

National Parks & Wildlife Service

Mongan Bog SAC
(site code 000580)

**Conservation objectives supporting document -
raised bog habitats**

Version 1

April 2016

Contents

1	INTRODUCTION	2
1.1	RAISED BOGS.....	2
1.1.1	<i>Raised Bogs Microtopography</i>	<i>3</i>
1.1.2	<i>Typical Flora of Irish Raised Bogs</i>	<i>5</i>
1.1.3	<i>Typical Fauna of Irish Raised Bogs</i>	<i>6</i>
1.2	HABITATS DIRECTIVE RAISED BOG HABITATS IN IRELAND	9
1.2.1	<i>Restoration of Active Raised Bog in Ireland</i>	<i>10</i>
1.3	MONGAN BOG SAC	10
1.3.1	<i>Flora of Mongan Bog</i>	<i>11</i>
1.3.2	<i>Fauna of Mongan Bog</i>	<i>12</i>
2	CONSERVATION OBJECTIVES	13
2.1	AREA	13
2.2	RANGE	14
2.3	STRUCTURE AND FUNCTIONS	14
2.3.1	<i>High bog area.....</i>	<i>15</i>
2.3.2	<i>Hydrological regime: water levels.....</i>	<i>15</i>
2.3.3	<i>Hydrological regime: flow patterns.....</i>	<i>17</i>
2.3.4	<i>Transitional areas between high bog and surrounding mineral soils (includes cutover areas).....</i>	<i>17</i>
2.3.5	<i>Vegetation quality: central ecotope, active flush, soaks, bog woodland</i>	<i>18</i>
2.3.6	<i>Vegetation quality: microtopographical features.....</i>	<i>19</i>
2.3.7	<i>Vegetation quality: bog moss (Sphagnum) species percentage cover</i>	<i>19</i>
2.3.8	<i>Typical species: bog flora</i>	<i>20</i>
2.3.9	<i>Typical species: bog fauna</i>	<i>20</i>
2.3.10	<i>Elements of local distinctiveness.....</i>	<i>21</i>
2.3.10.1	<i>Site features</i>	<i>21</i>
2.3.10.2	<i>Rare flora</i>	<i>21</i>
2.3.10.3	<i>Rare fauna.....</i>	<i>21</i>
2.3.11	<i>Negative physical indicators</i>	<i>21</i>
2.3.12	<i>Vegetation composition: native negative indicator species</i>	<i>22</i>
2.3.13	<i>Vegetation composition: non-native invasive species.....</i>	<i>22</i>
2.3.14	<i>Air quality: nitrogen deposition</i>	<i>22</i>
2.3.15	<i>Water quality</i>	<i>23</i>
3	REFERENCES	24

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

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

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

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 Mongan Bog Special Area of Conservation (SAC) has been designated.

Mongan 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.

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 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

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 together (where known) with scientific names.*

communities. In Ireland, most lags 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, 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 Bogs 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).

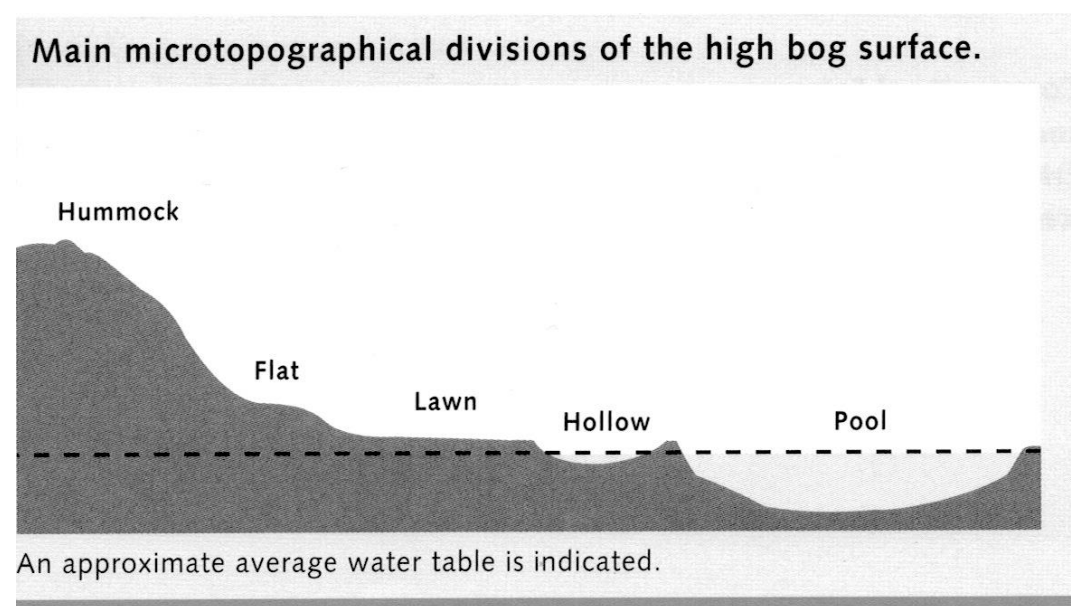


Figure 1 Raised bog microtopographical divisions on the high bog surface (reproduced from Kelly & Schouten 2002).

