National Parks & Wildlife Service

Carrownagappul Bog SAC
(site code 001242)

Conservation objectives supporting document - raised bog habitats

Version 1

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Contents

1 Introduction

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

Carrownagappul 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 based on phytosociological and morphological characteristics (Schouten, 1984): 1. Western or intermediate raised bogs, and 2. True midland or eastern raised bogs. 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

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

communities. In Ireland, most laggs have been lost through drainage and land reclamation (Fossitt 2000).

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

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

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

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

1.1.1 Raised 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).

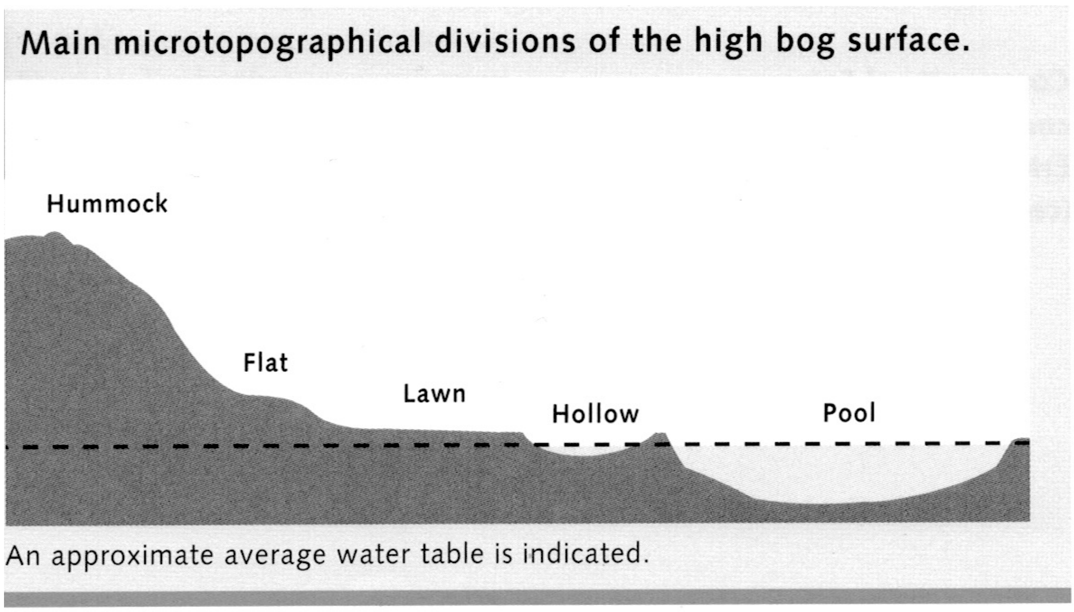

Figure 1 Raised bog microtopographical divisions on the high bog surface (reproduced from Kelly & Schouten 2002).

