

National Parks & Wildlife Service

Kilcarren-Firville Bog SAC  
(site code 000647)

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

Version 1

January 2016

## Contents

<b>1</b>	<b>INTRODUCTION .....</b>	<b>2</b>
1.1	RAISED BOGS .....	2
1.1.1	<i>Raised Bogs Microtopography.....</i>	3
1.1.2	<i>Typical Flora of Irish Raised Bogs.....</i>	5
1.1.3	<i>Typical Fauna of Irish Raised Bogs.....</i>	6
1.2	HABITATS DIRECTIVE RAISED BOG HABITATS IN IRELAND .....	9
1.2.1	<i>Restoration of Active Raised Bog in Ireland.....</i>	10
1.3	KILCARREN-FIRVILLE BOG SAC.....	11
1.3.1	<i>Flora of Kilcarren-Firville Bog.....</i>	11
1.3.2	<i>Fauna of Kilcarren-Firville Bog.....</i>	12
<b>2</b>	<b>CONSERVATION OBJECTIVES.....</b>	<b>12</b>
2.1	AREA .....	13
2.2	RANGE.....	14
2.3	STRUCTURE AND FUNCTIONS .....	14
2.3.1	<i>High bog area .....</i>	15
2.3.2	<i>Hydrological regime: water levels .....</i>	15
2.3.3	<i>Hydrological regime: flow patterns .....</i>	17
2.3.4	<i>Transitional areas between high bog and surrounding mineral soils (includes cutover areas) .....</i>	18
2.3.5	<i>Vegetation quality: central ecotope, active flush, soaks, bog woodland .....</i>	19
2.3.6	<i>Vegetation quality: microtopographical features .....</i>	19
2.3.7	<i>Vegetation quality: bog moss (Sphagnum) species .....</i>	20
2.3.8	<i>Typical species: bog flora .....</i>	21
2.3.9	<i>Typical species: bog fauna .....</i>	21
2.3.10	<i>Elements of local distinctiveness .....</i>	21
2.3.11	<i>Negative physical indicators.....</i>	22
2.3.12	<i>Vegetation composition: native negative indicator species.....</i>	22
2.3.13	<i>Vegetation composition: non-native invasive species.....</i>	22
2.3.14	<i>Air quality: nitrogen deposition.....</i>	23
2.3.15	<i>Water quality.....</i>	24
<b>3</b>	<b>REFERENCES .....</b>	<b>25</b>

**Map 1: Extent of potential active raised bog on Kilcarren-Firville Bog.**

**Map 2: Distribution of raised bog ecotopes on Kilcarren-Firville Bog.**

**Map 3: Digital elevation model and drainage patterns at Kilcarren-Firville 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 bog' (habitat code 7110) (hereafter referred to as Active Raised Bog (ARB)), for which Kilcarren-Firville Bog Special Area of Conservation (SAC) has been designated.

Kilcarren-Firville 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*<sup>1</sup> 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

---

<sup>1</sup> 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 (where known) are used throughout the text together 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, 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 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

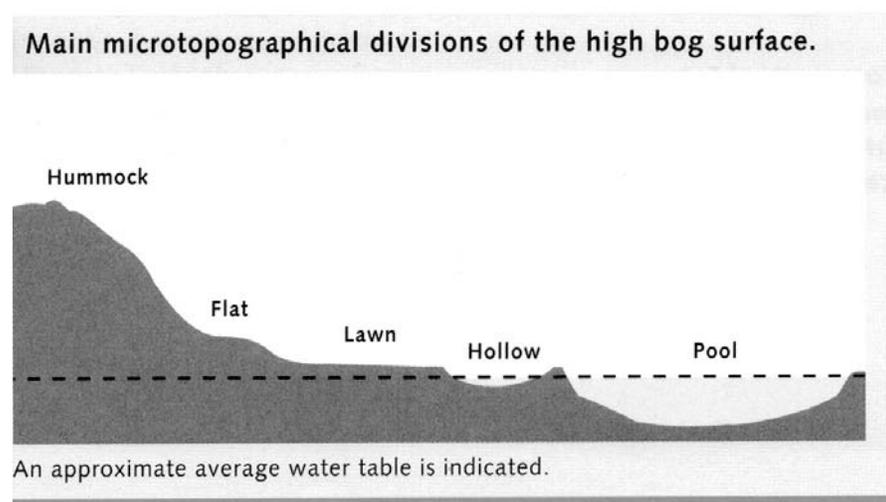
These are shallow hollows or flat areas where one species dominates to form a lawn. This is frequently a *Sphagnum* species, such as *Sphagnum magellanicum*, or *S. papillosum* which can completely fill in a hollow to form a small lawn.