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 (ed.) (2002).*

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

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 have 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 microinvertebrate 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 Duinen (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 (ed.) (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)) (Ciara Flynn pers. comm.).

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 (ed.) 1987; Cross 1990; Renou-Wilson *et al.* 2011; Bracken & Smiddy 2012).

Common name	Scientific name
Mammal species	
Irish hare	<i>Lepus timidus hibernicus</i>
Otter	<i>Lutra lutra</i>
Pygmy shrew	<i>Sorex minutes</i>
Fox	<i>Vulpes vulpes</i>
Bird species	
Skylark	<i>Alauda arvensis</i>
Mallard	<i>Anas platyrhynchos</i>
Greenland white-fronted goose	<i>Anser albifrons flavirostris</i>
Meadow pipit	<i>Anthus pratensis</i>
Hen harrier	<i>Circus cyaneus</i>
Cuckoo	<i>Cuculus canorus</i>
Merlin	<i>Falco columbarius</i>
Kestrel	<i>Falco tinnunculus</i>
Snipe	<i>Gallinago gallinago</i>
Red grouse	<i>Lagopus lagopus</i>
Curlew	<i>Numenius arquata</i>
Golden plover	<i>Pluvialis apricaria</i>
Lapwing	<i>Vanellus vanellus</i>
Reptiles and amphibians	
Common lizard	<i>Lacerta vivipara</i>
Common frog	<i>Rana temporaria</i>
Typical invertebrates	
Black slug	<i>Arion ater</i>
Large heath butterfly	<i>Coenonympha tullia</i>
Marsh fritillary butterfly	<i>Euphydryas aurinia</i>
Bog-pool spider	<i>Dolomedes fimbriatus</i>
Water striders	<i>Gerris</i> and <i>Velia</i> species
Oak eggar moth	<i>Lasiocampa quercus</i>
Four-spotted chaser dragonfly	<i>Libellula quadrimaculata</i>
Fox moth	<i>Macrophyllacia rubi</i>
Ant	<i>Myrmica ruginodis</i>
Emperor moth	<i>Saturnia pavonia</i>
Great green bog grasshopper	<i>Stethophyma grossa</i>
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 (crane flies) 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 'active raised bogs': "*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 'Active Raised Bog' 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 ecotopes, 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*. 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 ($\leq 0.3\%$ 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 Mongan Bog SAC

The SAC includes the raised bog, known as Mongan Bog and surrounding areas which include cutover bog, scrub and broadleaved woodland, wet grassland, and improved grassland.

The SAC has been selected for the following Annex I habitats:

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

Mongan Bog is a true midland raised bog of medium size situated immediately east of the monastic site of Clonmacnoise, Co. Offaly, and 12 km south of Athlone. It is situated in a

well-defined basin, surrounded on 95% of its perimeter by high ground on mineral soil.

Mongan Bog is a mostly intact and unusually wet raised bog with classic hummock and pool formations over a large proportion of the surface. The bog has several features of special zoological interest. In addition, its lowest strata are thought to be among the oldest in Ireland. Scenically it is part of area landscape rich in intact natural features (callows, eskers, limestone pavement) which enhances its importance even more.

The bog has been the subject of considerable scientific research since the 1970s.

1.3.1 Flora of Mongan Bog

Mongan bog is considered to be a true midlands raised bog, although the presence of *Carex panicea*, *Sphagnum denticulatum*, and *Pleurozium purpurea* is more typical of western raised bogs.

The centre of the dome has a large area of tear pools with abundant *Menyanthes trifoliata* and *Sphagnum cuspidatum*, although some pools have dead *Sphagnum*, pointing to drying episodes. Hummocks with the mosses *Sphagnum austinii* and *S. fuscum* occur with high frequency and other species present include *Rhynchospora alba*, *Rhynchospora fusca*, *Drosera anglica* with abundant *Calluna vulgaris*, *Erica tetralix*, *Eriophorum vaginatum*, *Narthecium ossifragum*, and *Carex panicea*. *Vaccinium oxycoccos* can be found on hummocks.

Radiating out from the central area, the tear pools have a higher algal cover and towards the facebank the hollows are dominated by *Narthecium ossifragum*. Towards the edge of the high bog, the surface becomes more dominated by *Calluna vulgaris* and *Trichophorum germanicum*, although *Sphagnum* mosses are still present.

Myrica gale can be found in some areas. At the facebank, quite tall and dense stands of *Calluna vulgaris* are found and there is much *Hypnum jutlandicum* present in the bryophyte layer.

An unusually large number of hummocks, sometimes 1m high, largely composed of the moss *Leucobryum glaucum* are widespread on the bog. Pools found on the site contain *Utricularia minor*, *Drosera anglica*, the liverwort *Cladopodiella fluitans* and the bog mosses *Sphagnum cuspidatum* and *S. denticulatum*. The bog supports a rich lichen flora, including *Cladonia portentosa*, *C. arbuscula*, *C. tenuis*, *C. floerkeana* and *C. glauca*, due, in part, to the absence of burning over much of it. Many of the lichens occur on old *Calluna vulgaris* stems.

