Vegetation succession post rehabilitation of an industrial cutaway Atlantic blanket bog.

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Carried out under the supervision of Dr. James Moran and Dr. Catherine Farrell

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Declaration

I confirm that this thesis has not been submitted to any other institution and that with acknowledged exceptions, this is entirely my own work.

Signed ________________________________/Date ___________________________

To Niamh, Odin, Etain and Bump.

Abstract

Bord na Móna harvested peat at Bellacorick (Oweninny works) in County Mayo between 1961 and 2003. Milled peat was harvested from an area of over 6,500 ha of former Atlantic blanket bog and associated habitat types. The peat was supplied to the adjoining peat burning power station at Bellacorick. Peat production ceased in 2003 and a large scale site specific rehabilitation plan was designed and implemented. The main aims of the rehabilitation were to ensure environmental stabilisation of the former industrial peat production area (cutaway bog) and mitigation of silt run-off.

A baseline ecology survey of the site was completed in 2001. The rehabilitation work on the cutaway bog was carried out in phases between 2001 and 2005 and comprised an extensive and comprehensive programme of drain blocking, wetland creation, terracing to mitigate erosion on slopes and silt pond decommissioning. The site was re-surveyed in 2011 and the main changes in vegetation cover and composition between 2001 and 2011 were recorded.

The study found that sections of the site where the rehabilitation work allowed for water retention were quick to re-vegetate. Sections of the site where water retention was not possible (slopes and gravel ridges) have been slower to re-vegetate. Vegetation cover has increased across the site, bare peat occupied 53.3% of the site in 2001, and by 2011 this had reduced to 11.7%.

Quadrats were set up across the site in order to analysis the vegetation and monitor future vegetation changes. Data Analysis of the vegetation data found that seven vegetation communities were present across the former peat production areas. Six of the vegetation communities belonged in the poor fen category with one belonging to a dry heath vegetation type. The six poor fen vegetation types were found to be at various stages of development ranging from dry, *Juncus effusus* dominated to *Sphagnum*-rich/abundant. A sequence of development within the poor fen communities has been identified where *Juncus effusus* is the first plant to colonise the bare peat and in doing so allows other plant species to become established. With time these areas become more diverse, culminating in *Sphagnum*-

rich/abundant poor fen in areas where the hydrology is suitable. Following on from the rehabilitation work, pioneer poor fen vegetation has increased by 44.4% and *Sphagnum*-rich, poor fen (>50% *Sphagnum*) cover has increased by almost 7% across the site. The establishment of habitats with a high cover of *Sphagnum* indicates that there is significant potential for sections of the site to revert to peat-forming systems.

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Chapter 1 Introduction

1.1 Aims and objectives

Peatlands have provided fuel for heating and a range of other uses for people living in close proximity to them for centuries. However, in more recent times Ireland's peatlands are being viewed in a different light and scientific research is demonstrating how they provide a range of ecosystem services that have been overlooked in the past. Peatlands contribute significantly to the biodiversity of Ireland (Feehan and O'Donovan, 1996). They are now also considered to be a significant carbon store and are estimated to store more than 75% of the soil organic carbon in Ireland (Renou-Wilson *et al*., 2011). Peatlands that were previously once considered waste lands are gradually being appreciated and valued for the full suite of ecosystem services that they provide.

Peat is currently harvested in Ireland for domestic fuel and the generation of electricity. In the 21st century, Ireland is faced with the challenge of diminishing energy supplies and a shift away from more traditional, finite energy sources is occurring. Peat as an Irish industrial energy source is unlikely to extend past 2030 (Bord na Móna, 2011; Feehan and O'Donovan, 1996). The peatlands that supplied the fuel for past energy generation in Ireland will require rehabilitation so that any remaining peat on these sites is stabilised and former peat production areas are left in an environmentally stable condition. This will prevent any potential loss of peat while re-establishing self-sustaining habitats on former bare peat areas. Rehabilitation of cutaway bogs can also aid the development of tourism projects and increase the level of biodiversity occurring within them, as already demonstrated at the Lough Boora Parklands in County Offaly (Egan, 2008).