### 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 (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 across 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 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 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 (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 (*Acrionicta 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 presented 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
<b>Mammal species</b>	
Irish hare	<i>Lepus timidus hibernicus</i>
Otter	<i>Lutra lutra</i>
Pygmy shrew	<i>Sorex minutes</i>
Fox	<i>Vulpes vulpes</i>
<b>Bird species</b>	
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>
<b>Reptiles and amphibians</b>	
Common lizard	<i>Lacerta vivipara</i>
Common frog	<i>Rana temporaria</i>
<b>Typical invertebrates</b>	
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>Macrothylacia 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:	<p>Araneae (spiders and mites)</p> <p>Ceratopogonidae (biting-midges)</p> <p>Chironomids (non-biting midges)</p> <p>Coleoptera (beetles)</p> <p>Collembola (springtails)</p> <p>Diptera (true flies)</p> <p>Dytiscidae (water beetles)</p> <p>Hemiptera (true bugs)</p> <p>Hymenoptera (bees, wasps, ants and sawflies)</p> <p>Lepidoptera (butterflies and moths)</p> <p>Odonta (dragonflies and damselflies)</p> <p>Orthoptera (grasshoppers)</p> <p>Syrphidae (hoverflies)</p> <p>Tipulidae (craneflies)</p> <p>Tabanidae (horseflies)</p>

## 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 Kilcarren-Firville Bog SAC

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

The SAC has been selected for three Annex I habitats:

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

Kilcarren-Firville Bog is situated approximately 2km east of the village of Carrigahorig in north Co. Tipperary. It is a lowland raised bog complex which extends about 4.5km from east to west and is bisected into two roughly similar sized sections by a road running north-south through the bog. Kilcarren Bog is located to the west and Firville Bog to the east.

The uncut high bog is surrounded by a large cutover area. *Betula pubescens* woodland is widespread in most cutover areas, and *Pinus sylvestris* is common in a few locations.

Peripheral areas at Kilcarren-Firville Bog have been extensively damaged by past peat-cutting, drainage, and land reclamation. The structure of the high bog has been detrimentally affected by drainage effects over a long period of time through a lowering of the water table. Despite this, Kilcarren-Firville Bog SAC is of high conservation importance, particularly due to the areas of ARB it supports.

#### 1.3.1 Flora of Kilcarren-Firville Bog

Kilcarren-Firville Bog contains substantial areas of ARB, which are largely confined to the wetter, more central areas of high bog. The vegetation here is typical of midland raised bogs, with *Calluna vulgaris*, *Erica tetralix*, *Eriophorum angustifolium*, *Trichophorum germanicum*, *Carex panicea*, *Narthecium ossifragum*, and bog mosses all being common. The ARB areas, and to a lesser extent the non-active areas, support occasional pool areas and quaking lawns dominated by *Rhynchosporion* vegetation. Typical species of the habitat are the bog moss *Sphagnum cuspidatum*, *Menyanthes trifoliata*, *Rhynchospora alba*, *Eriophorum angustifolium*, and *Drosera anglica*. The cover of *Sphagnum cuspidatum* typically exceeds 50% in these areas.

The non-active raised bog habitat tends to occur along the high bog margins where the peat has been subject to drying out. The surfaces here are usually dominated by a rather species-poor flora in which *Calluna vulgaris*, *Narthecium ossifragum*, *Eriophorum vaginatum* and *E. angustifolium*, *Trichophorum germanicum*, and *Erica tetralix* are typically frequent. *Sphagnum* cover is low and permanent pool areas are rare. Localised flushes support *Betula pubescens* and *Pinus sylvestris*.

At Kilcarren Bog, ARB includes central and sub-central ecotopes as well as active flushes.

Central ecotope is found on Kilcarren Bog at one location and sub-central ecotope at 13 locations. The highest quality ARB sections consist of central ecotope within a depressed area featuring hummocks, lawns, hollows, and pools. *Sphagnum* cover ranges from 75% to 90%, but reaches >90% in places, and consists of *Sphagnum cuspidatum* dominated pools with lawns of *S. magellanicum*, low hummocks of *S. papillosum* and hummocks of *S. capillifolium* subsp. *rubellum*, *S. austinii*, and *S. fuscum*. Other species present include *Calluna vulgaris* (11-25%), *Erica tetralix* (4-10%), *Eriophorum vaginatum* (4-10%), *E. angustifolium* (<4%), *Narthecium ossifragum* (<4%), *Rhynchospora alba* (11-25%), *Menyanthes trifoliata* and *Drosera anglica*.

Most of the ARB at Kilcarren Bog consists of sub-central ecotope, where pools are generally absent, less defined or support a lower cover of *Sphagnum cuspidatum*. The overall *Sphagnum* cover is also lower (generally 34-50% but higher in places). The most dominant community types are characterised by an abundance of *Eriophorum vaginatum* and *E. angustifolium* respectively. ARB also includes some active peat forming flushes.

