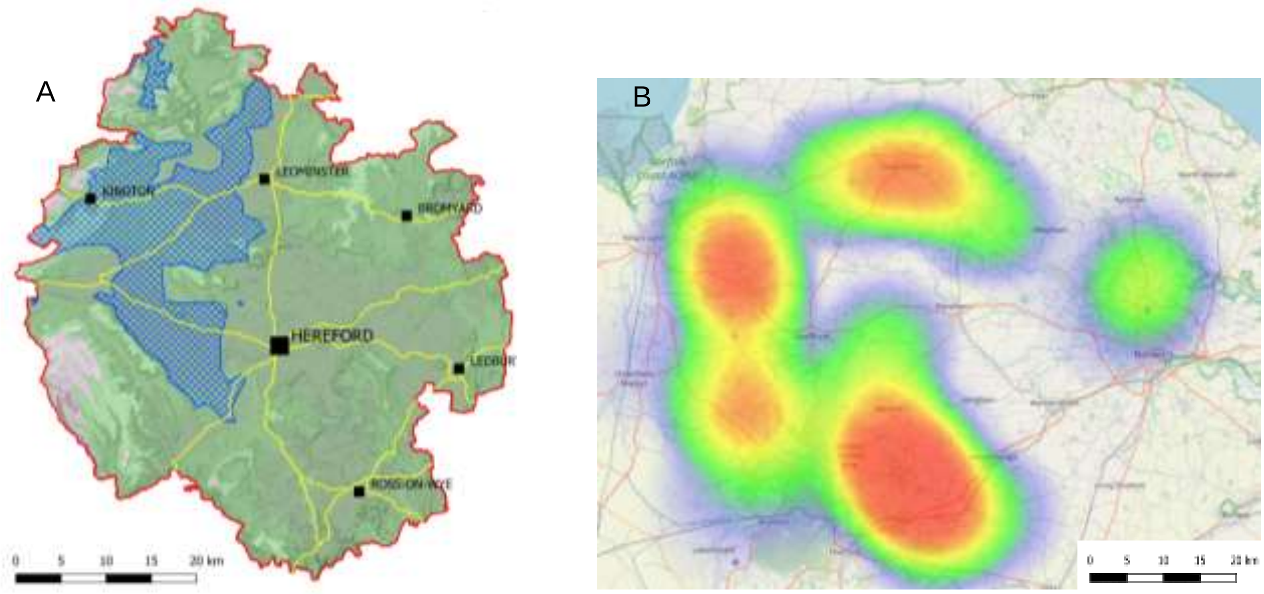

Figure 4.5. Two regions in England with some of the most significant concentrations of ice age ponds. A. The county of Herefordshire where a range of ice age pond types occur in areas of moraine from the Devensian Glaciation (shaded blue). B. A heat map showing the distribution and concentration of ground ice depressions in Norfolk identified by the Norfolk 'Pingo' Mapping Project 2008.

3.4 Habitat description

3.4.1 Biodiversity value

England's Ice Age Ponds support some of the most important freshwater assemblages in the UK including relict species that are rare and endangered in other habitat types. For example, in a 2014 survey of just 10% of the ground ice ponds on Thompson Common, Norfolk, Hammond (2014) recorded, *inter alia*, 20 red listed and 18 Nationally Scarce water beetles, marsh beetles, reed beetles and aquatic weevils including *Hydroporus glabriusculus*, *H. scalesianus* and *Dryops griseus*; together with a range of rare water snails e.g. Shining Ramshorn (*Segmentina nitida*) and the Scarce Emerald damselfly *Lestes dryas*. Many of the species recorded are endangered in Britain or in Europe as a whole. A high proportion of invertebrates were also relict fen taxa found only in long established wetlands. Amongst the wetland plants were 21 red listed species including Milk parsley (*Peucedanum palustre*), Frogbit (*Hydrocharis morsus-ranae*), Fen pondweed (*Potamogeton coloratus*) and Marsh Stitchwort (*Stellaria palustris*), together with restricted and declining plants such as Saw Sedge (*Cladium mariscus*) and the floating liverwort Fringed Heartwort (*Ricciocarpos natans*).

