National Parks & Wildlife Service

Clara Bog SAC
(site code 000572)

Conservation objectives supporting document - raised bog habitats

Version 1

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Contents

1 Introduction

This document presents a summary of the background information that has informed the process of setting the Site-Specific Conservation Objective in relation to the priority Annex I habitat 'active raised bogs' (habitat code 7110) (hereafter referred to as Active Raised Bog (ARB)), for which Clara Bog Special Area of Conservation (SAC) has been designated.

Clara Bog SAC is also designated for two other related Annex I habitats, namely; 'degraded raised bogs still capable of natural regeneration' (habitat code 7120) (hereafter referred to as Degraded Raised Bog (DRB)) and 'depressions on peat substrates of the Rhynchosporion' (habitat code 7150). Based on the close ecological relationship between these three habitats types, it is not necessary to set specific Conservation Objectives for all three habitats individually. It is considered that should favourable conservation condition for ARB be achieved on the site, then, as a consequence, favourable conservation condition for the other two habitats would also be achieved.

Clara Bog SAC is also designated for the priority Annex I habitat 'bog woodland' (habitat code 91D0). A separate site-specific conservation objective has been set for bog woodland and therefore is not considered in this supporting document.

1.1 Raised Bogs

Raised bogs are accumulations of deep peat (typically 3-12m) that originated in shallow lake basins or topographic depressions. The name is derived from the elevated surface, or dome, that develops as raised bogs grow upwards through the accumulation of peat; the domed effect is often exaggerated when the margins of a bog are damaged by turf cutting or drainage, and are drying out. Raised bogs are most abundant in the lowlands of central and mid-west Ireland.

Irish raised bogs are classified into two sub-types (Schouten 1984): 1. Western or intermediate raised bogs, and 2. True midland or eastern raised bogs, based on phytosociological and morphological characteristics. In terms of overall morphology, the main difference between these two raised bog types is that while eastern raised bogs tended to stay more confined to the depressions in which they were formed, western raised bogs tended to grow out beyond their original basin, presumably a result of the higher rainfall levels (Cross 1990). In terms of vegetation differences the most obvious difference between the two bog types is the presence of a number of oceanic plant species on western raised bogs which are absent from the true midland raised bogs. The liverwort species *Pleurozia purpurea*[1] and the moss species *Campylopus atrovirens* grow on western raised bogs but not on eastern raised bogs; similarly, *Carex panicea* is generally more common on the high bog surfaces of western raised bogs (Schouten 1984). All of these plant species are widespread in the low-level Atlantic blanket bogs and their presence in western raised bogs is presumed to be due to the higher rainfall levels and greater rain-derived nutrient fluxes.

Exploitation has been extensive and none of the remaining Irish raised bogs are completely intact (Cross 1990). It is estimated that less than 10% of the original raised bog habitat in Ireland is in a near intact state (uncut), with less than 0.5% continuing to support ARB (DAHG 2014). Excavated face banks, whether active or inactive, are a common feature around the

[1] Note on species nomenclature: *In the case of plant species, only scientific names are used throughout the main text while common English names are included in tables. In the case of faunal species, common English names are used throughout the text (where known) together with scientific names.*

margins. Any areas where part of the bog has been removed are termed cutover bog, with the remaining area referred to as high bog or intact bog. In a natural state, raised bogs are circled by a wetland fringe, known as the lagg zone, which is usually characterised by fen communities. In Ireland, most laggs have been lost through drainage and land reclamation (Fossitt 2000).

The surface of a relatively intact raised bog is typically wet, acid, deficient in plant nutrients, and supports specialised plant communities that are low in overall diversity and comprising species adapted to the biologically harsh conditions. The vegetation is open, treeless and bog mosses or *Sphagnum* species dominate the ground layer. Small-scale mosaics of plant communities are characteristic and reflect the complex microtopography of hummocks and hollows on the bog surface (see Section 1.1.1 below). Raised bogs are driest at the margins and wetness generally increases towards the centre of the peat mass where well developed pool systems are most likely to occur.

Raised bogs may also contain soaks and flushes (wet 'active' or dry 'inactive') due to the increased supply of nutrients over time through concentrated surface flows, or where there are links with regional groundwater or the underlying mineral substratum. Slight mineral enrichment and / or constant through flow of water provide conditions suitable for a range of species that are not typically associated with other areas of raised bog.

When damaged by peat extraction or drainage, the water table in the peat drops and the bog surface becomes relatively dry; pools are rare or absent, cover of bog mosses is greatly reduced and *Calluna vulgaris* increases in abundance. The drop in water table causes the peat to compress under its own weight causing the bog surface to deform. Greater deformation occurs closest to areas where the water table has dropped. This increases the slope of the bog surface causing rain falling on the ground surface to flow off the bog more quickly. The effect is normally greatest around the margins and in a typical situation surface wetness increases towards the centre of the bog. Trees such as *Betula pubescens* and *Pinus sylvestris* frequently invade the drier cut margins, but may also occur in flushed areas.

In Ireland, the Annex I habitat ARB is currently considered to be in unfavourable bad conservation status principally as a result of marginal turf cutting, more recent semi-industrial peat extraction, and associated drainage effects caused by these activities (NPWS 2008; 2013). The lowering of regional groundwater levels is also known to have had an effect on some sites. Fires associated with turf cutting, dumping, or agricultural activities may also adversely affect the condition of the habitat.

1.1.1 Raised Bog Microtopography

Raised bogs are typically treeless and are characterised by a distinctive vegetation dominated by bog mosses (*Sphagnum*), sedges, and dwarf shrubs, all of which are adapted to waterlogged, acidic and exposed conditions. Bog mosses, which have unique properties, are the principal component of peat, and are largely responsible for the typical surface features of hummocks, hollows, lawns, and pools. The wettest bogs, which have extensive pool systems, have the greatest variety of plant and animal life and support a range of specialist species.

The following terms that describe microtopography are generally accepted in the study of mire ecology (Gore 1983). A schematic diagram showing the typical microtopographical divisions is presented in Figure 1.

Pools

Depressions in the bog surface where the water table remains above the surface level all year around or below surface level for only a very short period of time. They are

characterised by the presence of aquatic plant species such as *Sphagnum cuspidatum*, *S. denticulatum*, and *Cladopodiella fluitans*. In more degraded scenarios or where high seasonal water fluctuation occurs, the pools contain open water and/or algae. Tear pools are found on bogs where internal tensions, due to mass movement of peat, has taken place within the high bog and has caused the development of elongated pools. These are frequently found on western bogs and may be natural or anthropogenic in origin.

Hollows

These are shallow depressions (less than 5cm deep) on the bog surface where surface water collects, or where the water table reaches or lies just above ground level, depending on seasonal conditions. They are often filled with *Sphagnum* species such as *S. papillosum* and *S. cuspidatum*. They take many forms but are often eye shaped. Marginal hollows tend to be elongated as they are focused points for surface water run-off. They are often dominated by *Narthecium ossifragum*.

Lawns

These are shallow hollows or flat areas where one species dominates to form a lawn. This is frequently a *Sphagnum* species, such as *Sphagnum magellanicum,* or *S. papillosum* which can completely fill in a hollow to form a small lawn.

Flats

These are more or less flat areas which are intermediate between hollow and hummock communities. They tend to be drier than the above situations.

Hummocks

These are mounds on the bog surface which can range from a few centimetres to more than one metre in height. They are usually composed mainly of *Sphagnum* species, such as *Sphagnum magellanicum, S. capillifolium, S. austinii* and *S. fuscum* but other bryophyte species such as *Hypnum jutlandicum* and *Leucobryum glaucum* are also important, especially as the hummock grows taller and becomes drier. *Calluna vulgaris* is another important element, as it flourishes where the water table is not at surface level (Kelly & Schouten 2002).

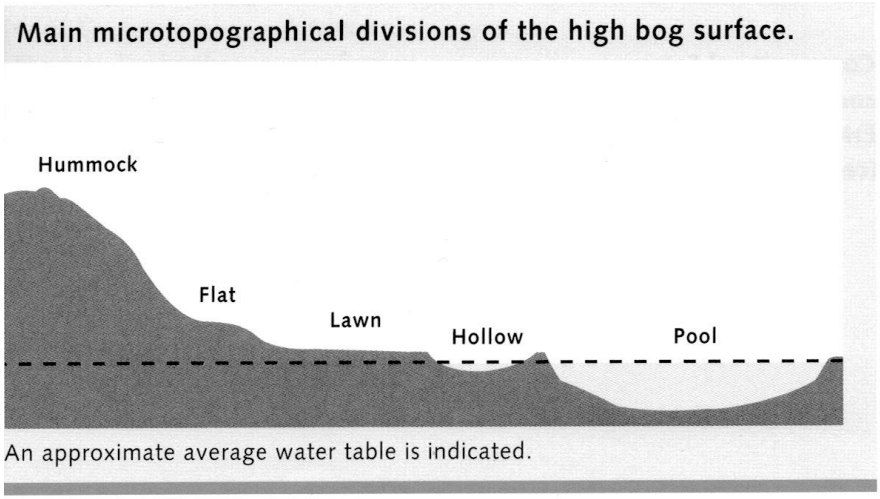


Figure 1 Raised bog microtopographical divisions on the high bog surface (reproduced from Kelly & Schouten 2002).

1.1.2 Typical Flora of Irish Raised Bogs

Raised bogs are characterised by a distinctive vegetation dominated by a variety of mosses (e.g. *Sphagnum spp., Hypnum spp., Racomitrium spp.*), sedges and grass-like species (e.g. *Eriophorum spp., Rhynchospora spp., Narthecium ossifragum, Molinia caerulea* and *Carex spp.*), and dwarf shrubs (e.g. *Calluna vulgaris, Erica tetralix, Vaccinium spp.* and *Empetrum nigrum*). In addition to these groups, a number of other species characterise raised bogs including carnivorous plants (e.g. *Drosera spp., Utricularia spp.*), lichens of both the bog surface and epiphytes on the stems of dwarf shrubs and the occasional trees on bogs (e.g. *Cladonia* spp*., Usnea* spp.). Herbaceous plants are not a significant element on raised bogs and include a few commonly occurring species such as *Menyanthes trifoliata, Pedicularis sylvatica*, and *Potentilla erecta* (Cross 1990).

Drier areas and hummocks usually support *Calluna vulgaris*, *Eriophorum vaginatum*, *Trichophorum germanicum*, *Erica tetralix*, lichens (*Cladonia* spp.), bog mosses (*Sphagnum capillifolium*, *S. austinii*, *S. fuscum*, *S. papillosum*), and other mosses (*Dicranum scoparium*, *Leucobryum glaucum*). Wet hollow areas and pools are characterised by *Eriophorum angustifolium*, *Rhynchospora alba*, *Narthecium ossifragum*, *Drosera* spp., *Menyanthes trifoliata*, bladderworts (*Utricularia* spp.), and bog mosses (*Sphagnum cuspidatum, S. denticulatum and S. magellanicum*).

A list of flora species that are regarded as being typical of ARB habitat in Ireland is presented in Table 1. A number of these typical species would have a restricted distribution and do not occur throughout the range of the habitat in Ireland (see above), therefore only a subset of these species would be expected to be present on any individual bog.