At Firville Bog, ARB includes central and sub-central ecotopes.

Central ecotope is found in Firville Bog at four locations and sub-central ecotope at 20 locations. The highest quality ARB on Firville Bog consists of central ecotope, located within a depressed area featuring high hummocks, lawns and interconnecting pools. *Sphagnum* cover is >90% and is complete (100% cover) in places. *Sphagnum cuspidatum* (75-90%) dominates along with *S. magellanicum*, *S. papillosum* and *S. capillifolium* subsp. *rubellum*. Other species recorded include *Drosera anglica*, *Menyanthes trifoliata*, and *Aulacomnium palustre*. The most widespread central ecotope present on Firville Bog is similar to the central area described above, but there are fewer pools (34-50% compared to 51-75% cover). Most of the central ecotope, however, is confined to areas where subsidence has occurred in association with an old drainage network. There is only one location where central ecotope is not associated with the drainage network.

The most widespread complex within sub-central ecotope consists of high hummocks, hollows and pools. The pools cover is 11-25% and the overall *Sphagnum* cover is 34-50% (51-75% in places) dominated by *S. cuspidatum*, *S. magellanicum*, *S. papillosum*, and *S. capillifolium* subsp. *rubellum*. Sub-central ecotope becomes wetter near central ecotope areas and the wettest and finest quality sub-central ecotope areas feature a higher cover of *Eriophorum vaginatum* and *E. angustifolium*; *Sphagnum* cover varies from 50 to 75% in these complexes, and pools are only very occasional.

The presence of *Myrica gale*, *Melampyrum pratense*, and *Dactylorhiza maculata* in many of the vegetation complexes indicates that there is some mineral enrichment. It is thought that the peat layer is quite thin over parts of Firville Bog. *Dactylorhiza maculata* occurs throughout Firville and Kilcarren Bogs in both dry and semi-dry areas. Its presence is indicative of mineralisation and on this bog the plant is found in the vicinity of rising ground at the north of the site. At Firville Bog, *Platanthera bifolia* is seen on the high bog at the north of the site (Kelly *et al.* 1995).

At Kilcarren Bog, scrub on cutover provides habitat for a population of the nationally rare shrub *Frangula alnus*. Some of the cutover has been reclaimed for grassland.

### 1.3.2 Fauna of Kilcarren-Firville Bog

Hares (*Lepus timidus hibernicus*) occur in the SAC. Over-wintering Greenland white-fronted geese (*Anser albifrons flavirostris*), a species listed in Annex I of the Birds Directive, have been reported from the site in the past, but not in recent years (NPWS 1999). Breeding snipe (*Gallinago gallinago*) and red grouse (*Lagopus lagopus*) have been recorded in the SAC. The most recent record for the latter is from Firville Bog (Cummins *et al.* 2010)

## 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 Kilcarren-Firville 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.* (2014a,b,c). 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 Kilcarren-Firville Bog in 1994 is estimated to have been 59.7ha, while the area of DRB is estimated to have been 29.5ha 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 Kilcarren-Firville Bog would equate to 89.2ha (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 28.7ha (Fernandez *et al.* 2014a,b,c). This represents a decrease of 31.0ha (52.0%) during the period 1994-2011. An additional survey undertaken in 2005 confirms that this decrease mainly occurred during the period 1994-2005 (Fernandez *et al.* 2005).

The current extent of DRB as estimated using a recently developed hydrological modelling technique, based largely on Light Detection and Ranging (LiDAR)<sup>2</sup> data is 86.1ha (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 60.3ha 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, it is therefore concluded that the maximum achievable target for ARB on the high bog is 89.0ha, which is only 0.2ha 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 drains in the cutover

---

<sup>2</sup> 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.

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 Kilcarren-Firville Bog in 1994, 2005, and 2011 (Source: Kelly *et al.* 1995; Fernandez *et al.* 2014a,b,c).

1994		2005		2011	
ARB (ha)	DRB (ha)	ARB (ha)	DRB (ha)	ARB (ha)	DRB (ha)
59.7	29.5	30.9	Unknown	28.7	60.3

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 3.4ha of ARB could be restored in this area. The long term achievable target for ARB on Kilcarren-Firville Bog is therefore set at 92.4ha which is 3.2ha 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 92.4ha, 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 Kilcarren-Firville Bog as set out in Section 2.1 above will contribute to safeguarding the national range of the habitat.

The ARB habitat at Kilcarren-Firville includes central and sub-central ecotopes, as well as active flush on Kilcarren Bog. A map showing the most recent distribution of ecotopes throughout Kilcarren-Firville 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 Kilcarren-Firville Bog SAC in 1994 was mapped as 362.6ha, while the corresponding area in 2012 is 362.3ha (based on interpretation of LiDAR and aerial photography flown in 2012), representing a loss of 0.3ha 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 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.