Bord na Móna was established in 1946 in order to develop and manage some of Ireland's extensive peat resources on an industrial scale. At that time it was the Irish Government's policy that Bord na Móna acquire extensive peatlands for the industrial harvesting of peat for energy (electricity production and briquettes) and as horticultural growing media. These lands currently extend in total to approximately 80,000 hectares and are located mainly in the midlands of Ireland with one site located in North West Mayo.

Bord na Móna began to develop industrial peat harvesting operations in North West Mayo in 1948 and peat production ceased in 2003. Prior to the cessation of peat production, emerging vegetation at the Bellacorick site was recorded and a programme of rehabilitation measures were drawn up as part of an overall site rehabilitation plan to stabilise the remaining peat at the site (Farrell, 2001). This rehabilitation programme was completed between 2001 and 2005.

Following on from the completion of the rehabilitation work, green house gas (GHG) studies have been ongoing at Bellacorick since 2008 (Wilson *et al.,* 2012a). These studies aim to calculate the extent to which different pioneer habitats that have developed on the Bellacorick cutaway since peat production ceased are functioning in terms of GHG emissions, primarily carbon dioxide (CO_2). Wilson *et al.* (2012a) has found that some plant communities are reverting to carbon sinks, particularly where plant communities are dominated by typical peatland species.

The main aims of this study are as follows;

1) Determine the range of plant communities currently present on the Bellacorick site (2011) and investigate the extent of vegetation changes at the former peat production site at Bellacorick since the initial study by Farrell in 2001.
2) Evaluate the success of the rehabilitation measures that were carried out at Bellacorick based on the extent of the level of vegetation cover.
3) Establish permanent quadrats to allow for future monitoring of vegetation.

1.2 Global peatlands

Globally, peatlands are to be found stretching from the tropical regions to the poles with peatlands being found in 175 countries around the world and covering 3% of the Earth's land mass (Bain *et al*., 2011). The majority of the world's peatlands are to be found in Eurasia and North America, while some peatlands are also located in more unlikely areas such as Patagonia, Ethiopia, South Africa, Mongolia and Iran (Renou Wilson *et al*., 2011). In Europe peatlands account for 515,000 km² (Bain *et al*., 2011), while in Ireland peatlands and peat soils account for 1,466,469 ha or 20.6% of the national land area (Renou Wilson *et al*., 2011).

1.3 Peatlands in Ireland

In Ireland peatlands can be broken into two broad categories – fens and bogs. Fens are considered to be mineral rich and relatively fertile, while bogs are acid and nutrient deficient (Doyle and Ó Críodáin, 2003). Table 1.1 demonstrates the main differences between fen and bog. Bogs can be further broken down into raised bog, blanket bog and mountain (montane) blanket bog and are described in more detail in this chapter. Fens can be subdivided into poor fens and rich fens, poor fens are low in plant nutrients and are similar to bogs in terms of floristic composition. Rich fens have higher concentrations of minerals, both rich and poor fens are characterised by a build up of peat. Fens differ from bogs because they are less acidic and have relatively higher mineral levels. They are therefore able to support more diverse plant and animal communities (Foss, 2007).

Table 1.1 Characteristics of fens and bogs, from Doyle and Ó Críodáin (2003)

	Fens	**Bogs**
Water level	Standing water all year round	Waterlogged for about 90% of the time
Nutrient supply	Mineral-rich water from outside the system and rainfall (minerotrophic)	Rainfall (ombrotrophic)
Peat pH	pH 4.5 to pH 8	pH 3.2 to pH 4.2
Mineral (ash) content	± 20%	1% to 3%
Fertility	Relatively nutrient-rich but variable	Nutrient-poor, especially in nitrogen and phosphorus
Peat humification	Highly humified	Highly/poorly humified
Peat type	Cyperaceous peat	Cyperaceous/*Sphagnum* peat
Vegetation character	Dominated by cyperaceous species, but with some dicotyledonous species present	Cyperaceous species, ericoid shrubs and peat mosses (*Sphagnum*)

The Derived Irish Peat Map (Figure 1.1) demonstrates the extent of peatlands and peat soils across Ireland. It should be noted that this map includes bogs and fens, including degraded forms of both.