Table 1 Flora species typically associated with active raised bog in Ireland (after NPWS 2013). *Species list is based on vegetation communities defined by Kelly (1993) and Kelly & Schouten (2002).*

Common name	Scientific Name
Bog rosemary	*Andromeda polifolia*
Bog bead moss	*Aulacomnium palustre*
Bristly Swan-neck moss*	*Campylopus atrovirens**
Lichen	*Cladonia ciliata*
Lichen	*Cladonia portentosa*
Long leaved sundew	*Drosera anglica*
Intermediate leaved sundew*	*Drosera intermedia**
Round leaved sundew	*Drosera rotundifolia*
Common cotton grass	*Eriophorum angustifolium*
Hare's tail cotton grass	*Eriophorum vaginatum*
Large white moss	*Leucobryum glaucum*
Bogbean	*Menyanthes trifoliata*
Bog asphodel	*Narthecium ossifragum*
Purple spoonwort*	*Pleurozia purpurea**
Woolly fringe moss*	*Racomitrium lanuginosum**
White beak-sedge	*Rhynchospora alba*
Austin's bog moss	*Sphagnum austinii*
Red bog moss	*Sphagnum capillifolium*
Feathery bog moss	*Sphagnum cuspidatum*
Cow-horn bog moss*	*Sphagnum denticulatum**
Rusty bog moss	*Sphagnum fuscum*
Magellanic bog moss	*Sphagnum magellanicum*
Papillose bog moss	*Sphagnum papillosum*
Golden bog moss*	*Sphagnum pulchrum**
Lustrous bog moss	*Sphagnum subnitens*
Bladderwort	*Utricularia minor*
Cranberry	*Vaccinium oxycoccos*

*Notes: * Species more typical of western raised bog sites.*

1.1.3 Typical Fauna of Irish Raised Bogs

Raised bogs are extremely nutrient poor ecosystems. Acidic, waterlogged and exposed conditions make them an unattractive habitat for animal life. As a consequence they are relatively poor both in terms of species diversity and population densities. Many species are opportunists, vagrant or temporary rather than specialists, but nonetheless may have an important impact on the ecosystem through nutrient imports and exports or other interactions (Cross 1990). A list of fauna species that would be typically associated with raised bog habitat in Ireland is presented in Table 2. The species listed are not confined to ARB and most, if not all, will use other areas of the bog and surrounding habitats.

Raised bog is unsuitable habitat for many vertebrates due to the lack of available foraging and suitable breeding places. The Irish hare is the only mammal commonly occurring. The common frog is the most common vertebrate predator.

Although 18 species of birds have been reported breeding on raised bogs (Wilson 1990) many of these species utilise the bog as a nesting habitat only. They are dependent on other neighbouring habitats such as open water bodies, callows and wet grassland particularly for

feeding. Just a few species of bird, including meadow pipit (*Anthus pratensis*), skylark (*Alauda arvensis*) and curlew (*Numenius arquata*) complete their full breeding cycle on the bog and the first two species are the commonest species occurring (Bracken *et al.* 2008). Red grouse (*Lagopus lagopus*) must also be included as a typical bog species, occurring year round as a resident. Red grouse and curlew have declined significantly on raised bogs in recent times. BirdWatch Ireland has published an Action Plan for Raised Bog Birds in Ireland which lists 13 species of conservation concern that are associated with Raised Bogs (O'Connell 2011). A recent review of birds of conservation concern in Ireland has since added meadow pipit (*Anthus pratensis*) to the red (most endangered) list of Birds of Conservation Concern in Ireland (BoCCI) (Colhoun & Cummins 2013).

Our knowledge of the invertebrate assemblages associated with Irish raised bogs remains incomplete (particularly micro-invertebrate species) with few studies undertaken (Reynolds 1984a; Reynolds 1984b; Reynolds 1985; De Leeuw 1986; O Connor *et al*. 2001; Crushell *et al.* 2008; Hannigan & Kelly-Quinn 2011; Wisdom & Bolger 2011; Nolan 2013). Van Duinan (2013) highlights the importance of structural diversity at various spatial scales (e.g. micro-scale of hummock hollow topography to macro-scale which would include the landscape setting of the bog, see Schouten (2002)) as a prerequisite for hosting the full species diversity of raised bog landscapes.

A recent study of Lepidoptera associated with raised bogs identified two species that appear to be characteristic of higher quality raised bog habitat, namely bordered grey (*Selidosema brunnearia* (Villers, 1789)) and light knot grass (*Acronicta menyanthidis* (Esper, 1789)) (Flynn 2014).

Recent research on spiders has revealed that a number of species are known to occur in Ireland only on raised bog habitats, all of which are considered local/uncommon or rare across Europe (Myles Nolan pers. comm.). Five of these species that can be considered useful indicators of ARB include: *Glyphesis cottonae* (La Touche 1945), *Walckenaeria alticeps* (Denis 1952), *Satilatlas britteni* (Jackson 1913), *Pirata piscatorius* (Clerck 1757), and *Minicia marginella* (Wider 1834) (Myles Nolan pers. comm.).

The information currently available on other invertebrate groups of peatland systems in Ireland is not sufficient to allow a determination of many species that are typically associated with or may be characteristic of higher quality ARB. A selection of invertebrate species and species groups that are known to be typically associated with raised bogs are included in Table 2.

Table 2 Fauna species typically associated with raised bog ecosystems in Ireland (after O'Connell 1987; Cross 1990; Renou-Wilson *et al.* 2011; Bracken & Smiddy 2012).

Common name	**Scientific name**
Mammal species	
Irish hare	*Lepus timidus hibernicus*
Otter	*Lutra lutra*
Pygmy shrew	*Sorex minutes*
Fox	*Vulpes vulpes*
Bird species	
Skylark	*Alauda arvensis*
Mallard	*Anas platyrhynchos*
Greenland white-fronted goose	*Anser albifrons flavirostris*
Meadow pipit	*Anthus pratensis*
Hen harrier	*Circus cyaneus*
Cuckoo	*Cuculus canorus*
Merlin	*Falco columbarius*
Kestrel	*Falco tinnunculus*
Snipe	*Gallinago gallinago*
Red grouse	*Lagopus lagopus*
Curlew	*Numenius arquata*
Golden plover	*Pluvialis apricaria*
Lapwing	*Vanellus vanellus*
Reptiles and amphibians	
Common lizard	*Lacerta vivipara*
Common frog	*Rana temporaria*
Typical invertebrates	
Black slug	*Arion ater*
Large heath butterfly	*Coenonympha tullia*
Marsh fritillary butterfly	*Euphydryas aurinia*
Bog-pool spider	*Dolomedes fimbriatus*
Water striders	*Gerris* and *Velia* species
Oak eggar moth	*Lasiocampa quercus*
Four-spotted chaser dragonfly	*Libellua quadrimaculata*
Fox moth	*Macrothylacia rubi*
Ant	*Myrmica ruginodis*
Emperor moth	*Saturnia pavonia*
Great green bog grasshopper	*Stethophyma grossa*
Other species groups that are well represented on raised bogs include:	Araneae (spiders and mites)
	Ceratopogonidae (biting-midges)
	Chironomids (non-biting midges)
	Coleoptera (beetles)
	Collembola (springtails)
	Diptera (true flies)
	Dytiscidae (water beetles)
	Hemiptera (true bugs)
	Hymenoptera (bees, wasps, ants and sawflies)
	Lepidoptera (butterflies and moths)
	Odonta (dragonflies and damselflies)
	Orthoptera (grasshoppers)
	Syrphidae (hoverflies)
	Tipulidae (craneflies)
	Tabanidae (horseflies)

1.2 Habitats Directive Raised Bog Habitats in Ireland

Four habitat types listed on Annex I of the EU Habitats Directive are typically associated with raised bogs in Ireland, two of which are priority habitats (*):

- 7110 Active raised bogs (ARB)*
- 7120 Degraded raised bogs still capable of natural regeneration (DRB)
- 7150 Depressions on peat substrates of the *Rhynchosporion*
- 91D0 Bog woodland*

The interpretation manual of EU habitats gives the following description for ARB: "*Acid bogs, ombrotrophic, poor in mineral nutrients, sustained mainly by rainwater, with a water level generally higher than the surrounding water table, with perennial vegetation dominated by colourful Sphagna hummocks allowing for the growth of the bog (Erico-Sphagnetalia magellanici, Scheuchzerietalia palustris p., Utricularietalia intermedio-minoris p., Caricetalia fuscae p.). The term "active" must be taken to mean still supporting a significant area of vegetation that is normally peat forming, but bogs where active peat formation is temporarily at a standstill, such as after a fire or during a natural climatic cycle e.g., a period of drought, are also included*." (CEC 2007).

DRB should be, according to the interpretation manual capable of regeneration to ARB in 30 years if appropriate measures are put in place (i.e. no major impacting activities are present and any necessary restoration works are implemented).

In Ireland, the identification of ARB is made at ecotope level based on the vegetation classification developed by Kelly (1993) and Kelly & Schouten (2002).

Raised bog vegetation communities are grouped into a series of community complexes and these complexes are then amalgamated into a series of ecotopes characterised by different physical characteristics using the approach outlined by Kelly & Schouten (2002).

The main ecotopes that community complexes are grouped into include:

- Central ecotope
- Sub-central ecotope
- Active flushes and soaks
- Sub-marginal ecotope
- Marginal ecotope
- Inactive flushes
- Face-bank ecotope

Actively accumulating peat conditions occur within the sub-central and central ecotope, which are the wettest on the bog and an indication of good quality ARB. Active flushes and soaks are also dominated by *Sphagnum* mosses and typically have wet conditions. These features are associated with ARB and contribute to the overall diversity of the habitat.

The adjacent surrounding marginal, sub-marginal, and face-bank bog areas typically have a supporting function for the central and sub-central communities but are not peat accumulating. These drier ecotopes may or may not correspond to the Annex I habitat DRB, as it depends on whether they are capable of regeneration to ARB. Other drier ecotopes recorded on the high bog that do not correspond to ARB include 'inactive flushes' which typically have a low *Sphagnum* cover.

The Annex I habitat Rhynchosporion depressions (7150) typically occurs along pool edges and on flats underlain by deep, wet and quaking peat. Typical plant species include *Rhynchospora alba*, *Drosera anglica*, *Narthecium ossifragum*, *Sphagnum cuspidatum*, *S. denticulatum*, *S. magellanicum*, *S. papillosum*, *Menyanthes trifoliata*, and *Eriophorum angustifolium*.

The priority Annex I habitat bog woodland is also actively peat-forming and overlaps with the ARB habitat. Such woodlands are usually dominated by *Betula pubescens* with a characteristic ground cover dominated by *Sphagnum* moss species, which often form deep carpets, and other mosses including species of *Polytrichum*. A separate conservation objective has been prepared for bog woodland. Woodland areas are occasionally found on raised bogs that have an absence of the characteristic moss layer and are not regarded as peat forming. Such areas do not correspond to the Annex I habitat.

1.2.1 Restoration of Active Raised Bog in Ireland

As already mentioned in the section 1.1, ARB is currently considered to be in unfavourable bad conservation status in Ireland. In addition, according to its definition, DRB should be capable of regeneration to ARB in a 30-year timescale. Thus, it follows that restoration measures are required in order to halt further losses and increase the area of ARB as well as to improve the condition of existing areas of the Annex I habitat.