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

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

1.1.3 Typical Fauna of Irish Raised Bogs

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

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

Although 18 species of birds have been reported breeding on raised bogs (Wilson 1990) many of these species utilise the bog as a nesting habitat only. They are dependent on other neighbouring habitats such as open water bodies, callows and wet grassland particularly for feeding. Just a few species of bird, including meadow pipit (*Anthus pratensis*), skylark (*Alauda arvensis*) and curlew (*Numenius arquata*) complete their full breeding cycle on the bog and the first two species are the commonest species occurring (Bracken *et al.* 2008). Red grouse (*Lagopus lagopus*) must also be included as a typical bog species, occurring year round as a resident. Red grouse and curlew have declined significantly on 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 (*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 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
Mammal species	
Irish hare	*Lepus timidus hibernicus*
Otter	*Lutra lutra*
Pygmy shrew	*Sorex minutes*
Fox	*Vulpes vulpes*
Bird species	
Skylark	*Alauda arvensis*
Mallard	*Anas platyrhynchos*
Greenland white-fronted goose	*Anser albifrons flavirostris*
Meadow pipit	*Anthus pratensis*
Hen harrier	*Circus cyaneus*
Cuckoo	*Cuculus canorus*
Merlin	*Falco columbarius*
Kestrel	*Falco tinnunculus*
Snipe	*Gallinago gallinago*
Red grouse	*Lagopus lagopus*
Curlew	*Numenius arquata*
Golden plover	*Pluvialis apricaria*
Lapwing	*Vanellus vanellus*
Reptiles and amphibians	
Common lizard	*Lacerta vivipara*
Common frog	*Rana temporaria*
Typical invertebrates	
Black slug	*Arion ater*
Large heath butterfly	*Coenonympha tullia*
Marsh fritillary butterfly	*Euphydryas aurinia*
Bog-pool spider	*Dolomedes fimbriatus*
Water striders	*Gerris* and *Velia* species
Oak eggar moth	*Lasiocampa quercus*
Four-spotted chaser dragonfly	*Libellua quadrimaculata*
Fox moth	*Macrothylacia rubi*
Ant	*Myrmica ruginodis*
Emperor moth	*Saturnia pavonia*
Great green bog grasshopper	*Stethophyma grossa*
Other species groups that are well represented on raised bogs include:	Araneae (spiders and mites)
	Ceratopogonidae (biting-midges) Chironomids (non-biting midges) Coleoptera (beetles) Collembola (springtails) Diptera (true flies) Dytiscidae (water beetles) Hemiptera (true bugs) Hymenoptera (bees, wasps, ants and sawflies) Lepidoptera (butterflies and moths) Odonta (dragonflies and damselflies) Orthoptera (grasshoppers) Syrphidae (hoverflies) Tipulidae (craneflies) Tabanidae (horseflies)

1.2 Habitats Directive Raised Bog Habitats in Ireland

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

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

The interpretation manual of EU habitats gives the following description for '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 (≤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 Carrownagappul Bog SAC

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

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*

Carrownagappul Bog is a large western raised bog of the ridge river basin type (Cross 1990; Kelly 1993) situated about 3km north of Mountbellew, in east Co. Galway. The bog has an approximately triangular shape and is somewhat fragmented due to numerous bog roads, tracks, and drains that extend into the centre of the bog.

Peat cutting has been carried out extensively over a long period in the SAC, and there are substantial cutover areas around much of the high bog margin and alongside the bog roads. However, peat cutting has ceased at the site in recent years (Fernandez et al. 2014a, b). The site has been subject to relatively frequent burning, with a significant area of the high bog showing evidence of a recent burn during a survey undertaken in 2012 (Fernandez et al. 2014a, b).

The bog contains a number of different kinds of flushes, including an excellent example of a wooded swallow-hole flush system. A small area of permanent open water in this area has an abundance of stoneworts.

1.3.1 Flora of Carrownagappul Bog

Carrownagappul Bog has high quality ARB which consists of both central ecotope and active flush as well as areas of sub-central ecotope (Fernandez et al. 2014a, b). The microtopography of central ecotope consists of pools, low hummocks, high hummocks, hollows and lawns, and the wet ground is mostly very soft to quaking.

The pools are generally large and interconnecting, with substantial *S*. *cuspidatum* cover and only occasional algae, and they cover in the range of 11-25% of the central ecotope. *Sphagnum papillosum* and *S*. *magellanicum* are frequent at pool edges, while *S*. *capillifolium* dominates the interpool hummocks.

Hummocks of *Sphagnum austinii* and *S. fuscum* are also present, though rare. Total *Sphagnum* cover is in the range of 76-90%. In common with much of the high bog, the central ecotope was showing the effects of a recent fire event in 2012 (Fernandez et al. 2014a, b), with dead *Sphagnum* hummocks, dead *Calluna vulgaris* stems, bare peat and an almost total absence of *Cladonia* species.