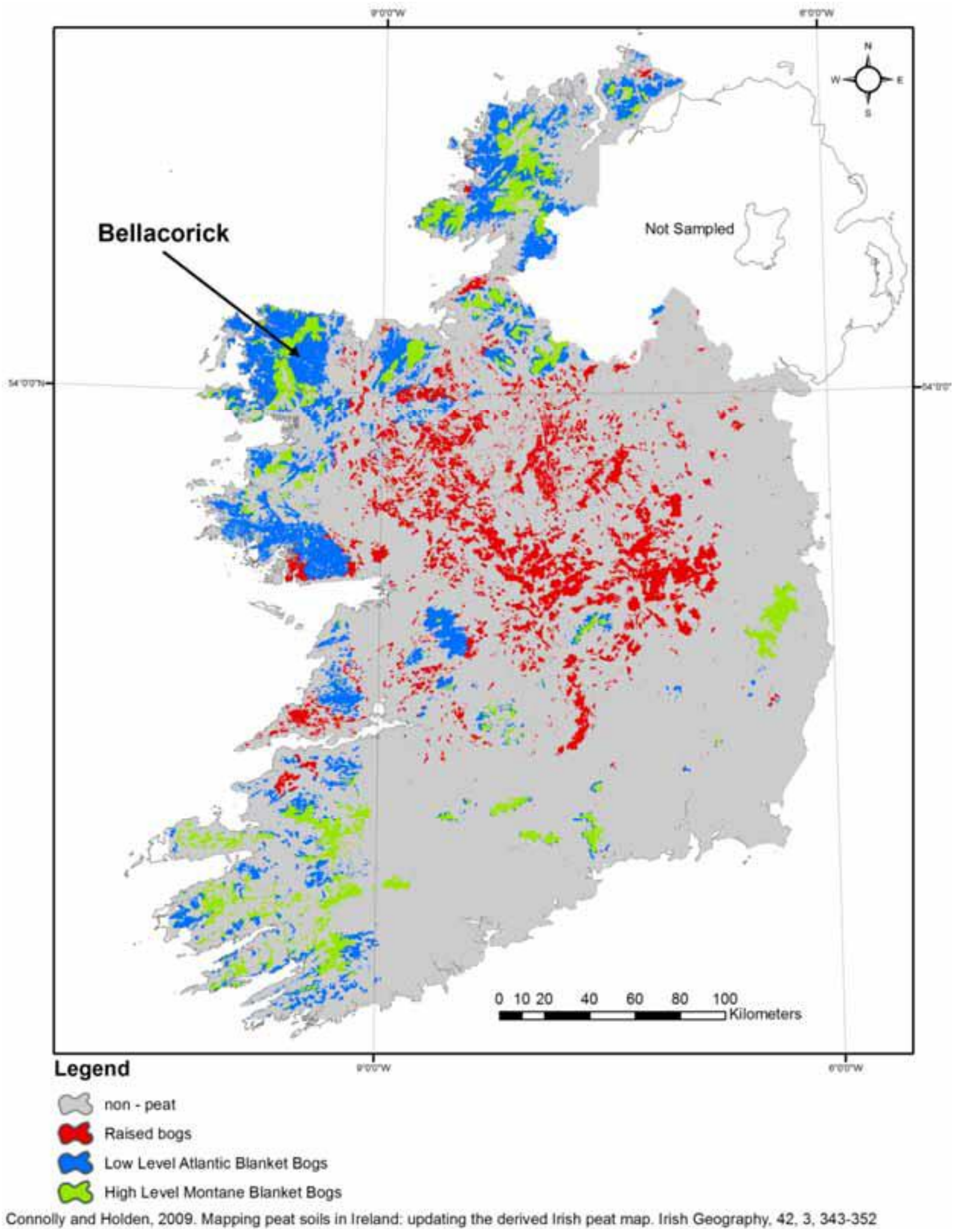


Figure 1.1 Derived Irish Peat Map, Connolly and Holden (2009)