In Herefordshire, another recognised centre for ice age ponds, including kettle hole, ground ice and glacial channel ponds, the wide range of uncommon and restricted species includes important assemblages of water beetles. Red-listed species restricted to ice age ponds include the diving beetles *Graphoderus cinereus* and *Agabus undulatus* (Figure 4.7), the water scavenger beetle *Helochares obscurus* and the long-toed water beetle *Dryops auriculatus*, while other species including *Enochrus nigritus* and *Hydrochus elongatus* are also largely restricted to ice age ponds in the county. *Euconomelus lepidus*, a planthopper commonly found on spike rush, was newly discovered recently in Herefordshire at two ice age pond sites. Other notable species of these pools are Medicinal Leech (*Hirudo medicinalis*) and the red listed plants: Tubular Water-dropwort (*Oenanthe fistulosa*), and

Water Violet (*Hottonia palustris*). Moccas Park Lawn Pool, likely formed in an ancient glacial channel (Figure 4.3), is the only site in Herefordshire for Bladderwort (*Utricularia australis*).

Kettle holes in the north-east of England also include uncommon and poorly-dispersive invertebrate species such as the diving beetles *Agabus labiatus* and *A. uliginosus*. Small northern tarns can also support equally important assemblages including Medicinal Leech (*Hirudo medicinalis*), as well as Lesser Water-plantain (*Baldellia ranunculoides*) and the Habitat Directive priority species Floating Water-plantain (*Luronium natans*).

Figure 4.6 Birtley Pond, a Herefordshire kettle hole that supports Water Violet (*Hottonia palustris*). Photo credit: Will Watson

Key features that help to make ice age ponds especially ecologically valuable include:

- Age and continuity: these ponds often support poorly dispersing, relict species that find it difficult to colonise new waterbodies
- Clustering in the landscape, enabling species metapopulations to flourish
- The prevalence of closed depressions for some ice age pond types: the small catchment size, and usually the absence of inflows helps to protect these waterbodies from pollution
- Great variety of sizes, providing habitats for a wide range of species and therefore high regional species richness
- Varied hydrology: ranging from highly temporary to permanent, again encouraging high regional species richness
- Shallow, saucer-shaped profile with a broad drawdown zone, encouraging diverse assemblages of marginal species
- Most ice age ponds are naturally fish free, being above the level of river floodplains and not being connected to streams.

Figure 4.7. The red listed (NT) diving beetle *Agabus undulatus.* British populations are now centred on ice age pond and fen sites in Norfolk and the Fens, but it has also been recorded from Herefordshire where it is restricted to a single ice age pond. The species has now disappeared from outlying sites in southern and western England and survives precariously at a single northern site. Photo credit: Martin Hammond.

3.4.2 Threats

Ice age ponds are vulnerable to a wide range of threats that can impact both their quality and survival. Of particular importance are:

- Pollution, especially agricultural runoff where waterbodies are located in farmland
- Infilling, draining and ploughing: many ice age ponds are small and some are seasonal waterbodies. This means that, where there is lack of awareness, these features are easy to destroy. Ice age ponds in arable land are particularly vulnerable.
- Deepening and enlarging: commonly undertaken to create ponds for fish such as carp. Deepening and the addition of fish are ecologically damaging in their own right, but also remove geologically valuable sediments that record each pond’s unique and ancient history.
- Removal of traditional grazing (or addition of fencing) and subsequent scrub/tree growth increases pond shade which can reduce biodiversity value where shading is very heavy. Similarly, cessation of traditional routine tree management (e.g. repollarding) can lead to mature Crack Willows overgrowing and collapsing into ponds.
- Tree planting close to ponds, which causes excessive shading and siltation
- Invasive plant species, particularly New Zealand Pigmyweed (*Crassula helmsii*).

4 Ponds with long established floating vegetation mats including a bryophyte layer and diverse wetland plant community

For convenience, the full name of this habitat type can be shortened where appropriate to '*Ponds with floating vegetation mats'*

Ponds with floating vegetation mats often have an exceptional biodiversity value. To date, all ponds (where biological quality has been assessed) have qualified as Priority Ponds and an exceptionally high proportion have supported red-listed species including some of England's rarest freshwater plants and animals.