Most of the restoration works undertaken so far in Ireland have concentrated on the high bog (e.g. Clara Bog, Mongan Bog, Sharavogue Bog and Raheenmore Bog) to prevent further losses as well as to restore areas to ARB. Nevertheless, some restoration works have also been undertaken on cutover areas such as at Ballykenny and Fisherstown Bogs and Killyconny Bog. Such work aims to do one or more of the following (depending on the bog in question): restore ARB on the high bog; reduce further ARB and DRB loss on the high bog; restore peat forming habitats (such as ARB, bog woodland, poor fen) on the cutover.

Works undertaken by the NPWS have indicated that there are significant differences, both ecological and economic, when comparing the effectiveness of works carried out on the cutover with those carried out on the high bog. Positive and significant results (i.e. expansion or development of ARB) can be achieved over a relatively short timeframe (10 years) on favourable areas of the high bog by blocking high bog drains. In contrast, a longer time period (30 years+) is required to achieve active peat formation on cutover areas, and even then the results are generally confined to smaller areas; i.e. flat areas (≤0.3% surface slope) or enclosed depressions that have sufficient water flow (minimum catchment 0.5ha) to maintain wet conditions throughout the year. A longer time period (minimum 50-100 years) is likely to be required for high quality ARB habitat (vegetation structure and species diversity) to develop on such cutover areas. In addition, costs of restoration measures on cutover areas are typically significantly higher than those on high bog areas.

1.3 Clara Bog SAC

The SAC includes the raised bog, known as Clara Bog and an esker ridge that adjoins the northern boundary of the bog running in an east-west direction.

The SAC has been selected for five Annex I habitats. The peatland habitats for which the site has been selected are:

- [7110] Active raised bogs*
- [7120] Degraded raised bogs still capable of natural regeneration
- [7150] Depressions on peat substrates of the *Rhynchosporion*
- [91D0] Bog woodland*

Clara Bog is situated approximately 2km south of Clara village, County Offaly. Much of the site is state-owned and designated a statutory Nature Reserve. To the east of the bog the transition into calcareous woodland, and to the north the transition to the esker grassland have been included in the SAC. Some peripheral farmland is also included in the SAC, because management undertaken in these areas can have a profound effect upon the rest of the bog.

Clara Bog has long been regarded as one of the most important lowland raised bogs in the country, being the largest remaining example of the True Midland Sub-type (Hammond 1979). The bog has been the subject of much ecological and hydrological research since the 1970s (Schouten 2002).

The bog was divided into a western (Clara West) and an eastern section (Clara East) by the construction of a road and installation of associated drainage in the late 18th century. Clara East has been further damaged by the insertion of a dense network of surface drains in 1983/84. However, extensive restoration work on this part of the bog has since been undertaken involving the blocking of drains. Peat extraction, last carried out on the southern and western sides of the bog, ceased in 2012. The effects of peat-cutting and drainage (associated with both peat-cutting and agriculture) along the southern margin of the SAC has been shown to be having far-reaching impacts on the western side of the bog, threatening the soak systems and surrounding ARB habitat (Regan 2013; Regan & Johnston 2010a). This area requires major restoration works.

1.3.1 Flora of Clara Bog

Clara West has quite extensive areas of wet, central vegetation with permanent pools, typically with high moss cover (*Sphagnum cuspidatum* and *S. magellanicum*), *Rhynchospora alba* and *Eriophorum angustifolium*. Lawns commonly consist of bog mosses such as *Sphagnum papillosum* or occasionally *S. capillifolium* with *Drosera rotundifolia*, *Erica tetralix*, and *Trichophorum germanicum*. Hummocks are formed by *Sphagnum capillifolium* or less frequently *S. austinii* with *Calluna vulgaris*, *Andromeda polifolia*, *Eriophorum angustifolium* and *Eriophorum vaginatum*. On drier areas of the high bog the *Sphagnum* presence is reduced (the acrotelm is less intact), *Calluna vulgaris* becomes more dominant and *Narthecium ossifragum* and *Trichophorum germanicum* are more frequent. Clara East has dried out more than Clara West and so the drier communities on the high bog described above are more typical of the vegetation, though a small area of wet central vegetation is found in the south. Some pool features in the north-east of the bog are thought to be man-made features, created over a century ago to attract wildfowl. The presence of well-developed soaks in the ARB habitat is one of the most significant features of this bog. The different types of soaks are described below.

Lough Roe soak has a wet central area with a floating raft of vegetation and a remnant of

open water. Species present include the bryophytes *Riccardia multifida* and *Aneura pinguis* (both indicators of base enrichment), *Nuphar lutea*, *Carex rostrata*, *Drepanocladus fluitans* (a moss), and *Menyanthes trifoliata*. This is surrounded by a drier band of vegetation with *Vaccinium oxycoccos*, *Calluna vulgaris*, and mosses including *Aulacomnium palustre*, *Sphagnum fallax,* and *S. palustre*. The vegetation continues to grade in bands through communities suggesting enrichment (indicated by presence of *Calliergonella cuspidata)* to ombrotrophic high bog vegetation. The smaller soaks on Clara East (west and south of Lough Roe) has similar vegetation but no open water. The Shanley's Lough soak has a central area of open water surrounded by extensive *Sphagnum cuspidatum* lawns with much *Carex rostrata*, *Hydrocotyle vulgaris*, *Vaccinium oxycoccos,* and *Menyanthes trifoliata*. At the southern edge of the open water a small area with *Juncus effusus* and some *Betula pubescens* occurs. Elsewhere the vegetation is dominated by *Molinia caerulea* and *Myrica gale* and other soaks on Clara West have similar communities. For further details see Kelly (1993), Crushell (2008) and Fernandez & Wilson (2009). Bog woodland is found in the vicinity of the soak systems on the high bog. For further details of the vegetation communities of Clara Bog see Kelly (1993).

1.3.2 Fauna of Clara Bog

The common frog (*Rana temporaria*) and the common lizard (*Lacerta vivipara*), are both known to occur on Clara Bog. Smooth newt (*Lissotriton vulgaris*), a species not typically associated with raised bog has also been reported from soaks and water bodies on Clara Bog (Crushell *et al.* 2008a).

The only mammal recorded from the high bog is Irish hare (*Lepus timidus hibernicus*). Mammal species that have been recorded from marginal areas (and watercourses) surrounding the bog include badger (*Meles meles*), otter (*Lutra lutra*), stoat (*Mustela erminea hibernica*), red fox (*Vulpes vulpes*), and pine marten (*Martes martes*).

A study has been carried out on the dispersion patterns and habitat relationship of breeding bird species on Clara Bog (Pohler 1996). The bird fauna of Clara Bog was studied by Bracken *et al.* (2008) in their research on the bird communities of peatlands. That study recorded six species breeding on the bog during 2006 including; mallard (*Anas platyrhynchos)*, common snipe (*Gallinago gallinago*), curlew (*Numenius arquata*), hooded crow (*Corvus cornix)*, skylark (*Alauda arvensis*) and meadow pipit (*Anthus pratensis*) as reported in Bracken & Smiddy (2012). Red grouse (*Lagopus lagopus*) was previously reported from Clara Bog but have not been recorded since the 1980s. Breeding curlew (*Numenius arquata*) were recorded on Clara Bog during the last national survey, in 2014 (NPWS unpublished data).

The terrestrial and aquatic invertebrate fauna of Clara Bog has been relatively well documented (Reynolds 1984a; Reynolds 1984b; Reynolds 1985; Wisdom & Bolger 2011; Hannigan & Kelly-Quinn 2011; Crushell *et al.* 2008a).

2 Conservation objectives

A site-specific conservation objective aims to define the favourable conservation condition of a habitat or species at site level. The maintenance of habitats and species within sites at favourable condition will contribute to the maintenance of favourable conservation status of those habitats and species at a national level.

Conservation objectives for habitats are defined using attributes and targets that are based on parameters as set out in the Habitats Directive for defining favourable status, namely area, range, and structure and functions. Attributes and targets may change or become more refined as further information becomes available.

National Conservation Objectives for raised bog SACs have recently been published in the Draft National Raised Bog SAC Management Plan (DAHG 2014). The various attributes and the justification of appropriate targets used to define favourable conservation condition for ARB relevant to Clara Bog SAC are discussed in the following sections.

2.1 Area

The national SAC target for the attribute 'habitat area' has been set at 2,590ha (DAHG 2014). This target is based on the estimated area of ARB (1,940ha) and DRB (650ha) present within the SAC network in 1994 (when the Habitats Directive came into effect).

The area of ARB at Clara Bog in 1994 is estimated to have been 146.5ha (surveyed 1992), while the area of DRB is estimated to have been 33.3ha at that time (see Table 3). Using the same approach that has been adopted in setting the national SAC target, the site-specific target for Clara Bog would equate to 179.8ha (sum of ARB and DRB in 1994). However, in setting the site-specific target the current hydro-ecological conditions on the bog (including cutover) have been considered in order to ensure that the target being set is based on a realistic appraisal of what is achievable as set out below.

The most recent monitoring survey of the bog (Fernandez & Wilson 2009) estimated the area of ARB to be 111.5ha. This represents a decline of 35ha (23.9%) during the period 1992-2009. An additional survey undertaken in 2004 shows that this decline occurred during the period 1994-2004, and that in fact, the area of ARB increased slightly during the period 2004-2009 (see Table 3) as a result of positive effects of high bog drain blocking and a reduction of peat cutting intensity (Fernandez & Wilson 2009).

The current extent of DRB as estimated using a recently developed hydrological modelling technique, based largely on Light Detection And Ranging (LiDAR)[2] data, is 87.6ha (see DAHG 2014 for further details of the technique). This represents the area of the high bog, which does not currently contain ARB but has topographical and hydrological conditions deemed suitable to support ARB (see Map 1 which shows the total area of current and modelled potential ARB). This area was refined to 61.3ha by estimating the area that could be restored by blocking drains on the high bog. This refinement was based on applying an efficacy factor (see DAHG 2014).

Based on the current assessment of the bog above, it is therefore concluded that the maximum achievable target for ARB on the high bog is 172.8ha, which is 7ha less than the estimated area at time of designation. It is expected that restoration of the DRB on the high bog could be achieved by undertaking restoration works (drain blocking) on the high bog alone coupled with the positive trends already seen on Clara East due to restoration works. However, it is important to note that this assumes no further decline of ARB due to enhanced vertical losses of bog water caused by drainage penetrating into underlying mineral soils as has been shown to occur along the southern margin of Clara West (Regan & Johnston 2010a & b).

[2] LiDAR is a remote sensing technology that measures vertical surface elevation by illuminating a target with a laser and analyzing the reflected light. This provides much more detailed topographical maps than can be collected by traditional surveying techniques.

Table 3 Area of ARB and DRB recorded within Clara Bog SAC in 1992, 2004 and 2009 (Source: Kelly *et al*. 1995; Fernandez *et al*. 2005; Fernandez & Wilson 2009).

1992		2004		2009	
ARB (ha)	DRB (ha)	ARB (ha)	DRB (ha)	ARB (ha)	DRB (ha)
146.5	33.3	100.3	Unknown	111.5	61.3

A recent eco-hydrological assessment of the cutover surrounding the high bog undertaken as part of the restoration planning process estimates that, by implementing appropriate management, an additional 6.9ha of ARB could be restored in this area.

The long term achievable target for ARB on Clara Bog is therefore set at 179.7ha.