1.4 Ecosystem services of peatlands

Peatlands contribute significantly to the biodiversity of the regions in which they are located and provide a suite of ecosystem services such as forestry production, energy, food, flood mitigation and maintenance of reliable supplies of clean water (Renou-Wilson *et al*., 2011).

Ecosystem services are fundamental life support services which can be direct or indirect. Broad examples of ecosystem services include (de Groot *et al.*, 2002) -

- Regulating (climate, floods, nutrient balance, water filtration)
- Provisioning (food, medicine, fur)
- Cultural (science, spiritual, ceremonial, recreation, aesthetic)
- Supporting (nutrient cycling, photosynthesis, soil formation)

As well as services such as biodiversity, peatlands present another important ecosystem service in the form of carbon storage. Carbon dioxide (CO_2) is one of the green house gases that contribute to global warming and climate change. As already stated peatlands account for 3% of the Earth's land mass but are capable of holding the equivalent of half of the carbon that is in the atmosphere as carbon dioxide (Dise, 2009). Parish *et al*., (2007) estimate that the carbon stored in peatlands represents approximately 25% of the world soil carbon pool (approximately 3 - 3.5 times the amount of carbon stored in the tropical rainforests (Renou Wilson *et al.*, 2011)). Dise and Pheonix, (2011) state that "*no other terrestrial biome is so efficient at slowly packing away and storing carbon, year after year, century after century*". Once drained, peatlands tend to release carbon dioxide (Rodney *et al.*, 2012).

Different groups in society also view natural habitats and the goods and services they provide in different ways. For example, in Iraq and Ireland, Maltby (2009) and Clarke (2010) point out that while marshland and wetland restoration is viewed as a benefit to the environment, while also allowing sustainable livelihoods to exist, there are sections of society that view such habitats as a barrier to economic progress and human well-being.

1.5 Peatland flora

Peatlands are unique ecosystems and support unique and often rare plant and animal species as demonstrated by Feehan and O'Donovan (1996) "*the bog is an austere world, and only those animals and plants which can meet the terms it lays down are able to live there*".

Peatland plants can be categorised into three main types – peat producing plants, plants adapted to waterlogged environments and plants that have specialised nutrient relations that maximise nutrient uptake and conservation (Doyle and Ó Críodáin 2003).

- Peat producing plants – peat mosses of the genus *Sphagnum* form large components of the vegetation of acidic bogs. Due to specialised adaption, *Sphagnum* mosses have the ability to absorb up to ten times their dry weight in water. This feature coupled with their ability to acidify surrounding substrate through cation exchange in their cell walls allow a waterlogged, acidic environment to develop in which decomposition of plant material is low and leads to the direct accumulation of peat annually in fully functioning bog habitats (Doyle and Ó Críodáin, 2003; Clymo, 1987).
- Plants adopted to waterlogged environments – specially adapted plant genera such as *Carex* (cyperaceous) and *Eriophorum* have the ability to grow in waterlogged conditions that exist on bogs while ericoids such as *Erica tetralix* and *Calluna vulgaris* have shallower rooting systems that enable them to survive in areas where the top layer of peat may remain drier than immediately surrounding areas, while they also have the ability to survive in permanently waterlogged peat soils such as the Atlantic blanket bogs of the west of Ireland (Doyle and Ó Críodáin, 2003; Lindsay *et al.,* 1988).
- Plants with specialised nutrient relations – peatland plants need to have special adaptions that enable them to obtain nutrients from the nutrient poor habitats that exist in peatland systems. Examples include ericoid shrubs such as *Calluna vulgaris* and other *Erica* species which, through their evergreen nature, conserve nutrients that would otherwise be lost by shedding of their leaves along with the ability to absorb and filter more water through transpiration. Thus the plants absorb more nutrients from their immediate environment than deciduous plant species may be capable of (Doyle and Ó Críodáin, 2003; Feehan and O'Donovan, 1996; Bain *et al.,* 2011). Graminoids including *Eriophorum vaginatum*, *Rhynchospora alba* and *Molinia caerulea* are capable of recycling nutrients efficiently transferred from older to younger leaves. Insectivorous plants form some of the most unique species that are found in bog ecosystems. These plants which include *Drosera* species and *Pinguicula* species have the ability to trap and digest insects and thus reduce their reliance on the surrounding nutrient poor ecosystem (Doyle and Ó Críodáin, 2003; Feehan and O'Donovan, 1996).