Floating mats that are mature enough to support a moss layer and create a platform for vascular plants are typically slow to develop and characteristically occur where old ponds occur in traditionally farmed or semi-natural landscapes. How, when and where these mats form remains unclear, and this is not a habitat that it has been possible to recreate.

4.1 Definition

This habitat type is defined as a pond that supports a mat of floating vegetation characterised by the frequent to dominant occurrence of wetland mosses intergrowing with a range of vascular wetland plant species. The floating mat may occur either as: (i) a vegetation island 'floating' over water or aqueous sediment, often towards the centre of the pond, (ii) a mat that grows out from the pond bank over water or aqueous sediment or, (iii) a combination of these two (Figure 3.1).

Ponds fitting this habitat type have:

(a) *One or more mat-forming plant species that form the core structure of the raft*: these may be rhizomatous species such as Bottle Sedge (*Carex rostrata*), plants with thick intergrowing stems e.g. Bogbean (*Menyanthes trifoliata*) or species that form dense mats of stems and roots e.g. Floating Sweet-grass (*Glyceria* species).

(b) *A bryophyte layer*: with mosses typically covering an extensive area of the floating mat.

(c) *A diverse assemblage of vascular wetland plant species*. Floating mats can be very biodiverse and often support plant species assemblages that differ widely between sites within the same region.

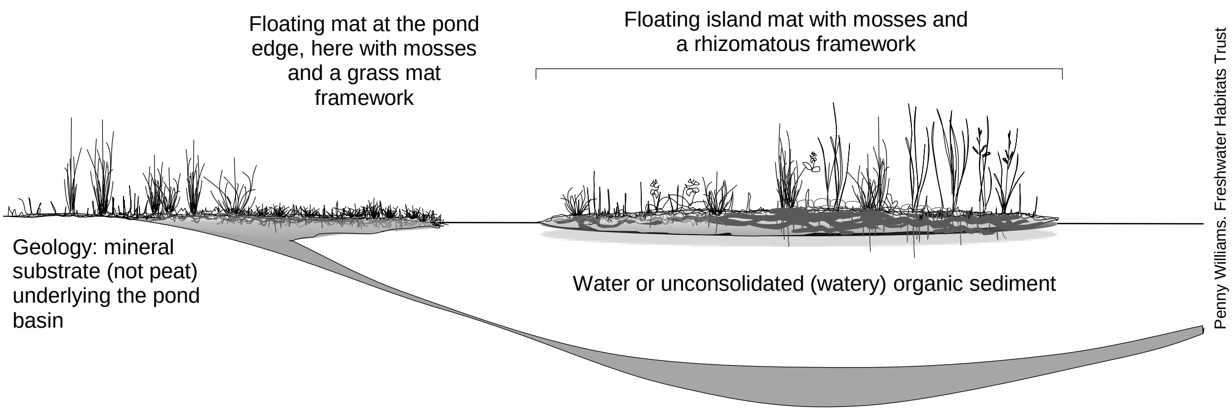

Figure 3.1 'Island' and 'edge' floating mats with examples of raft-forming root and rhizome structures

4.2 Criteria for defining the pond type

To qualify, waterbodies should have all of the following physical and biological characteristics:

- **Pond:** a standing waterbody between 1 m^2 and 2 ha in area. Ponds can hold water permanently or seasonally: potentially drying for up to 8 months of the year.
- **Floating vegetation mat:** a mat or raft of floating vegetation that has developed over water or loose aqueous sediment so that the mat wobbles (quakes) if walked on.
- The floating mat may occur as one or more floating islands within the pond or may extend out from the bank. In the latter case, edge floating mats need to extend well into the pond (have a width of at least 3 m), and need to occur around a good proportion of the waterbody (at least 20% of the pond edge)
- **Bryophyte layer:** moss, liverwort or hornwort species should be dominant or frequent across much of the mat surface. It is not necessary to identify bryophytes to species level to qualify for this habitat type.
- **Diverse wetland plant community**: a diverse assemblage of wetland plants, comprising at least one species with floating roots, stems or rhizomes that creates the underlying framework for the mat, plus a range of additional wetland species that create the mat community (minimum five species excluding trees).
- **Mineral geology (i.e. non-peat geology)**: Ponds with floating vegetation mats are limited to waterbodies underlain by bedrock or a 'mineral-based' superficial lithology. Specifically, they should not occur in areas where the superficial geology is mapped as peat. This distinguishes 'ponds with floating vegetation mats' from pools that are part of larger bog, fen, or swamp wetland habitats and are already included as irreplaceable under these categories.