In conclusion, the site-specific target for the attribute habitat area is: **Restore area of active raised bog to 179.7ha, subject to natural processes.**

2.2 Range

At a national scale, range represents the geographic range that encompasses all significant ecological variations of the ARB habitat. The national SAC target for the attribute 'range' has been set as 'not less than current range subject to natural processes'.

However, range, in the form of habitat distribution, may also be important at the site level, particularly within larger SACs, including those containing a number of individual bogs (i.e. complexes). The attribute therefore under the parameter of range is 'habitat distribution'. At the local level, it is important to conserve the variability and distribution of ARB across a raised bog SAC. This will help to ensure the diversity of the habitat is maintained while lessening the impact of localised damaging activities such as fire.

The conservation of ARB within Clara Bog as set out in Section 2.1 above will contribute to safeguarding the national range of the habitat.

The ARB habitat at Clara includes central and sub-central ecotope, as well as active flush and soaks systems, including areas of bog woodland. A map showing the most recent distribution of ecotopes throughout Clara Bog is presented in Map 2. Clara Bog can be divided into two distinct hydrological units (Clara Bog East and Clara Bog West), by the road that was constructed across the bog. ARB has been recorded on both Clara Bog East and Clara Bog West with central ecotope also recorded on both sides of the bog in the most recent survey (Fernandez & Wilson 2009). The best examples of ARB are reported from Clara Bog West. Drain blocking undertaken in Clara East during the 1990s is having a significant positive effect on the distribution of ARB on Clara Bog East (Fernandez & Wilson 2009).

The site-specific target for the attribute habitat distribution is: **Restore the distribution and variability of active raised bog across the SAC.**

2.3 Structure and functions

Structure and functions relates to the physical components of a habitat ("structure") and the ecological processes that drive it ("functions"). For ARB these include attributes such as the hydrological regime, water quality, habitat quality, species occurrence, elements of local distinctiveness, marginal habitats, negative physical indicators, and negative species occurrence. As several of these attributes are inter-connected, they are all included in order to better define habitat quality in a meaningful way. In some cases, attribute targets are not quantified; however, as more detailed information becomes available (for example through

further research), more measurable site-specific targets may be developed. Structure and functions attributes are expanded on in the sections below.

2.3.1 High bog area

On individual raised bogs adequate high bog is required to support the development and maintenance of ARB. Raised bog habitat that is classified as neither ARB nor DRB is still important particularly as a supporting habitat for those listed in Annex I of the Habitats Directive. It is an essential part of the hydrological unit which supports the ARB and DRB habitats. High bog is of value in its own right as a refuge for species characteristic of drier bog conditions as well as for providing a transitional zone between the Annex I habitats of the high bog and surrounding areas. Additional values for the maintenance of high bog include the preservation of its record of past environmental conditions and carbon storage. The area of high bog in the entire SAC network in 1994 was 10,740ha. The corresponding area in 2012 is 10,515ha – indicating that there has been a 225ha loss of high bog since 1994.

The national target for the attribute 'high bog' habitat is to ensure no decline in extent of high bog to support the development and maintenance of ARB.

The area of high bog within Clara Bog SAC in 1994 was mapped as 445.7ha, while the corresponding area in 2012 is 436.5ha (based on interpretation of LiDAR and aerial photography flown in 2012), representing a loss of 9.2ha of high bog (DAHG 2014). The extent of high bog within the SAC in 2012 is illustrated on Map 1.

The site-specific target for the attribute high bog is: **No decline in extent of high bog necessary to support the development and maintenance of ARB.**

2.3.2 Hydrological regime: water levels

Hydrological processes are key drivers of raised bog ecology. The different raised bog communities, assemblages, and species are affected by various hydrological attributes. For ARB, mean water levels need to be near or above the surface of bog lawns for most of the year. Seasonal fluctuations should not exceed 20cm, and water level should be within 10cm of the surface, except for very short periods of time (Kelly & Schouten 2002). Gentle slopes that limit intermittent lateral losses of water (through surface run-off) and encourage sustained waterlogging are the most favourable to achieve these conditions. These conditions may be maintained on steeper slopes in areas of focused flow (flushes).

The traditional view of water flowing across the bog laterally has been recently refined to also consider that water flows vertically through peat into the underlying mineral substrate. Water loss, by this route, depends on the permeability of the material through which the water must flow and the difference in head (water level elevation) in the bog and underlying mineral substrate; larger differences encountered in higher permeability materials will result in greater losses. Although the proportion of water lost in this manner may be small, the sustained loss during prolonged dry periods may be sufficient to impact bog ecotopes. Drains extending into the mineral substrate in marginal areas surrounding the bog can lead to an increased gradient between the head in the peat and the head in the underlying substrate resulting in increased vertical water losses from the bog.

Much of the knowledge regarding the hydrological requirements of raised bog communities in Ireland stems from the extensive ecological and hydrological work undertaken on Clara Bog since the early 1990s. The hydrology of Clara Bog is described in detail by van der Schaff (1999; 2002), Schouten (2002), ten Heggeler *et al*. (2005) and Regan & Johnston (2010a and b). The most recent description of drainage at Clara is presented in Fernandez & Wilson

(2009). Ten Heggeler *et al.* (2005) show that the cutover drains (none of which have been blocked) are also causing drying out of the high bog, particularly the deep cutover drains to the south of Shanley's Lough on Clara West. Recent studies have demonstrated the negative effects of deep marginal drains on the hydrology of the high bog (Regan 2013; Regan & Johnston (2010a and b).

More recent surveys of marginal drain hydrochemistry have identified limited intervals of focused regional groundwater discharge. Water level monitoring of piezometers installed into the substrate underlying the peat have demonstrated localized declines in water level (and associated water pressure) that support bog topography. This has resulted in significant changes in high bog topography in the vicinity of up-welling drains, including the further development of mounds and lakes and an associated decline of ARB. These changes in topography have altered surface water flow patterns on the high bog (see below).

The site-specific target for the attribute hydrological regime – water levels is: **Restore appropriate water levels throughout the site.**

2.3.3 Hydrological regime: flow patterns

As outlined above, ARB depends on water levels being near or above the surface of bog lawns for most of the year. Long and gentle slopes are the most favourable to achieve these conditions. Changes to flow directions due to subsidence of bogs can radically change water regimes and cause drying out of high quality ARB areas and soak systems.

Such a scenario is evident at Clara Bog where significant changes to ARB and a rheotrophic soak system have occurred due to subsidence and its associated changes in flow patterns on the high bog. Similarly, it is likely that the long term effects of subsidence and subsequent changes to surface water flow patterns have had an effect on Lough Roe soak system as reported by Crushell *et al*. (2009).

A map illustrating the slopes and drainage patterns on Clara Bog based on a digital elevation model generated from LiDAR imagery flown in 2012 is presented in Map 3. This map illustrates the profound impact that subsidence has had on flow patterns on Clara West, with one large catchment contributing flow through the area of Shanley's Lough. This illustrates the major impact the construction of the road has had on flow patterns on Clara West. Further subsidence continues to threaten Shanley's Lough, with recent evidence that the large catchment has fragmented due to past peat cutting and drainage of agricultural land (Regan 2013; Regan & Johnston 2013).

Flow patterns on Clara East are likely to have been adversely affected by drainage of the high bog surface. However, in general, flow patterns here appear to have improved to a more natural pattern of radial flow from the centre to the bog margins as a result of drain blocking.

The site-specific target for the attribute hydrological regime – flow patterns is: **Restore, where possible, appropriate high bog topography, flow directions and slopes.**

2.3.4 Transitional areas between high bog and surrounding mineral soils (includes cutover areas)

Transitional zones between raised bogs and surrounding mineral soils are typically cutover bog and drained lagg zones. The maintenance / restoration of these areas will help to maintain hydrological integrity of ARB and DRB, and support a diversity of other wetland habitats (e.g. wet woodland, bog woodland, swamp and fen) as well as species that they sustain. In some cases, these areas may assist in reducing further losses of ARB / DRB on the high bog and in time could develop into active peat forming habitats (including ARB - see

Section 2.1 above). These transitional zones, once restored, can provide ecosystem services through flood attenuation and water purification to downstream areas and potentially increase the carbon storage / sink function of the bog. The estimated extent of such transitional areas within the SAC network is 3,000ha (DAHG 2014). The national target for these transitional areas is to maintain / restore semi-natural habitats with high water levels around as much of the bog margins as necessary.

The transitional areas at Clara Bog include a range of different habitat types (e.g. improved grassland, wet grassland, cutover bog, scrub, woodland etc.) depending on a number of factors including prevailing land-use, topography, and drainage. The total area of cutover bog is estimated to be circa 97ha.

The most intact margins of the bog include a narrow transitional zone between the bog and the esker to the north, and a transition from the bog to an area of calcareous woodland to the east of the bog.

Studies undertaken on Clara Bog (Regan & Johnston 2010a & b) have shown that deep drainage associated with peat-cutting and agriculture in the transitional area along the south-western margin of the bog have caused significant subsidence and subsequent alteration of hydrology across the western part of the bog. The effects of this drainage are likely to continue until such time that restoration works are undertaken in the cutover to halt the vertical losses of bog water.

The site-specific target for the attribute transitional areas is: **Restore adequate transitional areas to support / protect ARB and the services it provides.**

2.3.5 Vegetation quality: central ecotope, active flush, soaks, bog woodland

A diverse good quality microtopography on raised bogs consists of *Sphagnum* dominated pools, hollows, lawns and hummocks, which support the highest diversity of species including hummock indicators: *Sphagnum fuscum* and *S. austinii*; pool indicators: *S. cuspidatum*, *S. denticulatum*, and indicators of lack of burning events e.g. some lichen species (*Cladonia* spp.) (Cross 1990).

The national target for the attribute vegetation quality has been set as "to maintain / restore sufficient high quality bog vegetation (i.e. central ecotope and / or flushes / soaks). At least 50% of ARB habitat should be central ecotope and / or flush / soaks." Bog woodland is also regarded as a desirable variant of ARB as it adds species and structural diversity to the habitat and therefore, where relevant, also contributes to the 50% target at site level.

The vegetation of Clara Bog has been the subject of considerable study and has been described in detail (e.g. Kelly 1993, Kelly & Schouten 2002; Fernandez *et al.* 2005; Crushell 2008; Fernandez & Wilson 2009). The ARB habitat at Clara includes central and sub-central ecotope, as well as, active flush mostly associated with the soaks systems.

The active flush ecotope areas mapped on Clara are of high quality and mostly associated with soaks.

There is also an area of birch woodland on Clara West which corresponds with the Annex I priority habitat bog woodland and is listed as a qualifying interest for the SAC. A separate Site-Specific Conservation Objective is being prepared for this habitat.

The finest examples of ARB are found on Clara West, with hummocks, hollows, lawns and frequent pools. The area of central ecotope is estimated to be 10.7ha on Clara West (Fernandez & Wilson 2009). There are two extensive soak systems on Clara West, known as the Western Soak and Shanley's Lough Soak. These soak systems are diverse with areas of wet scrub, wet woodland, open water, and central-like ecotope all present. The distribution

of ecotopes on Clara Bog as recorded in 2009 is illustrated in Map 2.