It has been shown that certain plant species occupy different niches within what is classified as the same habitat. Peatland vegetation is variable over small areas and peatland vegetation changes according to the immediate conditions (Lindsay *et al.*, 1998). For example, heathers (Ericoid shrubs) are more suited to drier areas while different species of *Sphagnum*, in general, are suited to wetter conditions.

1.6 Raised bog in Ireland

Raised bogs are, for the most part, centrally located in the midlands of Ireland (Figure 1.1) (Doyle and Ó Críodáin, 2003) while blanket bogs are restricted to oceanic areas where high levels of rainfall and low levels of evaporation allow for blanket bog development. Floristically raised bogs and blanket bogs are very different, however both ecosystems are the result of the accumulation of peat (Doyle and Ó Críodáin, 2003; Foss, 1997).

As the last ice age ended (c10,000 years ago), retreating ice fields left a very different landscape across much of Ireland than that which we see today. Lakes (ombrotrophic) developed in hollows and over time these lakes became in-filled with vegetation. Over an extended period of time organic matter accumulated and led to the development of fens. *Sphagnum* mosses colonised these fens as peat built up above the ombrotrophic level. These 'bog mosses' are capable of living above the level where groundwater has an influence and thrive in conditions where nutrient poor rainwater is the only source of water. The mosses grew above the fen layer, acting like a sponge and capable of maintaining water logged surfaces, higher than the surrounding mineral soil level, on the newly formed bog. *Sphagnum* mosses are particularly well suited to such an environment and over time led to the growth and development of domed raised bogs, as layers of *Sphagnum* and other plant material over time develop peat (Feehan, 2004; Foss and O'Connell, 1996; Schouten, 2002).

1.7 Blanket bog in Ireland

Blanket bog is the most common type of peatland in Ireland, covering an area of approximately 905,910 hectares (Foss, 1997). Blanket bogs form in areas where summers are cool, humidity is high, and there is more than 1,250mm of rain per annum (Feehan and O'Donovan, 1997; Lindsay *et al.,* 1988). There are two types of blanket bog in Ireland – Atlantic blanket bog (also called lowland blanket bog) and upland blanket bog. Atlantic Blanket bog is found extensively on areas of relatively flat ground below 150m. Western counties such as Galway, Mayo, Kerry, Cork and Donegal where high rainfall coupled with an acidic geology have extensive cover of Atlantic blanket bog. Upland blanket bogs are found in upland areas between 150m and 300m (Feehan and O'Donovan, 1996).

Climate is a key factor in the formation of Atlantic blanket bog. Evaporation rates are low (603mm) and rainfall must exceed evaporation at a ratio of 2:1 (Farrell, 2001; Doyle, 1997). Schouten (1984) describes blanket bogs as the most rain dependant type of bog that occurs in Ireland.