#### 2.3.2.1 Kilcarren Bog

The most recent description of drainage at Kilcarren Bog is presented in Fernandez *et al.* (2014c) who reported that 6.6km of unblocked drains are impacting upon the raised bog habitats. Most of the drains in Kilcarren Bog are classified as reduced functional (5.7km) with the remaining drains classified as functional (0.8km). In addition, 3.4km of unblocked drains were reported to be in-filled with vegetation; it is not known whether these drains are having any impact upon high bog habitats.

Cutover drains associated with former peat-cutting are present along the south and north-east, cutover. In addition, there are drains associated with adjacent agricultural land around most of the bog. A road separates Kilcarren Bog from Firville Bog and the drains associated with this road are likely to be impacting upon raised bog habitats.

Fernandez *et al.* (2014c) report that drainage maintenance is evident on the 2010 aerial photograph along the north-west margin of high bog, associated with agriculture improvements, as well as to the south-east of the bog. Fernandez *et al.* (2014c) report a significant decline in ARB in the north-eastern section of the high bog in the 2005-2011 reporting period and suggest that this is likely to be due to the negative influence of the peripheral drainage along the north-east of the bog. Loss of ARB was also reported in this area by Fernandez *et al.* (2005), which was also considered to be connected to peripheral drainage in this area.

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 only available hydrological study for Kilcarren Bog is the work carried out by Kelly *et al.* (1995). The hydrochemistry survey identified electrical conductivity (EC) values ranging from 100 – 530 $\mu$ S/cm in the old cutover to the south of the site, suggesting significant groundwater discharge into the drains as bog water typically has an EC value of < 100 $\mu$ S/cm reflecting the inert properties of the peat. EC values in the drains along the road ranged from 100 – 300 $\mu$ S/cm suggesting groundwater influence. Along the north-eastern and northern margin of the bog elevated EC values were also reported ranging from 230 $\mu$ S/cm to 610 $\mu$ S/cm, suggesting widespread groundwater upwelling.

Upwelling groundwater suggests that the drains intercept the regional groundwater table. This can result in a decline in groundwater head, which can impact on the surface of the bog through subsidence. The risk of subsidence depends on the permeability of the underlying substrate, which will influence the extents of impacts from changes to groundwater head. Geological maps show that Kilcarren bog is underlain by a massive unbedded lime-mudstone bedrock unit which is a locally important aquifer, as it is moderately productive only in local zones. Subsoil mapping indicates that limestone till is the main mineral subsoil in the area. The presence of a potentially permeable bedrock unit as well as potentially permeable substrate suggests that a decline in groundwater head may contribute to subsidence on the high bog. Further deepening of marginal drains has the potential to have significant impacts on Kilcarren Bog.

### **2.3.2.2 Firville Bog**

The most recent description of drainage at Firville Bog is presented in Fernandez *et al.* (2014b) who reported that 1.9km of unblocked drains are impacting upon the raised bog habitats. All of these drains are classified as reduced functional. In addition 4.6km of unblocked drains were reported to be in-filled with vegetation; it is not known whether these drains are having any impact upon high bog habitats.

Cutover drains associated with former peat cutting are present along the north-west, south and north-east cutover. The drain running parallel to the road separating Firville from Kilcarren Bogs is also likely to have some negative influence on high bog habitats. Fernandez *et al.* (2014b) also report that a review of 2010 aerial photography suggests that maintenance of marginal drainage along the eastern margin of Firville bog has taken place, which is associated with agriculture improvements.

As for Kilcarren Bog above, the only available hydrological study for Firville Bog is the work carried out by Kelly *et al.* (1995). The hydrochemistry survey identified electrical conductivity (EC) values of 705 – 730 $\mu$ S/cm in the main drain along the south and south-eastern boundary

of the bog. These high EC values indicate significant groundwater influence. An EC value of 300 $\mu$ S/cm was recorded in a drain separating the bog from agricultural land along the southern boundary suggesting groundwater influence. Elevated EC values were also reported along the north-eastern and eastern boundary (150 – 240 $\mu$ S/cm). EC values of 100 $\mu$ S/cm were recorded in the drains along the western cutover, suggesting little groundwater influence in this area.

Geological maps show that Firville Bog, like Kilcarren, is underlain by a massive unbedded lime-mudstone bedrock unit which is a locally important aquifer, as it is moderately productive only in local zones. A small section of the bog also appears to be underlain by a grey calcarenitic and oolitic limestone unit, which is a regionally important aquifer as it is subject to karstification (diffuse). Subsoil mapping indicates that limestone till is the main mineral subsoil in the area. The presence of a productive bedrock unit as well as potentially permeable substrate suggests that a decline in groundwater head may contribute to subsidence on the high bog. Further deepening of marginal drains has the potential to have significant impacts on Firville Bog.