Transitions to other habitat types

At a late stage, some ponds with floating mats become seasonal and the central mat may become progressively more attached to the base of the pond. In such cases ponds qualify as having a 'floating mat' as long as the mat floats (i.e. quakes when walked on), during times when the pond holds water.

In larger ponds, floating mats can be the precursors of, and grade into, habitats that are readily recognisable as bog, fen, or swamp wetland habitats in their own right. To create a practical means of separating these, the following criteria are used:

(a) *Small ponds* with vegetation mats (pond less than 0.2 ha). Mats of vegetation can extend across any area of the pond, and when well-developed can leave just a 'moat' of deeper water close to the pond edge.

(b) *Large ponds* (0.2 ha – 2 ha): floating islands or edge mats should occur across less than 50% of the pond area. Where the proportion is greater than 50% (i.e. mats are 0.1 ha or more in total area), these larger mats qualify as irreplaceable in their own right under a bog, fen, or swamp wetland habitat category.

Ponds and other habitats that are excluded

Ponds with rafts of emergent or floating-leaved species that *lack* a bryophyte layer are excluded. Rafts dominated by tall emergent plants such as Bullrush (*Typha latifolia*), Common Reed (*Phragmites australis*), floating plant such as water-lily (Nymphaeaceae species), and grasses (e.g. *Agrostis* and *Glyceria* species) can sometimes develop rapidly in ponds, particularly in nutrient rich and polluted waterbodies. These rafts do not have the more complex bryophyte and vascular plant communities associated with long-established rafts. Loose mats of bog-moss (*Sphagnum* species), that lack vascular plants are not included in this habitat type, nor are mats where the platform structure is created by a non-native plant species such as New Zealand Pigmyweed (*Crassula helmsii*).

Figure 3.2. A floating mat in a pond located in a meadow behind dunes on Sandscale Haws, NNR, Cumbria. This floating mat is dominated by Bogbean, sedges and Bulrush in an exceptionally rich pond in which combines acid and alkaline floras and includes a wide range of Red Listed species and regionally uncommon plants. Photo credit: Katy Williams, Freshwater Habitats Trust.

4.3 Occurrence and distribution

Floating mat habitats have been recognised globally, and some floating vegetation assemblage types are known to be widespread. For example, mats associated with Bottle Sedge (*Carex rostrata*), Marsh Cinquefoil (*Comarum palustre)* and Bogbean (*Menyanthes trifoliata)* are components of floating wetlands not only across northern Britain but in North America, Northern Europe and eastwards into Asia. The names given to unstable habitats in different countries are often distinctive (e.g. “schwingmoor”, “quaking bog”, “scragh”), and although these terms can include terrestrial peat bogs with an unstable surface, they also commonly refer to floating mats that extend out over lakes and ponds.

Ponds with floating vegetation mats have been poorly recognised in England and currently, there are relatively few documented examples. However, there is evidence that this habitat type is widespread, if uncommon. These ponds can occur in all landscapes in England where old ponds remain. They can span a wide range of water chemistry and water quality types from nutrient poor (dystrophic and oligotrophic) ponds where the bryophyte layer is likely to be dominated by *Sphagnum* moss, to nutrient rich (eutrophic) and alkaline ponds where the mats may develop fen-type assemblages.