Active flushes at the bog consist of pools, low hummocks and hollows. Hummocks of *Aulacomnium palustre* are common throughout, while other flush indicators include *Vaccinium oxycoccos*, *Empetrum nigrum*, and *Andromeda polifolia*. One of the two active flush areas mapped includes a substantial cover of scrub and small trees. The species here include *Betula pubescens*, *Ulex europaeus*, *Salix* sp., *Pinus* sp., *Rubus fruticosus* agg., and *Juncus effusus*. Total *Sphagnum* cover is in the range of 34-50%.

The sub-central ecotope includes a number of different community complexes and increased in overall extent during the period 2004-2012 due to the effects of recent drain blocking (Fernandez et al. 2014a, b).

DRB and supporting habitat cover the remainder of the high bog area and includes areas of sub-marginal, marginal, inactive flushes, and face bank ecotopes.

Sub-marginal ecotope has a less developed microtopography, and permanent pools and *Sphagnum* lawns are generally absent, though some good quality pools are present, in wetter community complexes areas. The interpool areas are dominated by *Narthecium ossifragum* and the total *Sphagnum* cover – mostly consisting of *Sphagnum capillifolium*, S. *cuspidatum*, *S. papillosum* and *S. austinii* - is in the range of 10-25%.

Marginal ecotope is slightly drier than sub-marginal ecotope and mainly occurs as a narrow band near the margins of the high bog, although there are some quite extensive tracts in the north and west of the site. The microtopography consists of *Calluna vulgaris* hummocks, low *Sphagnum* hummocks, flats, hollows, and tear pools. The vegetation is characterised by a higher cover of *Carex panicea*, *Narthecium ossifragum* and *Calluna vulgaris*. Overall *Sphagnum* cover is low at less than 10%.

The high bog also has a number of inactive flushes. A number of the flushes have a scrub element with species such as *Betula pubescens*, *Salix aurita*, and *Ulex europaeus*. *Molinia caerulea* and tall *Calluna vulgaris* are also typically present in the inactive flushes.

Rhynchosporion vegetation is widespread on Carrownagappul. It is found in ARB, DRB, and supporting habitat but tends to be best developed and most stable in the wettest areas of ARB. In these areas, the Rhynchosporion vegetation occurs within *Sphagnum* hollows and along *Sphagnum* pool edges and on lawns. Typical plant species include *Rhynchospora alba*, *Sphagnum cuspidatum*, *S. papillosum*, *S. magellanicum* and *S. capillifolium*. *Rhynchospora alba* is also present within inactive raised bog, but was generally uncommon and always associated with wet features such as hollows and run-off channels.

1.3.2 Fauna of Carrownagappul Bog

The common frog (*Rana temporaria*) is known to occur on Carrownagappul Bog.

Both red grouse (*Lagopus lagopus*) (resident) and hen harrier (*Circus cyaneus*) (wintering) have previously been reported from the site.

Many of the typical fauna species associated with raised bog habitats are likely to occur at Carrownagappul Bog (see Section 1.1.3 above). However, there is a lack of documented site-specific data relating to the fauna of the bog.

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 Carrownagappul 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 Carrownagappul Bog in 1994 is estimated to have been 28.0ha, while the area of DRB is estimated to have been 41.9ha 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 Carrownagappul Bog would equate to 69.9ha (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 surveys of the bog estimated the area of ARB to be 28.1ha (Fernandez et al. 2014a, b). This represents a slight increase of 0.1ha during the period 1994-2012.

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 52.1ha (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 refined to 36.5ha by estimating the area that could be restored by blocking drains on the high bog. This refinement was based on applying an efficacy factor (see DAHG 2014).

Based on the current assessment of the bog above, it is therefore concluded that the maximum achievable target for ARB on the high bog is 64.6ha, which is 5.3ha 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 losses of high bog caused by turf cutting and drainage activities associated with same (Fernandez et al. 2014a, b). Similarly, should the bog be significantly dependent on regional groundwater levels then any deepening of drains 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 Carrownagappul Bog in 1994, 2004, and 2012 (Fernandez et al. 2014a, b).