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.

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

The slopes and flow patterns on both bogs indicate that they are likely to have been affected by subsidence. Steeps slopes (>1%) extend into the centre of the bog, while areas of focused flow are evident suggesting differential subsidence has taken place.

#### **2.3.3.1 Kilcarren Bog**

There is a significant area of focused flow towards the southern margin of Kilcarren Bog, this coincides with the largest area of ARB suggesting that slopes have become steeper but the increased flow through this depression has allowed ARB to be maintained in this area. This may be a contributing factor to the reported loss of ARB in the north-east of the bog, since flow is directed towards the southern margin. Further changes to flow patterns or slopes arising from subsidence due to the effects of peat exploitation and drainage are likely to have a significant impact on raised bog habitats.

#### **2.3.3.2 Firville Bog**

There is a significant area of focused flow towards the northern/north-eastern margin of Firville Bog, this coincides with areas of ARB suggesting that slopes have become steeper but the increased flow through this depression has allowed ARB to be maintained in this area. Although the focused flow has allowed ARB to be maintained in the areas where flow converges, it is likely to have contributed to drying out other sections of the bog as water flows off the bog more rapidly. Further changes to flow patterns or slopes arising from subsidence due to the effects of peat exploitation and drainage are likely to have a significant impact on raised bog habitats.

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 the high bog 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 in Kilcarren-Firville Bog SAC include a range of different habitat types (e.g. wet grassland, improved grassland, woodland, cutover bog and scrub). The total area of cutover bog within the Kilcarren-Firville Bog SAC is estimated to be approximately 156ha. The development of habitats within cutover areas depends on a number of factors including prevailing land-use, topography, up-welling regional groundwater, and drainage.

At Firville Bog any areas of old cutover are dominated by *Calluna vulgaris*, *Eriophorum angustifolium* and *Juncus effusus* with *Molinia caerulea* occurring close to the bog edge with *Betula pubescens* and *Ulex europaeus* behind and *Pteridium aquilinum* in the clearings. *Myrica gale* is also found in the cutover to the north-west and south-east and *Osmunda regalis* also occurs at the south-east. The drop to the cutover in this area is 1.5m. In places, particularly along the northern edge, the *Ulex europaeus* and *Betula pubescens* scrub forms a boundary. There is mature *Betula* wood beyond the area of old peat cutting along the northern edge and at the north-east of the northern lobe with tall coniferous trees at the outer edge of the cutover to the north-west of the main bog. To the north of the northern lobe there are areas of regenerating *Sphagnum* pools with *Menyanthes trifoliata* close to the old drains. *Schoenus nigricans* was also growing near one of these pools. *Phragmites australis* occurs in some areas of old peat cutting around the bog and is associated with areas where there is rising ground off the bog to the north and near where a drain exits the bog at the south.

At Kilcarren Bog there is a section along the north edge of the high bog where the mineral soil is adjacent to the bog. There are no facebanks in this area and there is a sudden transition from the high bog to the mineral soil. Some meadow/pasture vegetation species are colonising the edge and *Phragmites* is encroaching in places. In the drain between this section of mineral soil and the adjoining fields there are deep drains. *Chara globularis* was recorded in these. Some of the old cutover areas, usually where there is rising ground off the bog, are dominated by *Phragmites australis* with a range of other species including *Lychnis flos-cuculi*, *Potentilla erecta*, *Molinia caerulea*, *Rubus fruticosus*, *Salix sp.*, *Betula* seedlings, *Ulex europaeus*, *Dactylorhiza maculata*, *Juncus conglomeratus*, *Succisa pratensis*, *Carex demissa*, *C. nigra*, *Anthoxanthum odoratum*, *Erica tetralix*, and a bryophyte layer of *Aulacomnium palustre*, *Sphagnum capillifolium*, *S. magellanicum*, *S. subnitens*, and *Polytrichum strictum*. Other old cutover areas, particularly to the west of the site, are dominated by mature *Betula pubescens* woodland with *Calluna vulgaris* and *Pteridium*

*aquilinum* in the clearings.

*Betula pubescens* woodland with some *Ilex aquifolium* and willow (*Salix* spp.) is widespread in most cutover areas, and *Pinus sylvestris* is common in a few locations. These scrub areas on Kilcarren Bog provide habitat for a population of the nationally rare shrub *Frangula alnus*. Some of the cutover has been reclaimed for grassland.

At both Firville and Kilcarren Bogs part of the northern edge the bog grades naturally into the adjoining mineral soil forming an infiltration lagg (Kelly *et al.* 1995).

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

A summary description of the vegetation of Kilcarren-Firville 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.* (2005 & 2014a,b,c).