A small strip of cutover bog, part of which is colonised by *Salix* spp. and *Betula* spp. scrub, on both the north and the south side of the bog adds diversity to the site.

Fernandez *et al.* (2014a, b) report that within the best quality ARB which covers a small area in the highest section of the dome there is good microtopography consisting of high and low hummocks, large *Sphagnum* lawns and pools and hollows. *Sphagnum* covers up to 90% of the ground and consists of *S. papillosum*, *S. subnitens*, *S. capillifolium* and *S. austinii* forming hummocks, and *S. cuspidatum* and *S. denticulatum* in pools. Other species present include *Menyanthes trifoliata*, *Leucobryum glaucum* and *Drosera anglica*.

Other ARB areas show good microtopography consisting of hummocks, regular pools, and tear pools. The hummocks consist of *Sphagnum subnitens*, *S. papillosum*, *S. austinii* and *S. fuscum*. *Racomitrium lanuginosum* hummocks are occasionally found with some supporting *Calluna vulgaris* and *Leucobryum glaucum*. Interconnected pools and tear pools at the margins of the complex are colonised by *Sphagnum cuspidatum*, *S. papillosum*, and also *S. magellanicum*. Further descriptions of the vegetation of the bog are presented in Kelly (1993) and Fernandez *et al.* (2014a, b).

1.3.2 Fauna of Mongan Bog

An extensive checklist of the fauna of Mongan Bog, is given in Tubridy (1984). Additional records of species for the site are given in Tubridy & Jeffrey (1987).

The common frog (*Rana temporaria*) is known to occur. The only mammal recorded from the high bog is the Irish hare (*Lepus timidus hibernicus*). Mammal species that have been recorded from marginal areas surrounding the bog include badger (*Meles meles*) and red fox (*Vulpes vulpes*).

The birds of Mongan Bog have been described in a report by Madden (1987). Surveying over one year (1985 to 1986), Madden recorded the presence of 12 species on the high bog and 36 species on the cutover, of which five and 19 respectively were breeding, and noted that the avian fauna is probably typical of Irish raised bogs without woodland. Mallard (*Anas platyrhynchos*), curlew (*Numenius arquata*), snipe (*Gallinago gallinago*), skylark (*Alauda arvensis*), and meadow pipit (*Anthus pratensis*) were recorded breeding on the high bog. The cutover bog provides habitat for a range of bird species, including birds of prey, thrushes, warblers and finches. In the past the bog was occasionally used as a refuge for Greenland white-fronted geese (*Anser albifrons flavirostris*) (up to 40 individuals) (Madden 1987), however there are no recent records of geese using the site.

The invertebrate fauna of Mongan Bog has been the subject of considerable study (Bond 1989; Good 1985, 1987; Higgins 1984; Nolan 2009; Reynolds 1984a, 1984b). Several rare invertebrate species have been recorded from the bog (see Section 2.3.10). The invertebrate fauna of the pools have been shown to be highly productive.

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 Mongan Bog SAC are discussed in the following sections.

2.1 Area

NPWS has commissioned a number of raised bog surveys between 1993 and the present - Kelly *et al.* (1995); Derwin & MacGowan (2000); Fernandez *et al.* (2005); Fernandez *et al.* (2006); Fernandez *et al.* (2014). Mapping from these surveys has been used to derive the area of ARB for each bog as shown in Table 3. More recent surveys have been able to employ more precise and detailed mapping techniques and more standardised ecotope descriptions. NPWS undertook a review of data from earlier surveys in 2014 taking into account these improved techniques with the aim of providing more accurate figures for ARB. This in some cases has resulted in a change in ARB area for these earlier time periods (NPWS, unpublished data).

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 Mongan Bog in 1994 is estimated to have been 50.9ha, while the area of DRB is estimated to have been 9.3ha 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 Mongan Bog would equate to 60.2ha (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 estimated the area of ARB to be 48.3ha (Fernandez *et al.* 2014a, b). This represents a decrease of 2.6ha (5.1%) during the period 1994 - 2011. An additional survey undertaken in 2004 suggests that this decrease occurred gradually during the period (see Table 3).

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 14.8ha (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 conditions deemed suitable to support ARB (see Map 1 which shows the total area of current and modelled potential ARB). This area was further refined to 10.4ha by estimating the area that could be restored by blocking

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

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, it is therefore concluded that the maximum achievable target for ARB on the high bog is 58.7ha, which is 1.5ha less than the estimated area at time of designation. However, it is important to note that this assumes no further decline of ARB due to impacting activities. Similarly, should the bog be significantly dependent on regional groundwater levels then any deepening of drainage in the cutover could further impact the potential restoration of ARB on the high bog.

Table 3 Area of ARB and DRB recorded on the high bog at Mongan Bog in 1994, 2004, and 2011 (Source: Fernandez *et al.* 2014a, b).

1994		2004		2011	
ARB (ha)	DRB (ha)	ARB (ha)	DRB (ha)	ARB (ha)	DRB (ha)
50.9	9.3	48.2	Unknown	48.3	10.4

A recent eco-hydrological assessment of the cutover surrounding the high bog being undertaken as part of the management planning process estimates that, by implementing appropriate management, an additional 4.1ha of ARB could be restored in this area. The long term achievable target for ARB on Mongan Bog is therefore set at 62.8ha which is 2.6ha more than the estimated area of ARB and DRB in 1994.