Currently, the best-known examples are ‘acid’ floating mats characterised by *Sphagnum* growing in association with mat-forming vascular plants such as Bottle Sedge (*Carex rostrata*) and Bogbean (*Menyanthes trifoliata*). These mats are most typical of upland ponds. Acid floating mats are uncommon in the lowlands but occur in ponds on base-poor strata in the north and west of England, and more occasionally on sandstone and siltstone lithologies in the South and East (e.g. the High Weald, the New Forest).

Prior to this report, there were few identified examples circum-neutral and alkaline ponds with floating mats. However, current evidence suggests that this habitat does occur in the lowlands. A census study of c 500 ponds in farmed areas of Leicestershire, Northamptonshire and Buckinghamshire (c.90 km^2 total area) identified four ponds which fulfilled this definition. This represented fewer than 1% of the ponds present in these areas (Williams 2010-2022 unpublished data). Of the four ponds, two were permanent water ponds and two were old semi-seasonal ponds where the mat floated only during winter, spring and in wetter summers.

Ponds with floating rafts are most likely to occur in areas of relatively low intensity land use including open moorlands and heathlands. In the lowlands, ponds are typically unshaded waterbodies, without inflows, located in low intensity grasslands. However, there are exceptions to this, with floating rafts occasionally recorded from large ponds in woodland and ponds in arable landscapes.

A list of currently known ponds that fit the criteria in Section 3.2, and map showing the distribution of these sites in England is provided in accompanying files. The distribution of these ponds suggests that they tend to occur in areas where ponds are an important and traditional element of the countryside: e.g. areas of Cumbria, Cheshire, Kent, Dorset, Herefordshire, Northumbria.

4.4 Habitat description

Creation and development
The mechanisms which lead to the formation of floating vegetation rafts remain poorly understood and in many cases an unusual combination of circumstances is likely involved. This is one reason why this habitat is rare and cannot be re-created (Hammond 2017). Formation has sometimes been linked to periods of extreme drought and flooding where buoyant rhizome masses of bottom vegetation are lifted from the pond base (Giller and Wheeler 1986, Van Wirdum 1995, Wheeler and Shaw 1995), whilst gasses in rhizomes, and from decay of organic matter in the mat may keep it buoyant (Hogg and Wein 1988). In North American literature, emphasis is placed on combinations of 'nucleating' factors (e.g. presence of tree stumps) to initiate expansion of vegetation out over the surface, Eastern Europe provides examples of 'skirts' of fibrous willow roots providing this initial platform.
In structure, floating mats are formed from the densely interlaced rhizomes, stolons, roots, stems or branches of emergent plants. This forms a platform which bryophytes and vascular wetland plant subsequently colonise. The mat-forming species can include larger rhizomatous sedges (*Carex* species), tall rhizomatous emergents such as Bulrush (*Typha* species) and Club-rush (*Schoenoplectus* species) as well as lower growing wetland plants

with robust stems such as bogbean (*Menyanthes trifoliata*) and fine-leaved water-dropwort (*Oenanthe aquatica*). Mats can also be created by wetland grasses; most often Floating Sweet-grass (*Glyceria fluitans*).

The bryophyte layer is typically dominated by generalist moss species that are widespread in the region. In neutral or base-rich ponds this may include Rough-stalked Feather-moss (*Brachythecium rutabulum*), Heart-leaved Spear-moss (*Calliergon cordifolium*), Pointed Spear-moss (*Calliergonella cuspidata*) and Knieff's Hook-moss (*Drepanocladus aduncus).* In Fenland sites Kneiff's Feathermoss (*Leptodictyum riparium)* and Showy Feather-moss *Oxyrrhynchium speciosum* can also be present. In waterbodies with more acid water, Spiky Bog-moss (*Sphagnum squarrosum*), Flat-topped Bog-moss (*Sphagnum fallax*) or Cow-horn Bog-moss (*Sphagnum auriculatum*) are common dominants. In well-developed mats, a more diverse range of bryophyte species may occur, for example Hammond (2017) recorded 12 species of moss and liverwort in a floating mat in a Humberhead Levels borrow pit pond.