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 ecotopes, and active flush. The target for this attribute is 46.2ha of high quality ARB (50% of ARB target area (92.4ha)).

**Table 4** Extent of ecotopes classified as ARB in 2005 and 2011 (modified from Fernandez *et al.* 2005 & 2014a,b,c).

Ecotope	2005		2011	
	ha	% of total ARB	ha	% of total ARB
Sub-central ecotope	23.4	75.7	21.2	73.9
Central ecotope	6.7	21.7	6.7	23.3
Soaks / active flush	0.7	2.3	0.7	2.4
<b>Total ARB</b>	<b>30.9</b>		<b>28.7</b>	

The site-specific target for the attribute vegetation quality is: **Restore 46.2ha 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 and pools are well developed on Kilcarren-Firville Bog (Kelly *et al.* 1995; Fernandez *et al.* 2014a,b,c).

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 *Sphagnum* 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 *et al.* (1995) and Fernandez *et al.* (2014a,b,c) provide information on the occurrence of *Sphagnum* species throughout Kilcarren-Firville 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*) species to ensure peat-forming capacity.**

### **2.3.8 Typical species: bog flora**

Kilcarren-Firville 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 Kilcarren-Firville Bog (Fernandez *et al.* 2014a,b,c).

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

### **2.3.9 Typical species: bog 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.

Kilcarren-Firville Bog is likely to support a 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.

#### **2.3.10.1 Site features**

In places along the northern edge of both Firville and Kilcarren Bogs, the high bog grades naturally into the adjoining mineral soil forming an infiltration lagg (Kelly *et al.* 1995).

#### **2.3.10.2 Rare flora**

At Kilcarren Bog cutover scrub areas provide habitat for a population of the nationally rare shrub *Frangula alnus*.

#### **2.3.10.3 Rare fauna**

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

Breeding red grouse (*Lagopus lagopus*) have been recently recorded from Firville Bog (Cummins *et al.* 2010)

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 fire at Kilcarren Bog (2009-2010) damaged circa 12% of the high bog area. However, no major evidence of damage was noted during the 2011 survey and therefore this activity is considered to have low importance/impact on high bog habitats (Fernandez *et al.* 2014a,b,c).

Fernandez *et al.* (2005) mentioned the occurrence of regular burning at Firville Bog and a fire (2008) was noted as damaging 7.6% of the high bog area during the 2011 survey. This activity is considered to have low importance/impact on high bog habitats (Fernandez *et al.* 2014a,b,c).

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).

Fernandez *et al.* (2005) described scattered *Pinus sylvestris* trees on a mineral mound at the centre of the high bog at Kilcarren, as well as a clump of five pine trees in the south-west. These trees still occurred on the high bog in 2011 but are not spreading.

Fernandez *et al.* (2005) also described isolated *Pinus sylvestris* trees across the high bog at Firville. Some *Ulex* and birch growing along the abandoned track leading into the site from the west was also reported. These trees and scrub still occurred on the high bog in 2011 but do not appear to be spreading.

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).

A small area of conifer plantation is found within the Firville/Kilcarren SAC. This is located to the north-east of Kilcarren Bog.

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 NO<sub>3</sub>- and NH<sub>4</sub>+), 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 Kilcarren-Firville 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 Kilcarren-Firville Bog as reported by Henry & Aherne (2014) is 12.6kg 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.

The only available hydrochemistry data for Kilcarren Firville Bog is the work carried out by Kelly *et al.* (1995). At Kilcarren Bog the survey identified electrical conductivity (EC) values ranging from 100 – 530 $\mu$ S/cm in the old cutover to the south of the site, suggesting significant groundwater discharge into the drains. Similarly, elevated EC values along the road and along the north-eastern and northern margins of the bog suggest significant contributions of mineralised groundwater.

At Firville Bog the survey identified EC values in the range of 705-730 $\mu$ S/cm indicating significant contributions of mineralised groundwater. An EC value of 300 $\mu$ S/cm was recorded in a drain separating the bog from reclaimed agricultural land along the southern boundary also suggesting mineral groundwater influence. Elevated EC values were also reported along the north-eastern and eastern boundary (150 – 240 $\mu$ S/cm). Lower EC values of 100 $\mu$ S/cm were recorded in the drains along the western cutover, suggesting little groundwater influence in this area.