In conclusion, the site-specific target for the attribute habitat area is: **Restore area of active raised bog to 62.8ha, 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 Mongan Bog as set out in Section 2.1 above will contribute to safeguarding the national range of the habitat. The ARB habitat at Mongan Bog includes central and sub-central ecotope. A map showing the most recent distribution of ecotopes throughout Mongan Bog is presented in Map 2.

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 Mongan Bog SAC in 1994 was mapped as 124.4ha, while the corresponding area in 2012 is 124.2ha (based on interpretation of LiDAR and aerial photography flown in 2012), representing a loss of 0.2ha of high bog (DAHG 2014). Peat cutting has now ceased at the site (Fernandez *et al.* 2014a, b). The extent of high bog within Mongan Bog 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 active raised bog.**

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. Such 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 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.

The most recent description of drainage at Mongan Bog is presented in Fernandez *et al.* (2012). This reports that 9.3km of high bog drains are considered to be impacting upon

raised bog habitats. Most of these drains have been blocked and are considered to be reduced functional, with only one very short drain considered to be functional (0.1km). A restoration project was undertaken in the 1984-1986 period, which included the blocking of the majority of high bog drains. Evidence of improvement (i.e. infilling, wet areas and areas rich in *Sphagnum*), were already noted by Fernandez *et al.* (2005) in areas with blocked drains. This trend continued as reported by the 2011 survey (Fernandez *et al.* 2012).

Cutover drains are located along the north-west and western margins of the high bog, as well as to the south. Fernandez *et al.* (2012) noted that according to NPWS regional staff, a drain parallel to the Bord na Móna railway line on the south-east side was deepened around 2011 (Noel Bugler pers. comm.). Sub-marginal vegetation stretches towards this location (into an areas that was previously classified as marginal ecotope) indicating that some water is flowing towards this direction.

In addition, overflow from previously dammed drains to the east created problems along the Bord na Móna machine pass in the past. As a result, water has been discharged at a lower level by deepening the drains beside the railway line (Noel Bugler pers. comm.). The impact of this activity has not been quantified. Some drain maintenance and deepening on the cutover grasslands to the southwest and west were also reported by regional NPWS staff (Noel Bugler pers. comm.) in the latest reporting period (2004-2011).

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. Available hydrological data for Mongan Bog includes the work carried out by Kelly *et al.* (1995) as well as a more recent survey of hydrochemistry carried out by RPS in 2013.

Kelly *et al.* (1995) identified that most of the water flowing from the bog and surrounding areas discharges into the marginal drains. However, groundwater in the northern esker and some of the water flowing in the drain to the north of Mongan Bog is thought to infiltrate into the esker deposits and flow towards the River Shannon rather than discharge as surface water via the drain. In addition, the extent of cutover peatland and the change in water level at the nearby fen at Fin Lough suggested that groundwater levels are much lower than in the past.

More recent hydrological investigations carried out by RPS in 2013 only identified water-bearing marginal drains around the northern and eastern margins of the site. Specific electrical conductivity (SEC) levels in the drains on the north-eastern side of the bog compare with levels noted in high bog water samples. By contrast adjacent marginal drains, approximately 30m further away from the bog margins, and set in cutover peat over 3m deeper, contain water with significantly higher SEC levels. SEC levels in the marginal drain along the northern side of the bog display significantly higher SEC signatures and reflect the influence of upwelling regional groundwater.

Towards the western side and southern areas of cutover the survey failed to detect interconnected water-bearing marginal drains. However, mineralised water was apparent in nearby drains installed in lower-lying agricultural land to the south. The occurrence of significant dry areas in peaty soils around the margins of Mongan Bog, particularly in areas underlain by permeable sand and gravel subsoils, point to more elevated regional groundwater levels in the past. Indeed the high bog displays evidence of mass movement reflecting the stresses operating on the peat in the past which exceeded its tensile strength, leading to the development of (now in-filled) tear pools. This may indicate impacts as a result of changes to regional groundwater levels; nevertheless, large areas of the high bog remain covered with good quality ARB suggesting the substrate immediately underlying the

peat has been effective in limiting the negative eco-hydrological effects associated with decreased regional groundwater levels.

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 Active raised bog areas and soak systems.

A map illustrating the slopes and drainage patterns on Mongan Bog based on a digital elevation model generated from LiDAR imagery flown in 2012 is presented in Map 3.

This map shows that Mongan Bog displays a domed topography as would be typical of a raised bog. However, the high bog catchment divide occurs closer to the southern margin than the northern margin of the site. The departure in topography from idealised conditions suggests that differential subsidence has occurred on Mongan Bog. Indeed the catchment boundary appears to have shifted further south than the boundary mapped by Kelly *et al.* (1995), although this must be considered with caution due to the lower quality of the topographic data available at the time. The area noted by Fernandez *et al.* (2012), where sub-marginal vegetation stretches towards the drain that was recently deepened, is in an area where further subsidence appears to have occurred.