Figure 3.3. A Cheshire pond with a mature floating grassy mat that supports a trio of rare species: Lesser Silver Water Beetle (*Hydrochara caraboides*),Tubular Water-dropwort (*Oenanthe fistulosa*) and Slender Mud Snail (*Omphiscola glabra*). Photo credits: Pond, David Orchard; Slender Mud Snail (inset), Martin Hammond

The assemblages of higher plants colonising floating mats is varied and there are few species that are especially characteristic, at least in the lowlands. However, there is a strong tendency for plants growing on floating mats to be less tolerant of nutrient pollution, and more likely to be nationally or regionally rare or threatened, than plants growing on the surrounding banks. Because the plants growing on vegetation mats are often different to bankside species, the total species-richness in these ponds often unusually high.

Well established mats can have a complex microtopography, with moss hummocks and small pools. Scrub and small trees (e.g. *Salix*, *Betula* species) may also become

Figure 3.4. A mature grass floating mat covering a pond in Herefordshire. Like many ponds with floating vegetation, this mossy mat supports uncommon species including the England red listed plants (inset): Lesser Marshwort (*Apium inundatum*), and Marsh Speedwell (*Veronica scutellata*). Photo credit: Will Watson

established. Ultimately, as pond floating mats develop and their ponds begin to fill with sediment, this pond type can develop in one of a number of directions. Ponds dominated by *Sphagnum* may develop into small rain-fed raised bogs, other mats develop into more permanent areas of fen or carr or swamp wetland habitat. In waterbodies with a considerable drawdown, the floating mat will often become increasingly attached to the pond base when water levels fall in summer, so that ultimately the mat no longer floats when the pond fills with water, and the waterbody becomes a seasonal pond.

4.4.1 Importance for biodiversity

Ponds with floating vegetation mats often have an exceptional biodiversity value. To date, all such ponds (where biological quality has been assessed) have qualified as Priority Ponds (now habitats of principle importance); and commonly qualify on more than one criteria (BRIG 2008).

An unusually high proportion of these ponds support England red-listed species, and many have plant and/or animal assemblages that are exceptional. This includes species such as Oxbow Diving Beetle (*Hydroporus rufifrons*), Lesser Silver Water Beetle (*Hydrochara caraboides*), Slender Mud Snail (*Omphiscola glabra*) and Medicinal Leech (*Hirudo medicinalis*), Brown Galingale (*Cyperus fuscus*), Pillwort (*Pilularia globulifera*), Three-lobed Water-crowfoot (*Ranunculus tripartitus*), Marsh Stitchwort, (*Stellaria palustris*) and Tubular Water-dropwort (*Oenanthe fistulosa*), together with declining mammals such as Water Vole (*Arvicola terrestris*).

Part of the reason ponds floating vegetation mats often have high biodiversity value may be because the waterbodies in which they occur are typically old, undisturbed ponds, located in areas where the surrounding land-use is semi-natural or low intensity. They most commonly occur in ‘pondscape’ areas where ponds occur at higher density. Such ponds and areas characteristically have high-quality freshwater floras and faunas that have often been lost from intensively managed landscapes.

However, there are also characteristics specific to floating mats that make them special. In particular, because plants on these rafts receive their nutrients from pond water and rainwater rather than (usually more enriched) bank soils, floating mats tend to support assemblages and species that are more characteristically ‘acid’ and nutrient poor than their surrounds. For example:

(a) ponds with floating mats in the agricultural lowlands can support NVC plant communities that include M4 Carex rostrata - Sphagnum recurvum [= S. fallax agg.] mire, M5 Carex rostrata - Sphagnum squarrosum mire and S27 Carex rostrata – Potentilla palustris [=Comarum palustre] tall-herb fen, which are rare and declining habitats in lowland landscapes.

(b) Floating mats can sometimes develop nutrient-zoned flora’s and floras that are highly species-rich and may include both rain-fed acid raised bog habitats in the centre of the mat grading to more nutrient-enriched habitats towards the edge (e.g. Hammond 2017).

(c) On larger ponds, as floating vegetation rafts develop and grow, they may become the precursor to 'transition mires and quaking bogs' – a European priority habitat.