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. & 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).
- 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.
- 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 Duinan, 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.
- Cummins, S., Bleasdale, A., Douglas, C., Newton, S., O'Halloran, J. & Wilson, H.J. (2010) The status of Red Grouse in Ireland and the effects of land use, habitat and habitat quality on their distribution. *Irish Wildlife Manuals*, No. 50. National Parks and Wildlife Service, Department of the Environment, Heritage and Local Government, Dublin, Ireland.
- 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, F., MacGowan, F., Crowley, W., Farrell, M., Croal, Y., Fanning, M. & McKee M. (2006) Assessment of the impacts of turf cutting on designated raised bogs 2003-06. Unpublished report, National Parks and Wildlife Service, Department of Environment, Heritage and Local Government, 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 – Firville Bog, Co. Tipperary – site report. 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. (2014c) Raised bog monitoring and assessment survey 2013 – Kilcarren Bog, Co. Tipperary – site report. 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.
- 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.
- Hannigan, E., and 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. and 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.
- 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.
- 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, M.L. (1993) *Hydrology, hydrochemistry and vegetation of two raised bogs in county Offaly.* PhD thesis, Trinity College Dublin.
- 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.
- 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. (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 (1999) Conservation plan for Kilcarren-Firville Bog cSAC, Co. Tipperary. Draft 2. Unpublished document.
- 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 11<sup>th</sup> 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*. Dúchas – 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.
- Turunen, J., Roulet, N.T., Moore, T.R. & Richard, P.J.H. (2004) Nitrogen deposition and

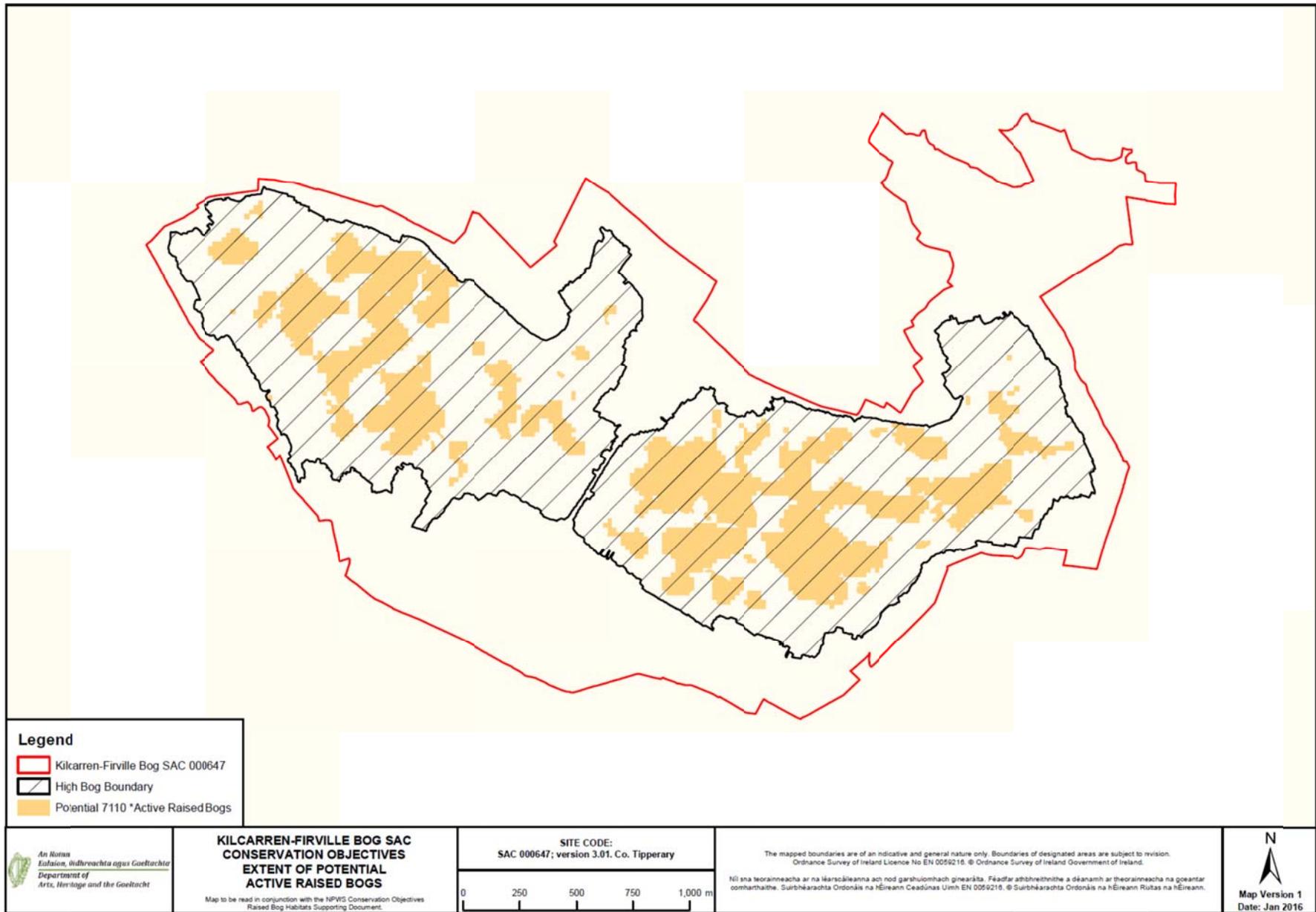
increased carbon accumulation in ombrotrophic peatlands in eastern Canada. *Global Biogeochemical Cycles*. 18 (3): GB3002.