1994		2004		2012	
ARB (ha)	DRB (ha)	ARB (ha)	DRB (ha)	ARB (ha)	DRB (ha)
28.0	41.9	18.2	Unknown	28.1	36.5

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 5.3ha of ARB could be restored in this area. The long term achievable target for ARB on Carrownagappul Bog is therefore set at 69.9ha, which is the same as 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 69.9ha, subject to natural processes.**

[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.

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 Carrownagappul Bog as set out in Section 2.1 above will contribute to safeguarding the national range of the habitat.

The ARB at Carrownagappul Bog includes central and sub-central ecotopes, as well as active flush systems. A map showing the most recent distribution of ecotopes throughout Carrownagappul Bog is presented in Map 2. Carrownagappul Bog is divided into a number of distinct sections, by the bog roads that are constructed across the bog. ARB has been recorded on three sections of the bog (Fernandez et al. 2014a, b). The best examples of ARB are reported from the south-western section of the bog. Drain blocking undertaken on Carrownagappul Bog during the 1990s is having a significant positive effect on the distribution of ARB on the bog (Fernandez et al. 2014a, b).

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 capable of regeneration 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 Carrownagappul Bog SAC in 1994 was mapped as 330.7ha, while the corresponding area in 2012 is 323.5ha (based on interpretation of LiDAR and aerial photography flown in 2012), representing a loss of 7.2ha of high bog (DAHG 2014). The extent of high bog within the SAC in 2012 is illustrated on Map 1.

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

2.3.2 Hydrological regime: water levels

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

The traditional view of water flowing across the bog laterally has been recently refined to also consider that water flows vertically through peat into the underlying 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 Carrownagappul Bog is presented in Fernandez *et al.* (2014). It is reported that overall 16km of high bog drains are considered to be impacting upon raised bog habitats. Most of these drains remain functional (12.1km) or reduced functional (3.9km), with an additional 1.1km of drains considered to be non-functional. Some drain-blocking activities have already been undertaken at Carrowngappul Bog with significant positive impacts reported (increase in area of ARB by 9.9ha between 2005 and 2012, Fernandez *et al.* (2014)). There is a very dense network of marginal drains associated with peat-cutting surrounding the entire high bog, which continue to cause impacts on the high bog habitats.

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 Carrownagappul is the work carried out by Kelly *et al.* (1995). This study identified that the bog is likely to lie within a groundwater recharge zone, with most of the flow from the bog expected to infiltrate vertically into a relatively permeable area of till within the centre of the bog and enter the water table as recharge. Groundwater discharges around this till island where heavy peat cutting has occurred. Electrical Conductivities (ECs) of approximately 200µs/cm were recorded in this area. Springs were also recorded on the high bog, mid-way along the two north-western bog tracks, with ECs of the order of 520µs/cm. Flow through the cutover drains on the south-eastern margin of the bog sinks at a karstic swallow hole 200m south-east of the bog. Overall the hydrochemistry survey carried out in 1994 identified few recorded instances of high EC in the cutover drains. Nonetheless, the presence of upwelling groundwater indicates that water levels (heads) in drains are lower than those in the substrate underlying the peat. Deepening of drains is likely to reduce the hydraulic resistance (hydraulic conductivity x peat thickness) making it easier for groundwater to discharge, and thus lowering regional groundwater levels giving rise to increased vertical infiltration on the uncut bog. Increased vertical infiltration will alter the water balance on the bog and may cause further declines of ARB.

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 Carrownagappul Bog based on a digital elevation model generated from LiDAR imagery flown in 2012 is presented in Map 3.

This map illustrates that Carrownagappul Bog does not display a domed topography as would be typical of a raised bog. The highest area on the bog is located towards the western side, with most flow directed towards the north-east, east and south. It is evident from Map 3 that there are several areas of focused flow which indicate that changes to groundwater heads in the past have affected the flow patterns on the bog surface.