Overall, Mongan Bog has demonstrated resilience to changes in regional groundwater levels, as indicated by the extent of ARB, suggesting that the high bog surface is much more isolated from the regional groundwater regime than some other raised bogs. However, the evidence of recent subsidence resulting in changes to flow on the southern side of the bog suggests that further changes to regional groundwater levels has the potential to impact on the eco-hydrology of Mongan Bog.

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, 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 Mongan Bog include a range of different habitat types (e.g. cutover bog, scrub, woodland, wet grassland, and dry semi-natural grassland). The total area of cutover bog is estimated to be circa 22ha. The development of habitats within cutover areas depends on a number of factors including prevailing land-use, topography, upwelling

regional groundwater, and drainage.

A number of different types of cutover bog have been recognised around Mongan Bog by Tubridy (1984) and Heery (1993), and the distinctions are still apparent (DEHLG 2005). Along a narrow band of cutover on the northern edge of the high bog, *Molinia caerulea* is quite abundant and accompanied by *Calluna vulgaris* and *Erica tetralix*. Some *Sphagnum* species are occasionally present. Where the cutover has been abandoned for some time, scrub has developed, while new areas of cutover are colonised by mosses such as *Hypnum jutlandicum* and *Campylopus introflexus*. At the west, the cutover bog is dominated by tall *Calluna vulgaris* with an understorey of grasses, predominantly *Molinia caerulea*. On the southern side of the bog, the cutover bog has *Molinia caerulea* flats with some *Salix atrocinerea* and other *Salix* spp. and depressions with *Sphagnum* spp., *Potentilla palustris*, and *Cardamine pratensis*.

Some enclosed fields at the west of the site have wet grassland vegetation with clumps of *Juncus effusus*. *Cardamine pratensis*, *Festuca ovina*, and *Rumex acetosa* also present. Along the southern margin some enclosed fields have *Holcus lanatus*, *Cardamine pratensis*, and *Filipendula ulmaria* abundant, accompanied by *Plantago lanceolata*, *Potentilla palustris*, and *Juncus effusus*. This species association occurs on partially reclaimed peat between the bog and the southern esker, Tubridy (1984) notes that this may reflect a relict bog/esker transitional community.

At the north of the site, calcareous grasslands are found on the lower slopes of the Pilgrim's Road Esker. In one area on the crest of a small hill and along slopes below the road, the grassland is unimproved. Species present on low-growing grassland include *Primula veris*, *Carex* spp., *Cerastium fontanum*, *Bellis perennis*, *Lotus corniculatus*, *Achillea millefolium* and *Anthoxanthum odoratum*. In one area just below the road a few spikes of *Orchis mascula* are present. On a steeply sloped area, the grassland is more rank and some *Pteridium aquilinum* or scrub of *Crataegus monogyna* and *Fraxinus excelsior* is present in small patches.

An area of birch wood is found on a former area of cutover peat to the west of the bog. Examination of Ordnance Survey maps shows that the wood was in existence in 1912. *Betula pubescens* is the dominant tree species with stems of widely varying ages, *Ilex aquifolium* is present, some *Pinus sylvestris* is found along the northern edge and the ground flora includes *Pteridium aquilinum*, *Rubus fruticosus*, and *Dryopteris filix-mas*.

The site-specific target for the attribute transitional areas is: **Restore adequate transitional areas to support / protect active raised bog 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 a site level.

A summary description of the vegetation of Mongan Bog is presented in Section 1.3.1 above. The vegetation and habitats of the bog have been described in more detail by Kelly *et al.* (1995) and Fernandez *et al.* (2014a, b).

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. During the most recent surveys the entire area of ARB comprised central and sub-central ecotope. The target for this attribute is to maintain 42.7ha central ecotope as this exceeds 50% of the total ARB present within the site (62.8ha).

Table 4 Extent of ecotopes classified as ARB in 2004 and 2011 (modified from Fernandez *et al.* 2014a, b).

Ecotope	2004		2011	
	ha	% of total ARB	ha	% of total ARB
Sub-central ecotope	5.5	11.4	5.6	11.6
Central ecotope	42.7	88.6	42.7	88.4
Total ARB	48.2		48.3	

The site-specific target for the attribute vegetation quality is: **Maintain at least 42.7ha 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 especially well developed in the western part of Mongan Bog. The central ecotope at the site has a complex of high and low hummocks, large *Sphagnum* lawns, pools, and hollows (Fernandez *et al.* 2012). Previous drainage efforts on the bog are reported to have had a negative effect on the surface microtopography (Kelly 1993; DEHLG 2005; Fernandez *et al.* 2012).

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

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

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.