Atlantic blanket bog development in Ireland commenced in topographical depressions at the postglacial/boreal transition, before 9000 BP, as evidenced in peat profiles described by Jessen (1949). Embryonic blanket bog in depressions were later invaded by pine (*Pinus sylvestris*) as is evidenced by the unearthing of Pine stumps from peat excavations. This first phase of pine, 4500 BP (Mitchell and Ryan, 2001) was succeeded by further peat development before further development of pine won over again for a period. The last phase of pine development gave way to highly humified, cyperaceous (sedge rich) peat accumulations (Doyle and Ó Críodáin, 2003). This period of peat development continues to the present day and has resulted in an average blanket bog peat depth of 3.5m, with some blanket bog peat accumulations reaching depths of 7m (Doyle, 1982).

Blanket bog as the name suggests, ‘blankets’ surrounding land as they grow. This is evident by the deposits of pine stumps that are revealed by peat harvesting and even ancient agricultural field systems have been unearthed from beneath blanket bogs such as in the Céide Fields in North West Mayo (Mitchell and Ryan, 2001).

Figure 1.2 Intact Atlantic Blanket bog (located adjacent to the Bellacorick site). This is an area of intact blanket bog where peatland plants surround small pools.

1.8 Blanket bogs in a global context

Blanket bog or variations of blanket bog are found in various locations around the world (Lindsay *et al*., 1988). However, obtaining a global figure for the amount of blanket bog in existence is difficult due to varying definitions of blanket bog. Lindsay *et al*. (1988) estimates that there are approximately 100 million ha of blanket bog globally. Foss (1997), puts Ireland's total area of blanket bog at 905,910 hectares, or approximately 9% of the global area of blanket bog. Lindsay *et al*. (1988) quotes Hugo Sjörs, Professor Emeritus at the University of Uppsala, Sweden "*nowhere occurs the blanket bog in more impressive expanse than in Ireland and Scotland*".

1.9 Peatland exploitation and peatland uses

Throughout history Irish peatlands have been used by humans to varying degrees. Hunting grounds and a fuel source would have formed the main uses for Irish bogs in the past and they have frequently been used to place offerings such as treasures and even places of human sacrifice, indicating that some level of fear and respect existed among pre-historic man for these places. Due to the anaerobic qualities of bogs many of these offerings have been preserved over many thousands of years only to be uncovered by peat harvesting procedures. This trend has also been evidenced in other peatland countries such as the UK and mainland Europe where similar evidence of human sacrifice have been uncovered (Mitchell and Ryan, 2001, Feehan and O'Donovan, 1996).

The use of peatlands for grazing is described by Clarke (2010) who highlights that landownership on bogs was generally in the form of commonage (in the ownership of many individuals with no boundaries) and that wide scale drainage was not attempted.

Archaeological evidence from about 2,500 BC in North West Mayo reveals how expanding blanket bog gradually engulfed agricultural lands (Mitchell and Ryan, 2001). The 17th century writer William King wrote an account of how Ireland was "*famous for laziness*" regarding the growth of bogs and fens over agricultural lands. The Dutch writer, Gerald Boate, in 1649, noted that the native Irish were careless in letting more and more of their good land grow boggy and commented on how English settlers in Ireland had set about draining bogs where they had settled (Clarke, 2010).

By the end of the 17th century the Irish population had increased and timber exports had led to the wide scale destruction of the island's forests (Mitchell & Ryan, 2001). The disappearance of forests and trees in the Irish landscape is believed to have led a then growing Irish population to look upon peatlands as an abundant fuel source. Feehan and O'Donovan (1997) state that domestic turf cutting for fuel became more popular during medieval times and involved hand-cut turf using a slean and drying the turf during the summer months before taking the '*saved*' turf home. It is estimated that before the 1950s approximately 750,000 acres (491,625 ha) of peatlands were cutaway as a result of domestic turf cutting (Feehan and O'Donovan, 1997).

Clarke (2010) describes how C.S. Andrews, a former chairman of Bord na Móna in the 1940s, said that "*the bog itself in the Irish minds was a symbol of barrenness*" and described the perception that "*anything to do with a bog spells inertia and ignorance*" and bogs were seen as areas of "*poverty and backwardness*".