The presence of karst springs in the vicinity of the bog is indicative of more widespread karstic conditions in the limestone bedrock. The impact of the bedrock hydrogeological regime on the eco-hydrology of Carrownagappul Bog depends on the hydraulic conductivity of the substrate separating it from the peat, and on the head difference between the peat and rock. Where the hydraulic connection is strong and water levels in the bedrock are significantly lower, declines in head, and thus pore water pressure, occur in the peat. This leads to compression (subsidence) of the peat and deformations in the bog surface. The occurrence of localised flow zones (flushes) on the bog, following linear trends, suggests that differential deformation has occurred. The correspondence in orientation between the flushes on the bog and lineaments / orientations in the trellis drainage pattern in the surrounding area suggests that flushes have developed in areas underlain by linear karstified features, and that the bog displays dependency on the groundwater levels in the underlying bedrock. Regional groundwater levels are suspected to have declined in recent years due to reductions in river base levels associated with arterial drainage. Under these circumstances, further reductions in base level can be expected to further increase differences between regional groundwater levels and those in the peat. The increased infiltration rates arising from this process can be anticipated to further impact the bogs water balance, leading to additional effects on existing areas of ARB.

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 Carrownagappul Bog include a range of different habitat types (e.g. improved grassland, cutover bog, scrub/woodland and a small mature conifer plantation). The total area of cutover bog is estimated to be circa 160ha. The development of habitats within cutover areas depends on a number of factors including prevailing land-use, topography, upwelling regional groundwater, and drainage.

Most areas are very old cutover with abundant *Molinia caerulea* and *Juncus* spp. Much of the older cutover around the west, south, and east of the site is grazed. *Betula pubescens* and *Ulex europaeus* invasion is also common. *Phragmites australis* is dominant in places where the underlying bedrock/soil is close to the peat surface.

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.

The ARB habitat at Carrownagappul includes central and sub-central ecotopes, as well as active flush.

A summary description of the vegetation of Carrownagappul Bog is presented in Section 1.3.1 above. The highest quality ARB corresponds with central ecotope and active flush. These areas have been described by Kelly *et al.* (1995) and more recently by Fernandez *et al.* (2014).

The extent of the different ecotopes that correspond with ARB based on the most recent surveys is presented in Table 4 and on Map 2. It can be seen that the proportion of ARB that comprises central and active flush is currently 14.6%. Comparing this to results of surveys undertaken in 2004 indicates that although the total area of ARB increased across the site, the proportion of central and active flush ecotopes declined.

The target for this attribute is 35.0ha of central ecotope and active flush and active flush (50% of ARB target area (69.9ha)). This requires an increase from the current area of central ecotope and active flush from 4.1ha to 35.0 ha.

Table 4 Extent of ecotopes classified as ARB in 2004 and 2012 (Fernandez et al. 2014a, b).

Ecotope	2004		2012	
	ha	% of total ARB	ha	% of total ARB
Sub-central ecotope	14.6	80.0	24.0	85.4
Central ecotope	2.5	13.7	2.7	9.6
Soaks / active flush	1.2	6.6	1.4	5.0
Total ARB	**18.2**		**28.1**	

The site-specific target for the attribute vegetation quality is: **Restore 35.0ha of central ecotope/active flush/soaks/bog woodland as appropriate.**

2.3.6 Vegetation quality: microtopographical features

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

Hummock and hollow microtopography is well developed in the western part of Carrownagappul Bog, with a hummock and interlocking pool system in places. Previous drainage associated with peat cutting activities has had a negative effect on the surface microtopography (Kelly *et al.* 1995; Fernandez et al. 2014a, b).

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 percentage cover

Bog mosses, which have unique properties, are the principal component of peat, and are largely responsible for the typical microtopographical features of ARB.

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

Kelly *et al.* (1995) and Fernandez *et al.* (2014) provide detailed information on the occurrence of *Sphagnum* species throughout Carrownagappul Bog.

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

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

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

2.3.8 Typical ARB species: flora

Carrownagappul Bog supports the full complement of plant species typically associated with a western raised bog (see Table 1 and Section 1.1.1 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 Carrownagappul Bog (Fernandez et al. 2014a, b).