Ongoing subsidence associated with peat-cutting and cutover drains along the southern section of Clara West has caused the localised expansion of ARB habitat in lower areas and further widespread drying out in higher areas. This has resulted in the local expansion of marginal and sub-marginal ecotope (i.e. expansion of drier mounds and ridges). Continued subsidence in Clara West appears to have altered the flow patterns which supply the flow of water through the soak systems (Regan & Johnston 2013).

The main soak system on Clara Bog East is Lough Roe, which has been described in detail by Kelly (1993) and Crushell (2008). Conditions within the soak have become more ombrotrophic in recent times with an expansion of bog communities across the former lake surface accompanied by a decline in the minerotrophic communities and open water that formerly prevailed.

The extent of the different ecotopes that correspond with ARB based on the most recent surveys is presented in Table 4 and on Map 2. It can be seen that the proportion of ARB that comprises central ecotope and active flush (soak) is currently 30.3%. Comparing this to results of surveys undertaken in 2004 indicates that although the total area of ARB increased across the site, the proportion of each of the component ecotopes remained relatively static.

The target for this attribute is 89.9ha of central ecotope, active flush, and soaks (50% of ARB target area (179.7ha)).

Table 4 Extent of ecotopes classified as ARB in 2004 and 2009 (modified from Fernandez & Wilson 2009).

Ecotope	**2004**		**2009**	
	ha	**% of total ARB**	**ha**	**% of total ARB**
Sub-central ecotope	68.6	69.4	76.8	68.9
Central ecotope	9.9	10.1	11.3	10.1
Active flush/soak	20.4	20.6	22.0	19.7
Bog woodland	1.3	1.3	1.4	1.3
Total ARB	**100.2**		**111.5**	

The site-specific target for the attribute vegetation quality is: **Restore 89.9ha of central ecotope, active flush, soaks, bog woodland as appropriate.**

2.3.6 Vegetation quality: microtopographical features

The characteristic microtopographical features of raised bogs are described in Section 1.1.1 above.

Hummock and hollow microtopography is well developed in the western part of Clara Bog. Previous drainage efforts on the eastern side of the bog have had a negative effect on the surface microtopography (Kelly 1993; Fernandez & Wilson 2009).

The site-specific target for the attribute microtopographical features is: **Restore adequate cover of high quality microtopographical features.**

2.3.7 Vegetation quality: bog moss (*Sphagnum*) species

Bog mosses, which have unique properties, are the principal component of peat, and are largely responsible for the typical microtopographical features as described in Section 1.1.1 above.

The vegetation of a typical raised bog that is still hydrologically intact is characterised by the dominance of several species of Sphagna and dwarf, ericoid shrubs. The most abundant species are *Sphagnum capillifolium, S. austinii* and *S. papillosum* which form hummocks or low ridges. *Sphagnum fuscum* may also form hummocks (Cross 1990). On the flats *Sphagnum magellanicum, S. papillosum, S. tenellum,* and *S. subnitens* are the key species. *Sphagnum pulchrum* may also be dominant in flats on western raised bogs. In permanently waterlogged hollows *Sphagnum cuspidatum* and *S. denticulatum* (western bogs) occur. *Sphagnum fallax* is common where there is slight flushing (Cross 1990). The most commonly occurring *Sphagnum* moss species that occur on raised bogs in Ireland are presented in Table 5 along with a summary of their ecology and typical contribution to peat formation.

Kelly (1993) and Kelly & Schouten (2002) provide detailed information on the occurrence of *Sphagnum* species throughout Clara Bog.

Table 5 *Sphagnum* species typically associated with raised bog ecosystems in Ireland. Ecology as described by Laine *et al.* (2009) with minor modifications.

Species	Ecology	Peat forming capacity
Sphagnum austinii	Hummock species	High
Sphagnum capillifolium	Forms small hummocks and carpets	Moderate
Sphagnum cuspidatum	Pool and hollow species	Low
Sphagnum denticulatum	Pool and hollow species	Low
Sphagnum fallax	Occurs in lawns and carpets, shade tolerant. Indicative of some nutrient enrichment (soaks and active flushes)	Low
Sphagnum fuscum	Forms dense low and wide, and occasionally high hummocks	High
Sphagnum magellanicum	Lawn species forming carpets and low hummocks	Moderate
Sphagnum palustre	Forms hummocks and dense carpets, often in shaded conditions. Indicative of nutrient enrichment (soaks and active flushes)	Low
Sphagnum papillosum	Lawn , hollow, and low hummock species	Moderate
Sphagnum pulchrum	Grows in lawns and hollows, more typical of western bogs	Moderate
Sphagnum squarrosum	Forms carpets and small mounds. Indicative of nutrient enrichment (soaks and active flushes)	Low
Sphagnum subnitens	Occurs as individual shoots or small cushions and lawns. Tolerant of minerotrophic conditions	Moderate
Sphagnum tenellum	Occurs as single shoots or weak cushions, typically in disturbed patches of the bog surface	Low

The site-specific target for the attribute bog moss (*Sphagnum*) species is: **Restore adequate cover of bog moss (*Sphagnum*) species to ensure peat-forming capacity.**

2.3.8 Typical ARB species: flora

Clara Bog supports the full complement of plant species typically associated with a true midland raised bog (see Section 1.1.2 above).

The key typical species that are indicative of high quality raised bog include *Sphagnum fuscum* and *S. austinii* which are associated with hummocks and *S. cuspidatum* and *S. denticulatum* which are associated with pools and hollows. All of these species have been reported from Clara Bog (Fernandez & Wilson 2009).

Fernandez & Wilson (2009) report that within the ARB on Clara East and especially the inter-connected pools on Clara West, that cover more than 50% of the ground in places, are mostly in-filled with *Sphagnum cuspidatum* and support *Menyanthes trifoliata*, *Drosera anglica* and *Eriophorum angustifolium*. Large *Sphagnum papillosum* and *S. magellanicum* hummocks surround the pools. *Sphagnum* cover is generally greater than 70% and reaches 100% in places. *S. papillosum* and *S. magellanicum* lawns are also frequent. Hummocks of *S. austinii* and *S. fuscum* are also found in these ARB areas, and less commonly on DRB.

The site-specific target for the attribute typical bog flora is: **Restore, where appropriate, typical active raised bog flora.**

2.3.9 Typical ARB species: fauna

Clara Bog supports a wide range of fauna species that are typically associated with raised bog habitat (see Section 1.1.3 above).

The site-specific target for the attribute typical bog fauna is: **Restore, where appropriate, typical active raised bog fauna.**

2.3.10 Elements of local distinctiveness

A range of features may be associated with raised bogs which add to the scientific, historical, or conservation value of a bog. These can include geological, topographical, archaeological and hydrological features (e.g. soaks, lakes, flushes) and noteworthy species of flora and fauna (Cross 1990). Notable species of flora and fauna include those listed in the Habitats and Birds Directives, Red-listed species and other rare or localised species. For this attribute, features that are particularly associated with ARB are relevant.

2.3.10.1 Site features

Soak systems are the main features of local distinctiveness on Clara Bog.

'Soak' is a term used in European bog literature to describe an area of fen vegetation occurring within an acid bog (Gore 1983; Cross 1990; Connolly *et al.* 2002; Rydin & Jeglum 2006). The presence of fen vegetation is due to increased nutrient / mineral supply by either minerogenous water (minerotrophic) or the lateral through-flow of ombrogenous water from the surrounding bog expanse (rheotrophic) (Osvald 1949; Gore 1983).

In contrast to the non-wooded vegetation dominated by ericaceous shrubs and *Sphagnum* mosses that typifies the oceanic raised bogs, soaks are characterised by oligo-mesotrophic open-water communities, poor fen and / or bog woodland vegetation (Cross 1990).

Soaks support a relatively high diversity of species and unusual flora and fauna assemblages not typically found within raised bogs (Overbeck 1975; Reynolds 1990; Kelly 1993) thereby adding to the heterogeneity and biodiversity of the ecosystem type (Verberk 2008).

The soak complexes on Clara can be included in two broad divisions (Kelly & Schouten, 2002): the soaks on Clara Bog West in which the higher nutrient availability is connected to

rheotrophic conditions and the Lough Roe complex, which indicates a minerotrophic influence (Kelly & Schouten 2002; Crushell 2008).

The soaks occurring on Clara West have communities dominated by bottle sedge (*Carex rostrata*) and flat-topped bog moss (*Sphagnum fallax)* in the wetter areas and surrounding the lakes. Elsewhere there are examples of downy birch (*Betula pubescens*) scrub and woodland, feathery bog moss (*Sphagnum cuspidatum)* lawns and tall herb communities dominated by purple moor-grass (*Molinia caerulea*). Shanley's Lough soak includes an area of well-developed bog woodland which is a qualifying Interest for the SAC.

On Clara Bog East, Lough Roe is a former lake approximately 1.2 hectares in extent. Palaeoecological studies undertaken on Lough Roe indicate that it had been an open water-body for over 6000 years and that it gradually enlarged as the surrounding bog developed (Connolly 1999). It then became terrestrialised by a floating raft of vegetation and by 1978 an area of approximately 125m^2 of open water remained, surrounded by a floating raft (scragh or schwingmoor) containing a high abundance of minerotrophic species (including: water mint (*Mentha aquatica*), forget-me-not (*Myosotis laxa*), wild angelica (*Angelica sylvestris*), marsh cinquefoil (*Potentilla palustris*), ragged robin (*Lychnis flos-cuculi*) and sweet vernal grass (*Anthoxanthum odoratum*) (Schouten, unpublished). This type of minerotrophic community is rare in Ireland and even more notable was its presence near the centre of an acid raised bog with no obvious source of mineral rich water nearby. Since then the ecological interest of the plant communities in this area has deteriorated due to further terrestrialisation and subsequent acidification (Crushell *et al.* 2006).

2.3.10.2 Rare flora

The rare moss, *Tetraplodon angustatus*, was previously recorded at the site, its only known Irish station. This moss is found growing on the scats of carnivores (usually fox), often perched on rocks or mounds of moss in scree and by paths (Atherton *et al.* 2010). The species was last recorded from the bog in 1988.

Notable flora species previously recorded from the site include:

- White sedge (*Carex curta*), rare in the south and west of the country, has been recorded in the western part of Lough Roe (Kelly 1993; Crushell 2008).
- Slender tufted sedge (*Carex acuta*), has only 13 post-1949 10 km records in Ireland. It was recorded by Kelly (Kelly & Schouten 2002) growing in a remnant lagg zone at the north-eastern margin of the bog.
- Waved fork-moss (*Dicranum undulatum*), a moss species previously thought to be extinct in Ireland (Lockhart *et al.* 2012) has recently been recorded on Clara Bog East (G. Smith pers. comm.).

2.3.10.3 Rare fauna

Breeding curlew (*Numenius arquata*) have been recently recorded on Clara Bog (NPWS unpublished data).

The following notable invertebrate species (mostly from Ryan *et al.* 1992) have been recorded; however, the current status of these species at the site is not known:

- *Lasiodiamesa sphagnicola* (a bloodworm), the only Irish record for this species is from Clara Bog
- *Parhelophilus consimilis* (a hoverfly), commonly associated with bog pools in Ireland. Its occurrence in Ireland is of international significance

- *Ampedus pomorum* (a click beetle)
- *Dictaenidia bimaculata* (a large cranefly), localized distribution
- *Argyra elongata* (a fly), highly characteristic of soaks
- *Cordylura rufipes* (a fly) highly characteristic of soaks
- *Ilybius chalconatus* (a water beetle) (Renou-Wilson *et al.* 2011), is listed as vulnerable in recent red list (Foster *et al.* 2009).