Fernandez *et al.* (2012) provide further information on the occurrence of *Sphagnum* species throughout Mongan 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
<i>Sphagnum austinii</i>	Hummock species	High
<i>Sphagnum capillifolium</i>	Forms small hummocks and carpets	Moderate
<i>Sphagnum cuspidatum</i>	Pool and hollow species	Low
<i>Sphagnum denticulatum</i>	Pool and hollow species	Low
<i>Sphagnum fallax</i>	Occurs in lawns and carpets, shade tolerant. Indicative of some nutrient enrichment (soaks and active flushes)	Low
<i>Sphagnum fuscum</i>	Forms dense low and wide, and occasionally high hummocks	High
<i>Sphagnum magellanicum</i>	Lawn species forming carpets and low hummocks	Moderate
<i>Sphagnum palustre</i>	Forms hummocks and dense carpets, often in shaded conditions. Indicative of nutrient enrichment (soaks and active flushes)	Low
<i>Sphagnum papillosum</i>	Lawn , hollow, and low hummock species	Moderate
<i>Sphagnum pulchrum</i>	Grows in lawns and hollows, more typical of western bogs	Moderate
<i>Sphagnum squarrosum</i>	Forms carpets and small mounds. Indicative of nutrient enrichment (soaks and active flushes)	Low
<i>Sphagnum subnitens</i>	Occurs as individual shoots or small cushions and lawns. Tolerant of minerotrophic conditions	Moderate
<i>Sphagnum tenellum</i>	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*) to ensure peat-forming capacity.**

2.3.8 Typical ARB species: flora

Mongan Bog supports the full complement of plant species typically associated with a true midland raised bog but also has species more typical of western raised bogs (see Sections 1.1.2 and 1.3.1 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 Mongan Bog (Fernandez *et al.* 2012).

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

As mentioned in section 1.1.3, a list of typical fauna specific to ARB has not been developed and the table contains species that use the wider raised bog habitat. This may be refined as more information becomes available.

Mongan Bog supports a wide range of fauna species that are typically associated with raised bog habitat. The fauna associated with Mongan Bog has been the subject of considerable study as described in Section 1.3.2 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

An unusually large number of hummocks, sometimes 1m high, largely composed of the moss *Leucobryum glaucum*, are widespread on the bog.

Mongan Bog is part of a wider landscape that has a rich cultural and natural heritage (Tubridy and Jeffrey 1987). This area is on Ireland's tentative list for nomination as a world heritage site (DEHLG 2009). The bog has been the subject of considerable scientific research since the 1970s (see DEHLG 2005).

2.3.10.2 Rare flora

No notable flora has been reported, although the scarce brown beak-sedge (*Rhynchospora fusca*) is found on the site.

2.3.10.3 Rare fauna

As mentioned above, there is a lack of documented site-specific data relating to species that are particularly associated with ARB, including rare species.

Notable bird species that have been recorded breeding on the bog (Madden 1987) include curlew (*Numenius arquata*) (red listed on BoCCI), however, their current status is unknown.

A number of notable invertebrate species have been recorded on Mongan Bog (DEHLG 2005).

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.

A burn during 2010 damaged approximately 40% of the high bog area (50ha). This fire event must have been light as only minor evidence of burning was noted in 2011 (Fernandez *et al.* 2012). Another smaller fire event also took place in 2004, but this event only affected the western cutover (Noel Bugler pers. comm.).

It has been suggested that the central vegetation complex is secondarily formed due to stresses on the peat surface due to marginal peat cutting which gave rise to large numbers

of tear pools (Kelly *et al.* 1995). Overall, the majority of drains in the high bog remain reduced functional. High bog drainage is considered to have medium importance/impact on high bog habitats. Bog margin drainage is also considered to have medium importance/impact on high bog habitats (Fernandez *et al.* 2014a, b).

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 native 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 have not been reported on Mongan Bog (Fernandez *et al.* 2014a, b).

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/yr. 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 Mongan 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). Total N deposition in the vicinity of Mongan Bog as reported by Henry & Ahern (2014) is 13.4kg 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. 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. There is some evidence of calcareous regional groundwater influences in cutover areas surrounding the high bog (Kelly *et al.* 1995).

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.
- 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).
- Bond, K. (1989) Clonmacnoise Heritage Zone, Co. Offaly, Ireland. Assessment of conservation value based on Lepidoptera recorded from 1983 to 1987. *Bull. Ir. Biogeog. Soc.* 12: 63-89.
- 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.
- 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.
- 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.
- 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., Robroak, B.J.M. & van Duinen, G-J. (2008) 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.
- 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.
- DEHLG (2005) Mongan Bog (Bogán na Móna Fionn) cSAC & SPA, Co. Offaly. Conservation Plan for 2005-2010. National Parks and Wildlife Service of the Department of Environment, Heritage and Local Government, Dublin.
- DEHLG (2009) The Monastic City of Clonmacnoise and its Cultural Landscape. World Heritage

Site Draft Management Plan 2009-2014. Prepared by the Department of Environment, Heritage, and Local Government and the Office of Public Works.

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, Dublin.

Fernandez, F., Connolly, K., Crowley, W., Denyer, J., Duff, K. & Smith, G. (2014a) 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.

Fernandez, F., Connolly, K., Crowley, W., Denyer, J., Duff, K. & Smith, G. (2014b) Raised Bog Monitoring and Assessment Survey 2013 - Mongan Bog (SAC 000580), Co. Offaly - site report. National Parks and Wildlife Service, Department of Arts, Heritage and Gaeltacht, Dublin, Ireland. Fossitt, J. (2000) A Guide to Habitats in Ireland. The Heritage Council, 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.