Fernandez *et al.* (2014) report that the highest quality ARB is located in the south-western part of the bog. Despite the presence of drains and a road nearby, these areas remain wet and in good condition after the blocking of drains in the surrounding area.

The vegetation is dominated by *Narthecium ossifragum*, *Carex panicea* and *Trichophorum germanicum*. *Calluna vulgaris* is also common, reaching an average height of 10-20cm. *Sphagnum* mosses cover a wide area and include species such as *Sphagnum cuspidatum, S. papillosum, S. magellanicum and S. capillifolium.* The indicator species *Sphagnum denticulatum, S. austinii* and *S. fuscum* are also present. The lichen community is well developed. The western bog indicators *Pleurozia purpurea* and *Racomitrium lanuginosum* are seen frequently over the site. There is a well developed hummock and interlocking pool system in places, with *Menyanthes trifoliata* often found growing in the water. Other species present include; *Vaccinium oxycoccos*, *Andromeda polifolia*, *Dactylorhiza maculata*, *Drosera* spp., and *Eriophorum* spp.

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.

Site specific information on the faunal assemblages associated with Carrownagappul Bog is currently limited. It is likely that most species groups referred to in section 1.1.3 occur on the bog.

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

A number of flushes are the main features of local distinctiveness on Carrownagappul Bog.

There are a number of flushes on the bog which incorporate swallow holes. One of these is an extensive linear feature dominated by *Molinia caerulea* with a number of swallow holes and a channel along its length. To the north of the main lobe there is a smaller, similar feature. Patches of *Phragmites australis* are seen in various places around the remainder of the bog (Kelly *et al.* 1995). The areas of *Phragmites* which occur on this site are probably associated with thinner peat occurring on sub-soil mounds.

2.3.10.2 Rare flora

No records of rare flora have been reported from Carrownagappul Bog.

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.

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.

Much of the older cutover around the west, south and east of the site is grazed. In places these areas are not fenced off from the bog and so poaching occurs. This is particularly true of the south and east of the south-east lobe.

There are five tracks/roads which cut through this bog. The drains associated with these have increased water run-off and caused sloping and alteration of the bog topography. The vegetation within the drains has been influenced by the exposure of the till underneath the peat, and run-off from the imported calcareous material of the roads themselves. The following species are more noticeable: *Betula pubescens, Salix* sp.*, Phragmites australis, Ulex* sp.*, Ilex aquifolium* and *Crataegus monogyna.*

Drains continue to impact on high bog habitats. Bog margin drainage is considered to have a medium importance/impact on high bog habitats (Fernandez et al. 2014a, b).

There are no forestry plantations on the high bog (Fernandez et al. 2014a, b), although there are two conifer plantations adjacent to the high bog.

During a survey of the bog in 2012, much of the high bog vegetation showed evidence of recent burning, which is believed to have occurred within the previous two years. Damage ranged from moderate to severe, and was most clearly evident in the damage caused to *Sphagnum* hummocks. Damage was often more severe in degraded raised bog habitats where the impact was rated as having a high influence/importance. Within ARB the damage was rated as being of medium importance.

Previous surveys also reported significant damage caused by burning (Douglas & Mooney 1984; Fernandez *et al*. 2005). Thus, it appears that burning has been a regular occurrence at the site and has contributed to the degradation of high bog habitats.

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) reported several *Pinus sylvestris* trees in the north-eastern section of the high bog.

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).

Fernandez *et al*. (2005) recorded the presence of a single *Rhododendron ponticum* bush on the high bog. There was no significant presence of invasive species noted during the 2012 survey (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 Carrownagappul 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 at Carrownagappul Bog as reported by Henry & Aherne (2014) is 11.9kg 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, runoff from surrounding mineral soils, and the release of nutrients through oxidation of peat resulting from reduced water levels.

Data presented by Kelly et al. (1995) confirmed the local discharge of regional groundwater at springs on the high bog, mid-way along the two north-western bog tracks, where elevated EC of the order of 520µs/cm was recorded. Overall the hydrochemistry survey carried out in 1994 identified few recorded instances of elevated EC in cutover drains.