Figure 3.5 Floating mat in a floodplain pond near Staveley, Cumbria. This pond supports the very rare Oxbow diving beetle and Slender Mud Snail: both species that are associated with floating mats elsewhere in England. Photo Credit: Freshwater Habitats Trust.

The very different physical and chemical environments found on floating mats mean that they can function differently to, and independently of, wetlands in the surrounds. This is particularly true of mature floating mats underlain by rhizomatous (rather than grassy) wetland plants, which can develop a complex microtopography that includes both aquatic habitats e.g. pools with stoneworts and a range of water beetles species, as well as tussocks and other higher ground areas with a terrestrial flora and invertebrate flora (e.g. spiders, ground beetles). There are also species which are likely to be drawn to ponds with floating vegetation because of the association with mosses, for example the water beetles: *Ilybius guttiiger, Agabus affinis* and *Enochrus ochropterus*.

Even where floating mats are relatively small or immature, they generally support species not found in the pond or around its edge. This adds to the overall biodiversity value of the pond, so that these sites are generally species rich

4.4.2 Threats

Ponds with floating vegetation mats are threatened by the same range of factors that widely degrade and destroy ponds: especially nutrient and other pollutants draining in from their surrounds, and the combination of disturbance and pollution that arises from excessive numbers of wildfowl, fish and use by dogs. Loss or reduction in traditional grazing around the pond edges may also reduce pond quality.

However, their distinctive floating mat structure also make these ponds particularly vulnerable to factors that destroy the floating mat's richness and integrity. For example:

- To non-pond specialists, the presence of mature floating mats can make a pond appear to be 'lost, 'overgrown' or 'dried up'. Hence these ponds are highly vulnerable to dredging or infilling.
- There are concerns that climate heating, including summer droughts, may result in very low pond water levels on a regular basis; hastening the rapidity with which mats become permanently attached to the pond base, and hence losing their distinction as largely rain-water fed habitats.

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Appendix 2. Methods and techniques

Geological Maps: Maps produced by the British Geological Survey show areas of hummocky morraine and glacial till (diamicton). Lowland ice age ponds are primarily located within these areas, although ground ice ponds may also occur in areas that were not glaciated. These maps should be used with caution at a local level, as glacial sediments and ice age ponds may occur outside the areas mapped as moraine.

Historical maps: Large numbers of ponds are marked on historical maps, especially the 1st edition Ordnance Survey maps produced in the 19th Century. Since many ice age ponds are small and/or seasonal, these are frequently mapped as marsh rather than water.

Aerial photography: Online aerial imagery is useful for detecting the presence of natural ponds and pond clusters. Since most photographs are taken during the summer months, even quite large ponds may appear as areas of damp vegetation rather than open water. Aerial images can also reveal the location of ponds that have been lost to infilling or ploughing; these ponds are likely to retain historically valuable sediments below the surface.

LIDAR: Lidar data can can be used to create high resolution topographical maps. It is possible to automate the process of mapping closed depressions which may contain ice age ponds.

Geophysical techniques: commonly a combination of Ground Penetrating Radar (GPR) and Electrical Resistivity Imaging (ERI). These non-invasive methods are relatively quick to deploy on the ground and make it possible to create a detailed image of the ground below a depression up to 20m below the surface.

Augering – this technique can be useful for identifying ice age sediments near the surface, typically around the margins of a pond. Augering also allows the detection of subsurface peat deposits which are often associated with ice age ponds. A soil chart is used for identification of soil samples from augering.

Peat coring (e.g. using a Russian Corer). This is used to sample sediments containing high amounts of organic material such as peat. Cores with peat or carbonaceous fragments can be evaluated using palynology and carbon dating .

Geological surveys. look for more detailed evidence, such as the presence of glacial landforms associated with Ice Age Ponds, rounded glacial pebbles, together with sand and gravel deposits and diamicton (boulder clay). Looking for evidence of peat, based on geological maps and taking soil samples in the field can be a further clue to a pond's origin. Trenches can be dug (e.g. across ground ice pond ramparts) to provide information about their stratigraphy.