In conclusion, the site-specific target for the attribute elements of local distinctiveness is: **Maintain features of local distinctiveness, subject to natural processes.**

2.3.11 Negative physical indicators

Raised bogs that have been damaged by marginal cutting and drainage, reclamation for agriculture, forestry activities, fire, surface drainage, or the lowering of regional water tables show a range of negative physical indicators (Cross 1990). Such negative physical features of ARB include: bare peat, algae dominated pools and hollows, marginal cracks, tear patterns, subsidence features such as dry peat and / or mineral mounds / ridges emerging or expanding, and burning evidence.

During a survey undertaken in 2009 fire damage, in the form of bare peat and damage to hummocks, was recorded in the north-eastern section of Clara West (date of fire reported as 2008) (Fernandez & Wilson 2009).

Peat cracking and slumping is evident in proximity to the facebanks along the southern margin of the bog.

There are major subsidence features in the form of dry mineral mounds and ridges present on Clara Bog West, particularly in the area West of Shanley's Lough. Elsewhere in this area, the subsidence has resulted in the recent appearance of large ponds (Fernandez & Wilson 2009). The major subsidence on Clara Bog has been described in detail by a number of authors (van der Schaaf 2002; ten Heggler 2005; Regan & Johnston 2013).

The site-specific target for the attribute negative physical indicators is: **Negative physical features absent or insignificant.**

2.3.12 Vegetation composition: native negative indicator species

Indicators of disturbance on a raised bog include species indicative of drying out conditions such as abundant *Narthecium ossifragum* and *Trichophorum germanicum*; *Eriophorum vaginatum* forming tussocks; abundant *Sphagnum magellanicum* in pools previously dominated by species typical of very wet conditions (e.g. *Sphagnum cuspidatum*). Indicators of frequent burning events include abundant *Cladonia floerkeana* and high cover of *Carex panicea* (particularly in the true midlands raised bog type).

The site-specific target for the attribute negative indicator species is: **Native negative indicator species at insignificant levels.**

2.3.13 Vegetation composition: non-native invasive species

Non-native invasive species that can commonly occur on raised bog habitats include: *Pinus contorta*, *Rhododendron ponticum*, and *Sarracenia purpurea* (Cross 1990).

Non-native species are not a major issue on Clara Bog although a few individual pine trees are present (Fernandez *et al.* 2006). Regenerating conifers occur in cutover to the south of site (Fernandez *et al.* 2006).

The site-specific target for the attribute non-native invasive species: **Non-native invasive species at insignificant levels and not more than 1% cover.**

2.3.14 Air quality: nitrogen deposition

Peatlands are highly sensitive to air pollution, particularly nitrogen deposition. Reactive nitrogen from fossil fuel combustion or intensive agriculture can contaminate rain and snow, causing soil acidification, nutrient enrichment, and a decline in species that are sensitive to these conditions. There is evidence that the combined impact of elevated nitrogen deposition and a warming climate could exceed the sum of the individual stressors and lead to a dramatic decline in the biodiversity of mosses, sensitive vascular plants, and microbes, potentially leading to catastrophic peat loss (PEATBOG project - http://www.sste.mmu.ac.uk).

Air pollution can change both the species composition and the functioning of peatlands. The primary atmospheric pollutant from the Industrial Revolution to the mid 1970s was sulphur deposition, but levels have since greatly declined. Reactive nitrogen (N) deposition (primarily NO3- and NH4+), which can both acidify and eutrophy, became significantly elevated over a widespread area in the early to mid-20th century and is now the major pollutant in atmospheric deposition across most of Europe (Fowler *et al.* 2005).

Nitrogen is commonly a limiting terrestrial nutrient and in un-impacted peatlands it is tightly cycled. With long-term elevated N deposition, vegetation composition typically shifts toward species adapted to higher nutrient levels, with an overall loss of diversity (Malmer & Wallén 2005). In peatlands, field experiments with N additions within the current European range have shown significant declines in bryophyte species-richness and productivity, and shifts in composition toward vascular plants (Bobbink *et al.* 1998; Bubier *et al.* 2007). Community shifts toward more nitrophilous bryophytes in N-enriched regions such as parts of the Netherlands are also well documented (Greven 1992). In the UK, both a general survey of peatlands across the country (Smart *et al.* 2003), and a targeted study of *Calluna* moorland (Caporn *et al.* 2007) showed significant inverse relationships between levels of nitrogen deposition and species richness, with bryophytes particularly impacted. Changes in the vegetation also impact below-ground communities and biogeochemical processes.

Moderate increases in N deposition from a low level may increase *Sphagnum* and vascular plant productivity without an equal increase in decomposition rates, leading to enhanced carbon accumulation (Turunen *et al.* 2004). However, shifts in species composition from bryophytes to vascular plants may increase the production of easily-decomposable plant material, leading to higher rates of decomposition, and reduced carbon accumulation (Lamers *et al.* 2000; Bubier *et al.* 2007).

The particular sensitivity of nutrient-poor ombrotrophic peatlands to nitrogen enrichment is reflected in the low critical load threshold of between 5 and 10kg N/ha/yr for these ecosystems (Bobbink & Hettelingh 2011), a level which is exceeded over a significant portion of their range. An Irish study during the late 1990s undertaken by Aherne & Farrell (2000) concluded that total N deposition shows a strong east-west gradient, with lowest deposition in the west at 2kg N/ha/yr and highest in the east and south-east at 20kg N/ha/yr. Average N deposition over the Republic of Ireland was estimated to be approximately 12kg N/ha/yr. The study also concluded that the Critical Load Threshold for N was exceeded in at least 15% of ecosystems studied. The critical load applied to peatland ecosystems by Aherne & Farrell (2000) was 10kg N ha^{-1} y^{-1}. This is in line with the recommendation by Bobbink & Hettelingh (2011) that the critical load should be set at the high end of the range in areas of high precipitation and at the low end of the range in areas of low precipitation assuming that Ireland represents a high precipitation area.

It is recommended in the case of Clara Bog that the level of N deposition should not exceed the low end of the range i.e. 5kg N/ha/yr. This recommendation is based on a precautionary approach, as the evidential basis for setting a higher level is not particularly strong as alluded to by Payne (2014). The bulk deposition level at Clara Bog reported by Tomassen *et al.* (2004) was 4.6kg N/ha/yr. The inputs of N were a number of times higher than other stations in midlands, possibly due to intensive agriculture locally in the surroundings (Tomassen *et al.* 2004). However, Total N deposition in the vicinity of Clara Bog as reported by Henry & Aherne (2014) is 14.1kg N/ha/yr.

The site-specific target for the attribute air quality is: **Air quality surrounding bog close to natural reference conditions. The level of N deposition should not exceed 5kg N/ha/yr.**

2.3.15 Water quality

Ombrotrophic peat waters found on the surface of raised bogs are characterised by low pH values (pH < 4.5) (Moore & Bellamy 1974) and also have low values of Electrical Conductivity (EC). This is due to the fact that the raised bog system derives its mineral supply from precipitation, which is usually acidic and low in nutrients. Raised bog vegetation exchanges cations with protons to further reduce the pH.

Hydrochemistry varies in the areas surrounding a raised bog. Locally, conditions may be similar to the high bog due to a dominance of water originating from the bog. However, elsewhere in the marginal areas, there may be increased mineral and nutrient content of the water due to regional groundwater influences, run-off from surrounding mineral soils, and the release of nutrients through oxidation of peat resulting from reduced water levels.

The hydrochemistry of Clara Bog is well documented as reported by Kelly & Schouten (2002). Only minor differences were noted in the hydrochemistry of the different vegetation communities that typically occur on the high bog. The water at the bog surface is a rain water type with an ionic dominance of sodium (Na) and chlorine (Cl); it is soft to very soft and with low EC – values (70-90 $\mu S\ cm^{-1}$) and pH values between 4.0 and 5.5.

Hydrochemistry of the soak systems on Clara Bog have been investigated by Kelly (1993) and Crushell (2008). These studies have confirmed that the water chemistry within Shanley's Lough and the Western Soaks is similar to that present in the surrounding bog. The constant through flow of water originating from the surrounding bog surface explains the different vegetation communities that persist in these areas (Kelly & Schouten 2002; Connolly *et al.* 2002).

Water chemistry within Lough Roe soak system indicates that the site has, until recently, been influenced by minerotrophic conditions as reported by both Kelly & Schouten (2002), Connolly *et al.* (2002) and Crushell *et al.* (2009). Recent work on the water and peat chemistry at the site suggests that the minerotrophic conditions at the site originate from within the bog basin. Crushell *et al.* (2009) propose that the most likely source is from the fen peat which underlies the soak and surrounding bog and that the minerals were originally transported towards the soak by a local hydrological flow from the surroundings during the phase of early bog development. Later the mineral rich conditions were maintained within and at the surface of the soak by high rates of decomposition and associated internal alkalinity generation.

Water quality in the transitional (cutover) areas around the bog varies dramatically, from low EC Na-Cl type waters resembling those encountered on the high bog, to high EC Ca-HCO_3 waters where deeper regional groundwater up-wells. These latter areas have associated minerotrophic vegetation, which in many cases is generated as a consequence of drains penetrating to depth and permitting regional groundwater to up-well.

The site-specific target for the attribute water quality is: **Water quality on the high bog and in transitional areas close to natural reference conditions.**

3 References

Aherne, J., & Farrell, E.P. (2000) Final Report: Determination and mapping of critical loads for sulphur and nitrogen and critical levels for ozone in Ireland. Environmental Protection Agency, Dublin, 212pp.

Atherton, I., Bosanquet, S. & Lawley, M. (2010) Mosses and Liverworts of Britain and Ireland: A Field Guide. Plymouth, U. K.: British Bryological Society. pp. 835.

Bobbink, R., Hornung, M. & Roelofs, J.G.M. (1998) The effects of air—borne nitrogen pollutants on species diversity and semi—natural European vegetation. Journal of Ecology 86: 717–738.

Bobbink, R. & Hettelingh, J.P. (2011) Review and revision of empirical critical loads and dose-response relationships. Proceedings of an expert workshop, Noordwijkerhout, 23-25 June 2010. RIVM report 680359002, Coordination Centre for Effects, National Institute for Public Health and the Environment (RIVM).

Bracken, F., McMahon, B. & Whelan, J. (2008) Breeding bird populations of Irish Peatlands: capsule peatlands are very important habitats for birds despite low species diversity. Bird Study 55 (2): 169-178.

Bracken, F. & Smiddy, P. (2012) Lowland bogs, fens and reedswamps, pp. 73-89. In: Nairn, R., and O'Halloran, J. (eds.) Bird Habitats in Ireland. The Collins Press, Cork.

Bubier, J., Moore, T. & Bledzki, L.A. (2007) Effects of nutrient addition on vegetation and carbon cycling in an ombrotrophic bog. Global Change Biology 13: 1168–1186.

Caporn, S.J.M., Edmondson, J., Carroll, J.A., Pilkington, M. & Ray, N. (2007) Long-term impacts of enhanced and reduced nitrogen deposition on semi-natural vegetation. Report to Defra. Terrestrial Umbrella. Work Package 2: Impacts, Recovery and Processes. Task 4. Defra London.