A populous view of peatlands in Ireland from the 1950's onwards was that once the wasteland (bog) was removed these sites could then be transformed into rich agricultural and forestry land holdings. These theories reinforced the ideas that led to the industrialisation of peat production activities.

1.10 Bord na Móna and the use of peatlands in Ireland

The 20th century brought with it many technological changes and these changes put increasing pressure on the new Irish state to modernise and develop indigenous industry. As early as 1919 the newly created Dáil established the Dáil Peat Committee which recommended the acquisition of bogs to conduct experiments on drainage, use of machines on bogs and the establishment of peat fired electricity stations. In 1934 C.S. Andrews, the then assistant principal in the Department of Industry and Commerce, succeeded in setting up the Turf Development Board (TDB). The TDB began to acquire large tracts of bog and set about producing sod turf for sale as fuel (Clarke, 2010).

World War II brought with it difficulties to the Irish domestic energy market when coal from imports, from which the majority of energy was derived, were restricted. After the war in 1946 the TDB became Bord na Móna and plans for large scale intensive peat production intensified.

Bord na Móna invested in specially designed machinery and recruited large numbers of workers in order to drain and produce peat. Narrow gauge railway systems were developed on each bog in order to transport the peat to its market. In conjunction with the ESB, six peat fired power stations were developed to produce electricity for the domestic market. Bord na Móna also produced sod turf and later, peat briquettes for use in homes. In the late 1940s peat moss was also produced for use in the horticulture industry in Ireland and also for export.

The majority of Bord na Móna's peat production activity was carried out on the midland raised bogs, however in the 1940s a need to provide work schemes in North West Mayo was identified. At the time the population of North West Mayo was heavily reliant on migratory work in England and Scotland. The advent of industrial peat production in North West Mayo saw a reduction in the numbers of people emigrating from the region (Feehan and O'Donovan, 1996).

Clarke (2010) describes how the industrial development of the peat industry in the Bangor and Bellacorick Atlantic blanket bogs in Mayo was proposed as early as 1946. However, it was not until 1961 that industrial harvesting of peat began in earnest on the Mayo bogs once the ESB had constructed a peat fired power station adjacent to the Oweninny Bogs in Bellacorick village (Farrell, 2001). The Oweninny Bogs being so named after the Oweninny River that flows through this area and includes lands stretching approximately 11 km x 7 km in the Bellacorick site and 4.5 km x 6.3 km in the Bangor site. Peat production continued until 2003 and then a rehabilitation plan was developed (see Chapter 2).

1.11 Peatland restoration and rehabilitation

Restoration and rehabilitation of natural habitats is a relatively new concept to science and its importance has been emphasised in recent years with a growing significance being placed on restoring habitats and natural capital (Aronson *et al.*, 2007). In the past, damaged ecosystems for the most part were allowed to either recover naturally or simply disappear completely along with their associated flora and fauna, leading to a reduction or indeed the cessation of the habitat's ecosystem services. Within certain regions, including Ireland legislation requires that exploited ecosystems to be rehabilitated once exploitation of the site's resources have finished. In Ireland industrial peat harvesting is carried out under license granted by the Irish Environmental Protection Agency (EPA). Rehabilitation and restoration of peatlands describes the next phase of human management of peatlands once management of a peatland for any use (forestry, fuel, agriculture etc), ceases.