Appendix 3. Examples of ground ice depression types

There continues to be research into the processes that create ground ice features and their classification. However, broadly, the distinctions made between pingos, palsas and lithalsas are as follows.

Pingos

Pingos form when a lens of ice accumulates within permafrost. The near-surface accumulation of this ice displaces the ground laterally and vertically, forming a dome at the surface. Surface tension cracks and seasonal thawing may cause sediments and soil to slip off the dome accumulating in a ring at the base. As warmer periods arrive, a pond may fill the depression that remains after the ice has melted and any sediments above it collapse into the hole that is left. Soil and sediment that accumulated at the base of the dome remains as a raised bank (rampart). Two types of pingo are commonly recognised:

a) Open-System (Hydraulic) Pingos

Open system pingos form by freezing groundwater injected into the permafrost by a spring or seepage. As water is forced upwards and freezes it pushes up a dome of ice upwards. Pingos are often rounded or oval, however, sometimes, spring-fed ice mounds that are developed during a succession of cold stages create overlapping ‘vermiform’ (worm-like) patterns of irregular pools and ridges such as those at East Walton Common, Norfolk (Walmsley 2008).

b) Closed-System (Hydrostatic) Pingos

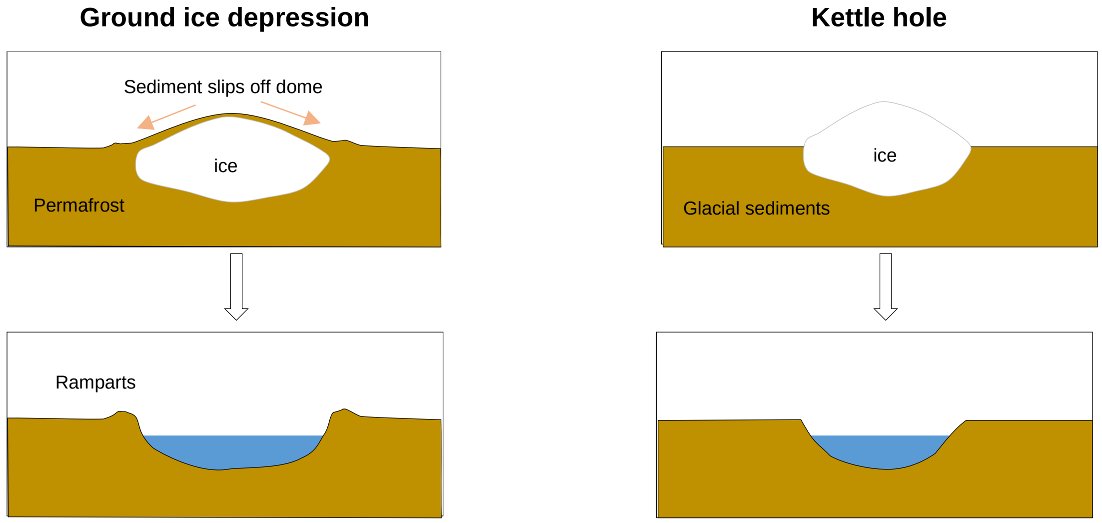
These pingos commonly form ‘segregation ice’; where water is gradually drawn from the surrounding substrate via ‘cryosuction’, forming a very ice-rich lens of permafrost. Today, they are found in wet lowland areas of discontinuous or continuous permafrost such as the Mackenzie Delta. They commonly occur in meltwater lake beds or river channels (Walmsley 2008, Elias & Alderton 2020).

Palsas

These have similarities to closed-system pingos, but are typically smaller and occur in peat bogs. They are less likely to survive to the current day as the former surface of the peat is largely restored when the ice mound melts and collapses (Walmsley 2008).

Lithalsas (mineral palsas)

Like palsas, these are formed by the development of localised segregation ice, but tend to develop in mineral soils on plateaux, often in areas of boreal forest, rather than in low-lying wetlands. With their low ramparts, ponds formed in lithalsa may have a similar appearance to pingos. Transitional forms between the two may also exist (Walmsley 2008, Elias & Alderton 2020).



Appendix Figure 3.1. Different modes of formation for ground ice ponds and kettle hole ponds