CEC (2007) Interpretation manual of European Union Habitats. Version EUR 27. European Commission, DG Environment, Brussels. Nature and Biodiversity.

Colhoun, K. & Cummins, S. (2013) Birds of Conservation Concern in Ireland 2014–2019. Irish Birds 9: 523-544.

Connolly, A. (1999) The palaeoecology of Clara Bog, Co. Offaly. Unpublished Ph.D. thesis, Trinity College Dublin.

Connolly, A., Kelly, L., Lamers, L., Mitchell, F.J.G., van der Schaaf, S., Schouten, M.G.C., Streefkerk, J.G. & van Wirdum, G. (2002) Soaks. In: Schouten, M.G.C. (ed.), Conservation and restoration of raised bogs: geological, hydrological and ecological Studies. Dúchas – The Heritage Service of the Department of the Environment and Local Government, Ireland; Staatsbosbeheer, the Netherlands; Geological Survey of Ireland, Dublin. pp. 170-185.

Cross, J. (1990) The Raised Bogs of Ireland, their ecology, status and conservation. Report to the Minister of State at the Department of Finance. The Stationery Office, Dublin.

Crushell, P.H., Schouten, M.G.C., Smolders A.J.P., Roelofs, J.G.M. & Giller, P.S. (2006) Restoration of Minerotrophic Vegetation within an Irish Raised Bog Soak System. Biology and the Environment, Proceedings of the Royal Irish Academy 106B (3): 371-385.

Crushell, P.H. (2008) Soak Systems of an Irish Raised Bog: a multidisciplinary study of their origin, ecology, conservation and restoration. PhD thesis, Wageningen University, with a summary in Dutch and Irish.

Crushell, P.H., Schouten, M.G.C., Robroak, B.J.M. & van Duinan, G-J. (2008a) The

contribution of soak lakes to macroinvertebrate diversity of raised bogs in Ireland. In: Crushell, P.H. (2008). Soak Systems of an Irish Raised Bog: a multidisciplinary study of their origin, ecology, conservation and restoration. PhD thesis, Wageningen University, with a summary in Dutch and Irish.

Crushell, P.H., Connolly, A., Schouten, M.G.C. & Mitchell, F.G. (2008b) The changing landscape of Clara Bog: the history of an Irish raised bog. Irish Geography 41 (1): 89-111.

Crushell, P.H., Smolders, A.J.P., Schouten, M.G.C., Roelofs, J.G.M. & van Wirdum, G. (2009) The origin and development of a minerotrophic soak on an Irish raised bog: an interpretation of depth profiles of hydrochemistry and peat-chemistry. The Holocene 19 (6): 921-935.

DAHG (2014) National Raised Bog SAC Management Plan. Draft for Consultation. Main report and appendices. Department of Arts, Heritage and the Gaeltacht.

De Leeuw, J.P.M. (1986) Een onderzoek naar het voorkomen en de verspreiding van aquatische macro- en mirofauna in de Ierse hoogvenen. Deel 1: Macrofauna. Aquatische Oecologie, Katholieke Universiteit Nijmegen, Nijmegen, The Netherlands.

Derwin, J. & MacGowan, F. (2000) Raised bog restoration project: a continuation of the investigation into the conservation and restoration of selected raised bog sites in Ireland. Unpublished report, Dúchas the Heritage Service, Dublin.

Fernandez Valverde, F., Fanning, M., McCorry, M. & Crowley, W. (2005) Raised bog monitoring project 2004-2005. Document 3: Site Reports and Maps Volume 1-5. Unpublished Report. National Parks and Wildlife Service, Dublin.

Fernandez Valverde, F., MacGowan, F., Crowley, W., Farrell, M., Croal, Y., Fanning, M. & McKee, A. (2006) Assessments of impacts of turf cutting on designated raised bogs 2003-2006. A Report to the Research Section of National Parks and Wildlife Service.

Fernandez Valverde, F. & Wilson, S. (2009) Clara Bog High Bog Ecological Survey. National Parks and Wildlife Service, Dublin.

Fernandez, F., Connolly, K., Crowley, W., Denyer J., Duff, K. & Smith, G. (2014) Raised bog monitoring and assessment survey 2013. Irish Wildlife Manuals, No. 81. National Parks and Wildlife Service, Department of Arts, Heritage and Gaeltacht, Dublin, Ireland.

Flynn, C. (2014) Nocturnal Lepidoptera of Midland Raised Bogs. A thesis submitted to the National University of Ireland, Maynooth for the Degree of Master of Science (MSc.).

Fossitt, J. (2000) A Guide to Habitats in Ireland. The Heritage Council, Ireland.

Foster, G.N., Nelson, B.H. & O Connor, Á. (2009) Ireland Red List No. 1 – Water beetles. National Parks and Wildlife Service, Department of Environment, Heritage and Local Government, Dublin, Ireland.

Fowler, D., Smith, R.I., Muller, J.B.A., Hayman, G. & Vincent, K.J. (2005) Changes in the atmospheric deposition of acidifying compounds in the UK between 1986 and 2001. Environmental Pollution, 137: 15-25.

Gore, A.J.P. (ed.) (1983) Ecosystems of the world 4A. Mires: Swamp, bog, fen and moor. General studies. Elsevier Scientific Publishing Company, Amsterdam.

Greven, H.C. (1992) Changes in the moss flora of the Netherlands. Biological Conservation 59: 133-137.

Hammond R.F. (1979) The Peatlands of Ireland. Soil survey Bulletin No. 35, An Foras Talúntais, Dublin.

Hannigan, E., & Kelly-Quinn, M. (2011) Chapter 2.6 - Aquatic macro-invertebrate diversity. pp. 140-157 In: Renou-Wilson, F. (ed.) BOGLAND: Sustainable Management of Peatlands in Ireland. Environmental Protection Agency, Wexford.

Henry, J. & Ahern, J. (2014). Nitrogen deposition and exceedance of critical loads for nutrient nitrogen in Irish grasslands. Science of the Total Environment 470–471: 216–223.

Kelly, M.L. (1993) Hydrology, hydrochemistry and vegetation of two raised bogs in county Offaly. PhD thesis, Trinity College Dublin.

Kelly, L., Doak, M. & Dromey, M. (1995) Raised Bog Restoration Project: An Investigation into the Conservation and Restoration of Selected Raised Bog Sites in Ireland. Part 1 Summary Reports. National Parks & Wildlife Service, Department of Environment, Heritage and Local Government, Dublin.

Kelly, L. & Schouten, M.G.C. (2002) Vegetation. In: Schouten, M.G.C. (ed.), Conservation and restoration of raised bogs: geological, hydrological and ecological Studies. Dúchas – The Heritage Service of the Department of the Environment and Local Government, Ireland; Staatsbosbeheer, the Netherlands; Geological Survey of Ireland, Dublin. pp. 110-169.

Laine, J., Harju, P., Timonen, T., Laine, A., Tuittila, E.S, Minkkinen, K. & Vasander, H. (2009) The Intricate beauty of Sphagnum mosses - A Finnish guide to identification. University of Helsinki Department of Forest Ecology Publications, 39: 1–190.

Lamers, L. P. M., Bobbink, R. & Roelofs, J. G. M. (2000) Natural nitrogen filter fails in polluted raised bogs. Global Change Biology, 6: 583–586.

Lockhart, N., Hodgetts, N. & Holyoak, D. (2012) Rare and Threatened Bryophytes of Ireland. Blackstaff Press, Belfast.

Malmer, N. & Wallén, B. (2005) Nitrogen and phosphorus in mire plants: variation during 50 years in relation to supply rate and vegetation type. Oikos, 109: 539–554.

Moore, J.J. (1959) Botanical notes. Irish Naturalists Journal 13: 102.

Moore, P.D. & Bellamy, D.J. (1974) Peatlands. Elek Science. London.

NPWS (2008) The Status of EU Protected Habitats and Species in Ireland. National Parks and Wildlife Service, Ireland.

NPWS (2013) The Status of EU Protected Habitats and Species in Ireland. Version 1.0. Unpublished Report, National Parks and Wildlife Services. Department of Arts, Heritage and the Gaeltacht, Dublin, Ireland.

NPWS (2014). National Peatland Strategy - Draft for Consultation. NPWS, Department of Arts, Heritage and the Gaeltacht, Dublin, Ireland.

O'Connell C. (ed.) (1987) The IPCC Guide to Irish Peatlands. Irish Peatland Conservation Council, Dublin.

O'Connell, P. (2011) Action Plan for Raised Bog Birds in Ireland 2011-2020. BirdWatch Ireland, Kilcoole, Co Wicklow.

O Connor, Á., Reynolds, J.D. & Kavanagh, B. (2001) Aquatic macroinvertebrate colonisation of artificial water bodies in cutaway oceanic raised bog in Ireland. In: Rochfort, L. and Daigle, J.Y. (eds.), Proceedings of the 11th International Peat Congress. pp. 742-750.

Osvald, H. (1949) Notes on the vegetation of British and Irish mosses. Acta Phytogeographica Suecica 26: 1-62.

Overbeck, F.Th. (1975) Botanisch-geologische Moorkunde. Wachholtz Verlag, Neumünster.

Payne, R.J. (2014) The exposure of British peatlands to nitrogen deposition, 1900–2030. Mires and Peat 14: Art. 4.

Pohler, T. (1996) Studies of dispersion patterns and habitat relationship of breeding bird species on raised bogs of the atlantic type in Central Ireland - Impact of drainage measures. Zoological Institute Technical University of Braunschweig, Braunschweig, Germany.

Regan, S. (2013) The Hydrogeology and Restoration of a Raised Bog. PhD Thesis, University of Dublin, Trinity College.

Regan, S. & Johnston, P. (2010a) Consequences of Marginal Drainage from a Raised Bog and Understanding the Hydrogeological Dynamics as a Basis for Restoration. European Geosciences Union (EGU) General Assembly 2010, Vienna, Austria.

Regan, S. & Johnston, P. (2010b) Groundwater as an Ecological Supporting Condition in Raised Bogs and the Implications for Restoration; an Example from Clara Bog, Ireland. XXXVIII International Association of Hydrogeologists, Krakow, Poland.

Regan, S. & Johnston, P. (2013) Catchment fragmentation and hydro-ecological modification of a raised bog wetland. Proceedings of H01, IAHS-IAPSO-IASPEI Assembly, Gothenburg, Sweden, July 2013 (IAHS Publ. 359, 2013) pp. 340-345.

Renou-Wilson, F., Bolger, T., Bullock, C., Convery, F., Curry, J., Ward, S., Wilson, D. & Müller, C. (2011) BOGLAND: Sustainable Management of Peatlands in Ireland. STRIVE Report Series No.75. Prepared for the Environmental Protection Agency. pp. 181.

Reynolds, J.D. (1984a) Invertebrate survey of Irish midlands raised bogs. Bulletin of the British Ecological Society 15: 81-82.

Reynolds, J.D. (1984b) Invertebrate fauna of Irish raised bogs. Part II: Odonata, aquatic Hemiptera and Trichoptera. Bulletin of the Irish Biogeographical Society 8: 98-102.

Reynolds, J.D. (1985) Invertebrates of Lough Roe, Co. Offaly; a rare and endangered bogland habitat. Bulletin of the Irish Biogeographical Society 9: 41-45.