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

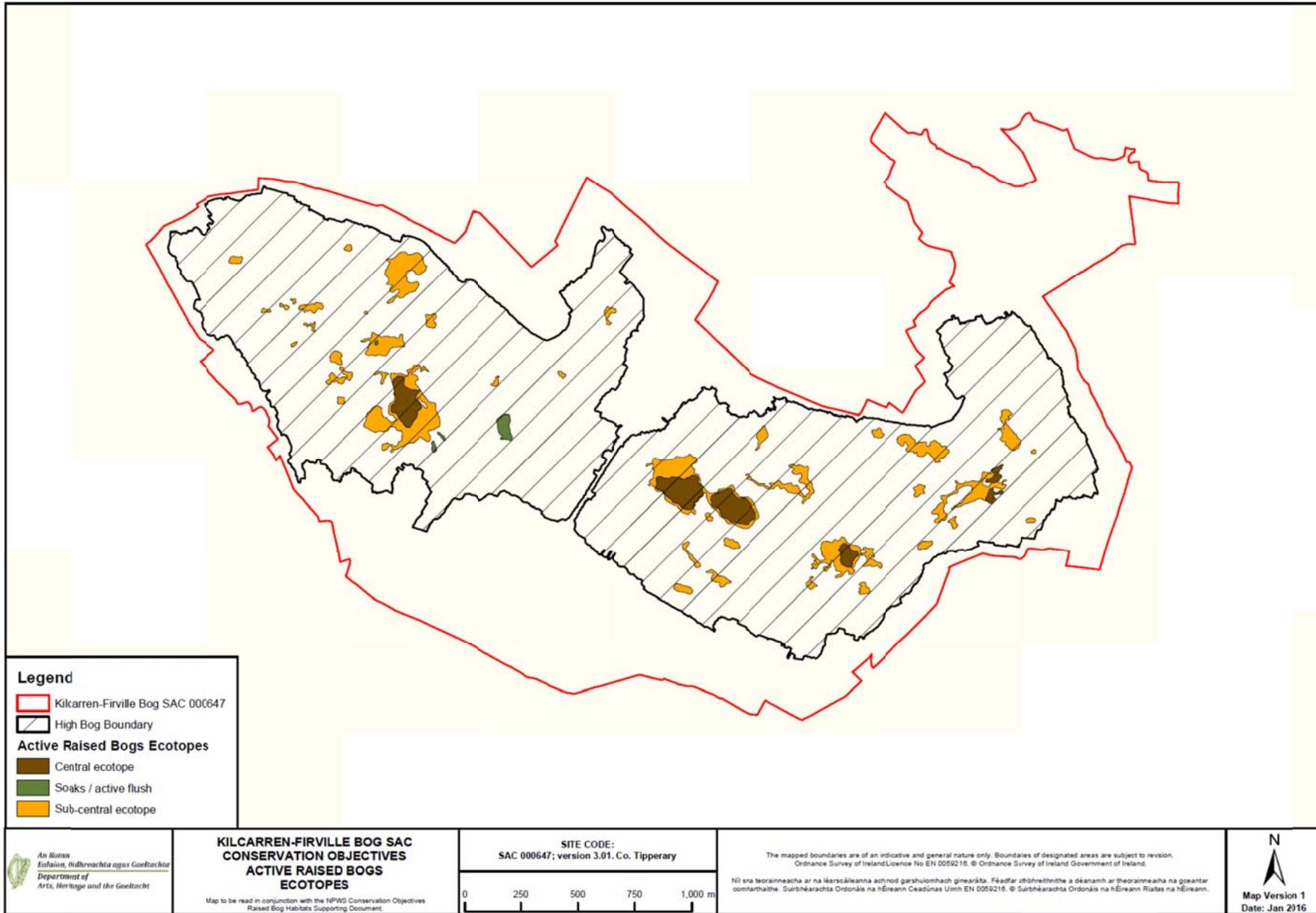
Wilson, H.J. (1990) Birds of raised bogs. pp. 29-36. In: Cross, J. (ed.) *The Raised Bogs of Ireland, their ecology, status and conservation*. Report to the Minister of State at the Department of Finance. The Stationery Office, Dublin.

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 Kilcarren-Firville Bog.



**Map 2: Distribution of raised bog ecotopes on Kilcarren-Firville Bog.**



Map 3: Digital elevation model and drainage patterns at Kilcarren-Firville Bog.