Good, J. (1985). Invertebrates of the Irish Midlands Raised bogs: Part IV Notes on Terrestrial Insects. *Bulletin of the Irish Biogeographical Society* 9: 2 - 10

Good, J. (1987). A Survey of the Soil Fauna of the Heritage Zone - a Preliminary Survey of the Staphylinidae (Coleoptera). Unpublished report to the Clonmacnoise Heritage Zone Group.

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.

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

Heery, S. (1993) NHA Boundary Survey. Unpublished report to the National Parks and Wildlife Service.

Higgins, D.G. (1984). *Invertebrates of Irish Midlands Raised Bogs: Part 3. Lepidoptera.* *Bulletin of the Irish Biogeographical Society* 8: 91 - 97.

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.
- Madden, B. (1987) The birds of Mongan Bog, Co. Offaly. *Irish Birds* 3: 441-448.
- 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, P.D. & Bellamy, D.J. (1974) Peatlands. Elek Science. London.
- Nolan, M. (2009) *Walckenaeria alticeps* (Denis, 1952) (Araneae: Linyphiidae) new to Ireland from two raised bogs in County Offaly. *Bulletin of the Irish Biogeographical Society* 33: 174-183.
- Nolan, M. (2013) Spiders (Araneae) of Irish raised bogs: Clara bog, Co. Offaly and Carrowbehy bog, Co. Roscommon. *Bulletin of the Irish Biogeographical Society* 37: 172-203.
- 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.
- 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.
- Payne, R.J. (2014) The exposure of British peatlands to nitrogen deposition, 1900–2030. *Mires and Peat* 14: Art. 4.
- 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.
- 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. Duchas – The Heritage Service of the Department of the Environment and Local Government, Ireland; Staatsbosbeheer, 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.

Tubridy, M. (ed.) (1984). Creation and Management of a Heritage Zone at Clonmacnoise, Co. Offaly, Ireland. Environmental Sciences Unit, Trinity College Dublin.

Tubridy, M. & Jeffrey, D. (eds.) (1987) Clonmacnoise Heritage Zone Project. A Portfolio of Management Plans. Environmental Sciences Unit, Trinity College Dublin.

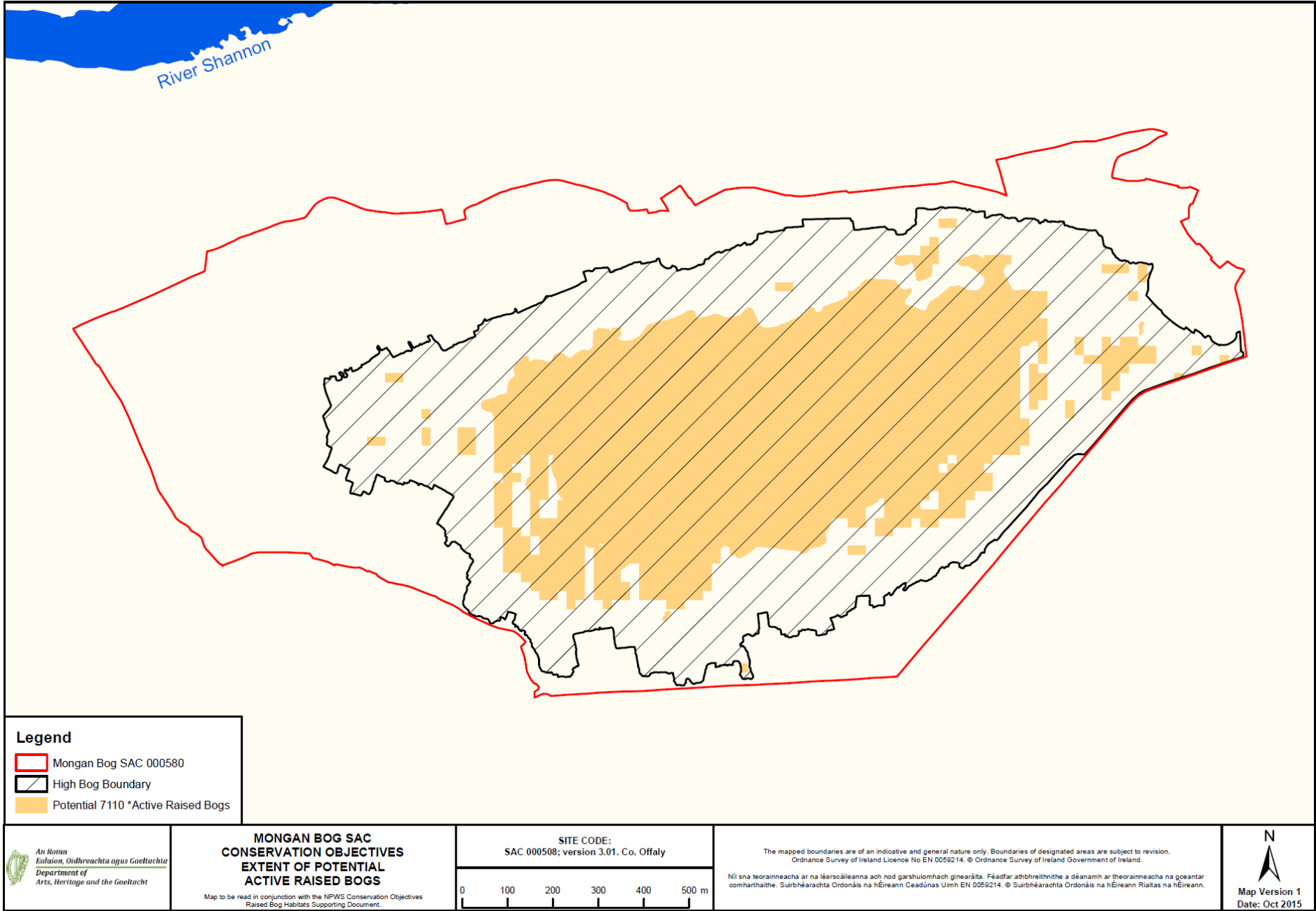
Turunen, J., Roulet, N.T., Moore, T.R. & Richard, P.J.H. (2004) Nitrogen deposition and increased carbon accumulation in ombrotrophic peatlands in eastern Canada. *Global Biogeochemical Cycles*. 18 (3): GB3002.