Reynolds, J.D. (1990) Ecological relationships of peatland invertebrates. In: Doyle, G.J. (ed.), Ecology and Conservation of Irish Peatlands. Royal Irish Academy, Dublin. pp. 135-143.

Ryan, J., Warner, P. & Douglas, C. (1992) Management Plan for Clara Bog National Nature Reserve, Co. Offaly. Unpublished report to the National Parks and Wildlife Service, Dublin.

Rydin, H. & Jeglum, J.K. (2006) The biology of peatlands. Oxford University Press, New York.

Schouten, M.G.C. (1984) Some aspects of the ecogeographical gradient in the Irish ombrotrophic bogs, paper presented to 7th Int. Peat Congress, Dublin, vol. 1, pp. 414-432, The International Peat Society, Helsinki.

Schouten, M.G.C. (ed.) (2002) Conservation and Restoration of Raised Bogs – geological, hydrological and ecological studies. Dúchas – The Heritage Service of the Department of the Environment and Local Government, Ireland; Staatsbosheheer, The Netherlands; and The Geological Survey of Ireland. pp. 220.

Smart, S.M., Robertson, J., Shield, E.J. & van de Poll, M.H. (2003) Locating eutrophication effects across British vegetation between 1990 and 1998. Global Change Biology 9: 1763-1774.

Ten Heggeler, M.M.A., van der Ploeg, M.J., Vuurens, S.H. & van der Schaaf, S. (2005) Subsidence of Clara Bog West and acrotelm development of Raheenmore Bog and Clara Bog East: a comparison of 1991-1992 and 2002-2003. Wageningen University, the Netherlands.

Tomassen H.B.M., Smolders A.J.P., Limpens J., Lamers, L.P.M. & Roelofs, J.G.M. (2004)

Expansion of invasive species on ombrotrophic bogs: desiccation or high N deposition? Journal of Applied Ecology. 41: 139–150.

Turunen, J., Roulet, N.T., Moore, T.R. & Richard, P.J.H. (2004) Nitrogen deposition and increased carbon accumulation in ombrotrophic peatlands in eastern Canada. Global Biogeochemical Cycles. 18 (3): GB3002.

Van der Schaaf, S. (1999) Analysis of the hydrology of raised bogs in the Irish Midlands. A case study of Raheenmore and Clara Bog. Ph.D. thesis. The Netherlands: Wageningen University.

Van der Schaaf, S. (2002) Bog Hydrology. In: Schouten, M.G.C. (ed.), Conservation and restoration of raised bogs: geological hydrological and ecological studies. Dúchas – The Heritage Service of the Department of the Environment and Local Government, Ireland, Staatsbosbeheer, the Netherlands and Geological Survey of Ireland, Dublin. pp. 54-109.

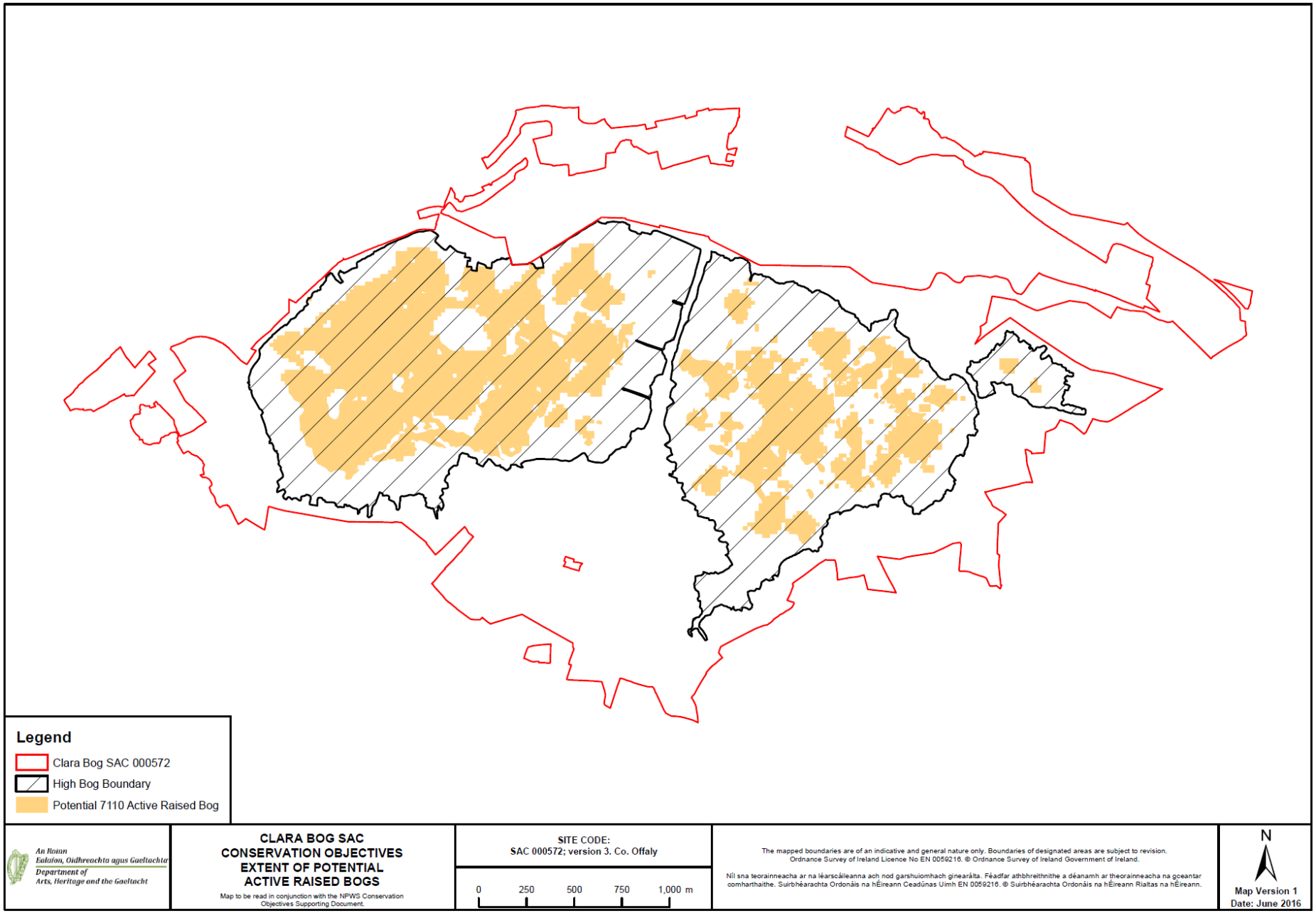
Van Duinen G.A. (2013) Rehabilitation of aquatic invertebrate communities in raised bog landscapes. PhD thesis, Radboud University Nijmegen, the Netherlands.

Verberk, W.C.E.P. (2008) Matching species to a changing landscape – Aquatic macroinvertebrates in a heterogeneous landscape. PhD thesis, Radboud University, Nijmegen.

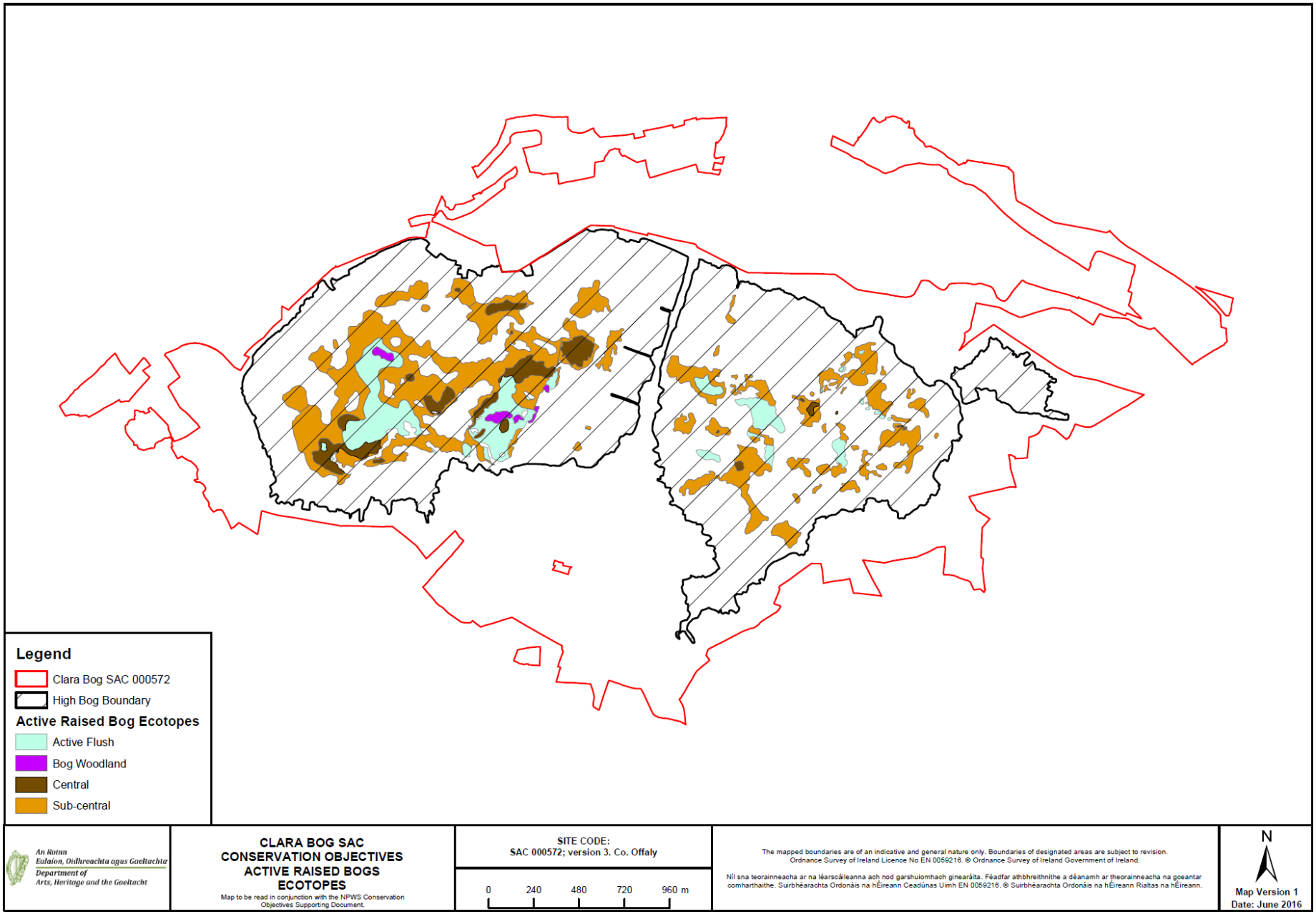
Wilson, H.J. (1990) Birds of raised bogs. pp. 29-36. In: Cross, J. (ed.) The Raised Bogs of Ireland, their ecology, status and conservation. Report to the Minister of State at the Department of Finance. The Stationery Office, Dublin.

Wisdom, R. & Bolger, T. (2011) Chapter 2.4 - Terrestrial invertebrate biodiversity. pp. 103-121 In: Renou-Wilson, F. (ed.) BOGLAND: Sustainable Management of Peatlands in Ireland. Environmental Protection Agency, Wexford.

Map 1: Extent of potential active raised bog on Clara Bog.



Map 2: Distribution of raised bog ecotopes on Clara Bog.



Map 3: Digital elevation model and drainage patterns at Clara Bog.