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.**

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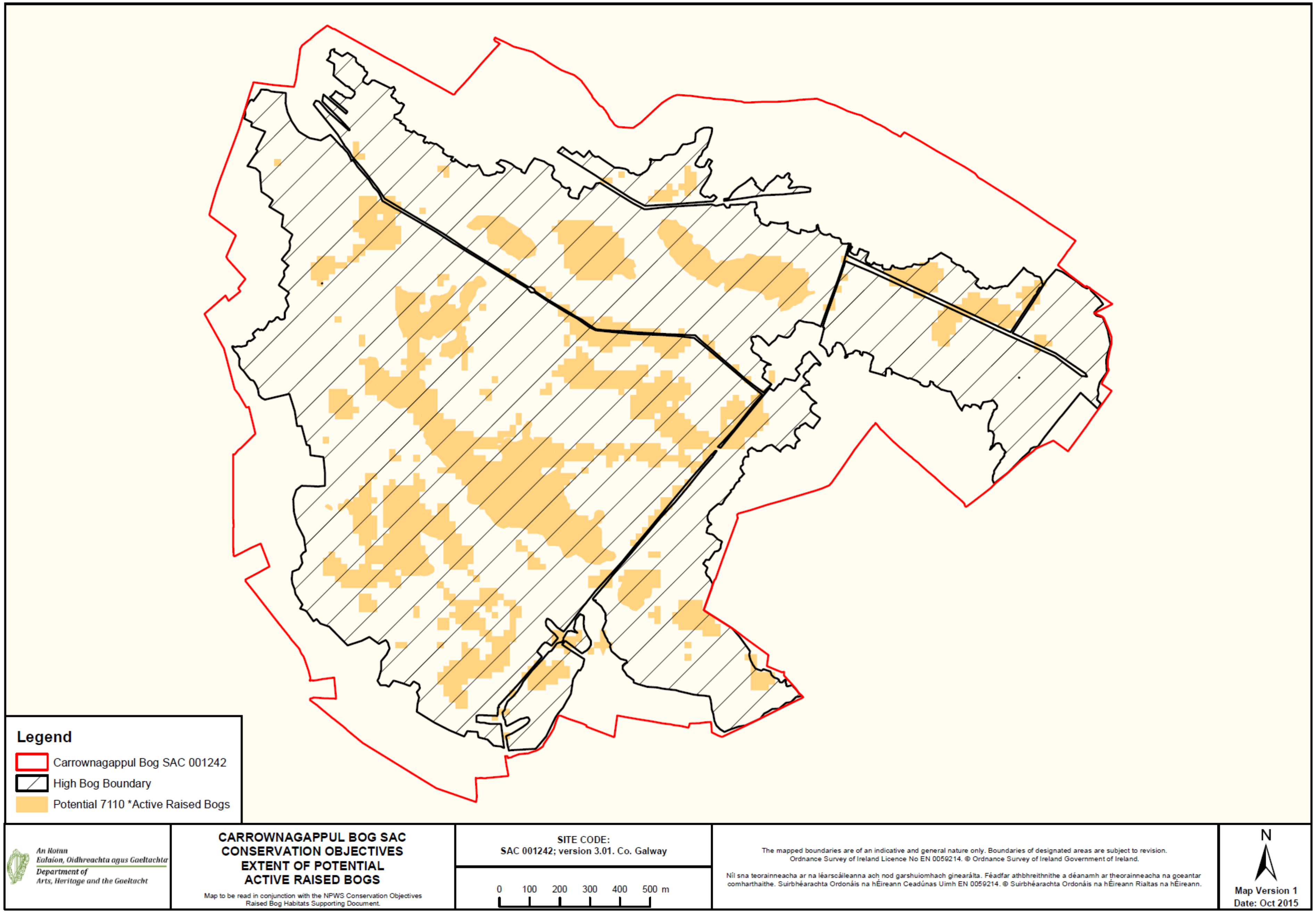
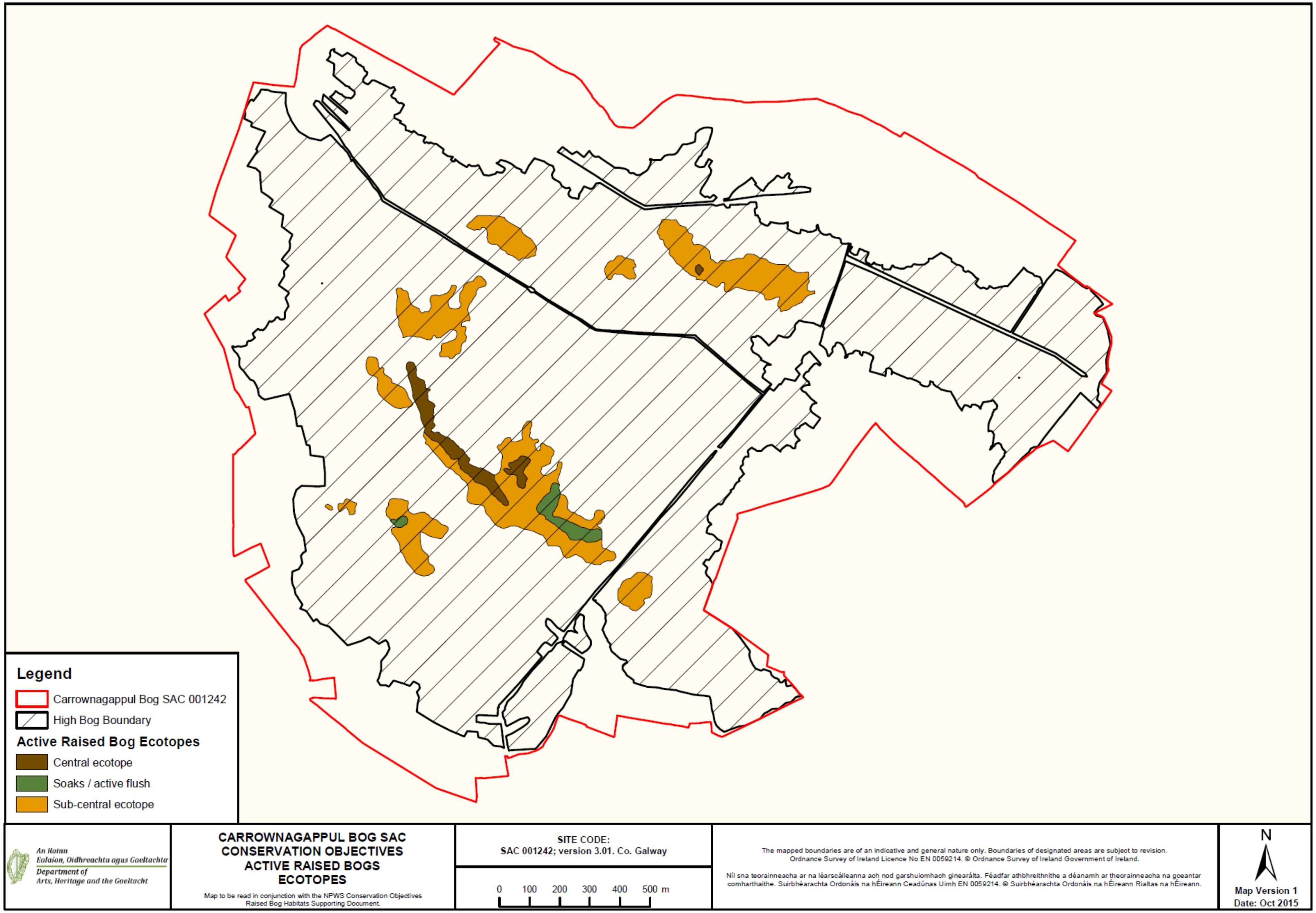
Map 1: Extent of potential active raised bog on Carrownagappul Bog.



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



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