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

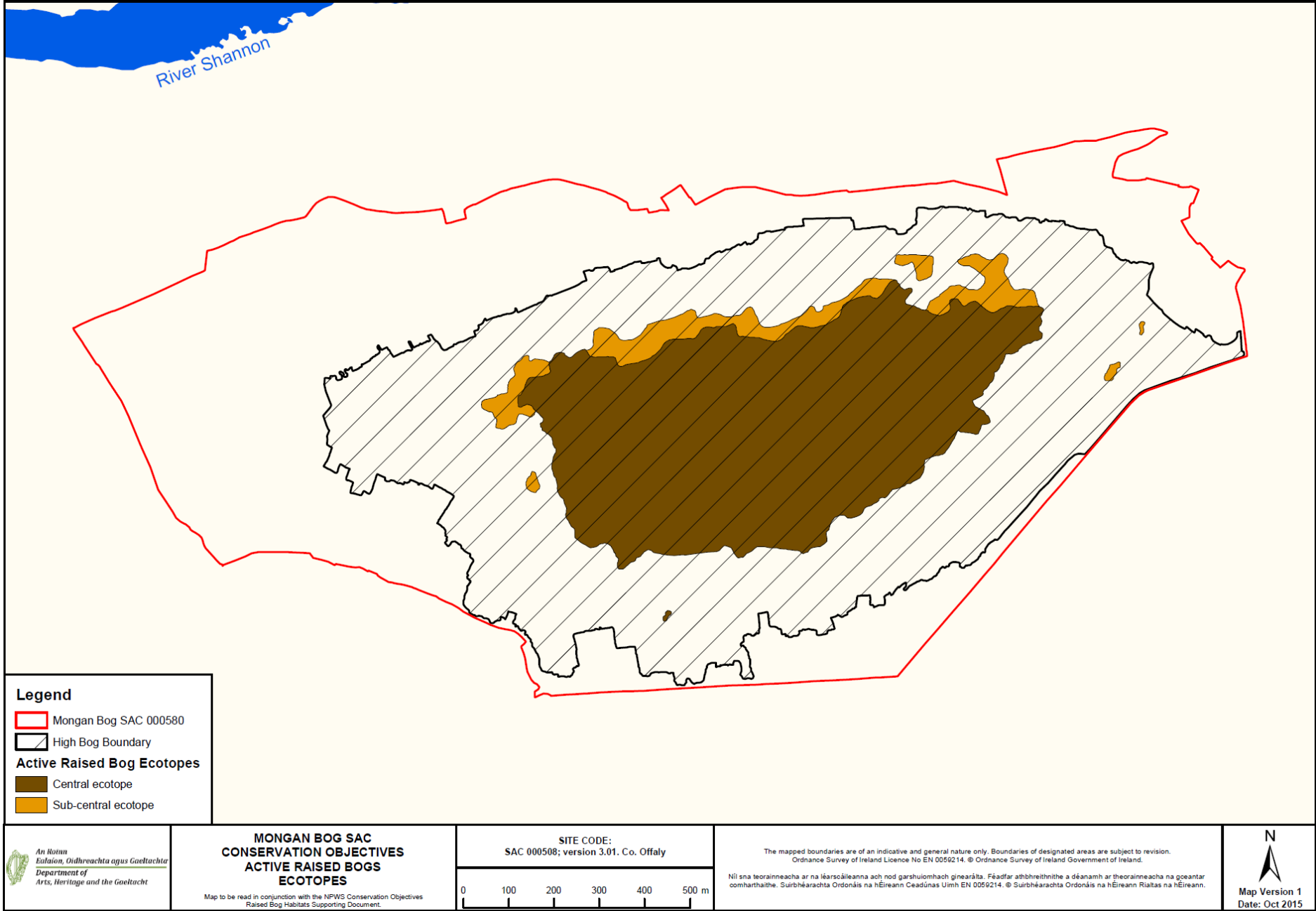
Wilson, H.J. (1990) Birds of raised bogs. pp. 29-36. In: Cross, J. (ed.) *The Raised Bogs of Ireland, their ecology, status and conservation*. Report to the Minister of State at the Department of Finance. The Stationery Office, Dublin.

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 Mongan Bog.



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



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