In Europe in general, peat extraction has intensified over the last century. Peatlands were drained and the land re-claimed for agriculture, forestry and for the extraction of peat as a fuel. As a consequence, the drained peatlands, in particular those drained for agriculture, of temperate Europe (especially in Germany, Poland, Belarus, Ukraine and European Russia) now constitute a source of green house Gas Emissions and are (after South East Asia) the second most important global hotspot for green house gas emissions (Tanneberger and Wichtmann, 2011). Efforts to restore and rehabilitate peatlands are actively ongoing in these areas (Silpola, 2011, Vasander *et al.*, 2003 and Tanneberger and Wichtmann, 2011). Projects are now running throughout the world to restore and rehabilitate degraded/drained peatlands to reduce green house gas emissions and enhance biodiversity

Rehabilitation is used here to describe the process of events that follow the industrial development of peatlands and the procedures that are put in place to ensure that the former bog systems are in an environmentally stable condition. For example, rehabilitation works already carried out on the cutaway Atlantic blanket bogs of North West Mayo involved encouraging vegetation to become established in order to stabilise the site by preventing further erosion of the peat. In this situation the peatland has been so significantly changed from the original ecological status, it was not possible to restore the peatland.

Restoration of bogs on the other hand involves restoring the fully functioning bog systems that were in place before drainage. An example is Clara Bog and Rahenmore Bogs in Co. Offaly, where damage had occurred due to drainage work on a raised bog. Drains were subsequently blocked in order to attempt to restore the bog as a functioning raised bog ecosystem. Valverde *et al.* (2005) and Wheeler and Shaw (1995) acknowledge, two important factors must be considered prior to any restoration work being carried out: "*a site can never be returned exactly to its former state and restoration of peatland communities will require an indefinite period of time*".

Rewetting of peatlands is a process where the hydrological regimes of degraded peatlands are restored. This is achieved by drain blocking and may also entail the creation of berms to further halt the loss of water from the site. This process is often part of the ecological restoration of a peatland. Rewetting is a practice currently being promoted particularly for drained agricultural peat soils in Germany and Eastern Europe (described later).

Rehabilitation is an umbrella term that can encompass activity concerning rewetting and restoration.

1.12 Rehabilitation of industrially developed peatlands

Peatland development for the industrial production of peat is a significant anthropogenic disturbance – bogs are drained, vegetation is removed, and a thick layer of soil (peat) is harvested. The practice usually occurs over a period of several decades on any peatland area. A post mined peatland can be a harsh environment for plants and there can be local, regional and national influences that can affect the ability of plants to re-colonise a region (Lavoie *et al*., 2003). Rehabilitation and restoration of industrially used peatlands therefore needs to take account of various factors before any work can begin. Such factors include depth of peat remaining, the previous method of peat production, hydrology and exposure along with the specific objectives of any work to be carried out (Wheeler and Shaw, 1995).

Rehabilitation of industrially used peatlands was first documented in the Netherlands. Peat production had been on going in the Engbertsdijksvenen region under license from the Dutch Government. These licenses expired in 1953 which prompted the state to initiate rehabilitation works that aimed to re-establish the ombrotrophic bog vegetation (Charman, 2002). Further work was carried out in Germany but it was not until the 1980s that a widespread interest in peatland rehabilitation began in Europe. Charman (2002) goes on to state that restoration of cutover peatlands has increased in that period, largely due to the peat industry attempting to respond to environmental responsibilities and a need to create a more sustainable and responsible peat industry.

1.13 Rehabilitation and restoration of peatlands – Irish case studies

Given the range of peatland types in Ireland, there are a range of '*starting points*' for restoration and rehabilitation and this is reflected in the methods used.

1.13.1 The Irish Raised Bog Restoration Project

Initial bog restoration projects in Ireland were led by a joint working group of Irish and Dutch scientists in a bid to prevent further degradation and loss of the internationally significant Irish raised bog habitats. The Irish and Dutch partnership resulted in the establishment of a comprehensive overview of the problems with respect to management and restoration of the Irish raised bogs. The main challenges identified were to overcome the impacts of drainage (Schouten 2002). These areas are now part of the SAC network in Ireland (Douglas *et al*., 2008; Valverde *et al.*, 2006).

Extensive baseline ecological and hydrogical studies were carried out on two restored Co. Offaly bogs, Raheenmore and Clara Bogs (also called All Saints Bog in some reports). Drain blocking was carried out on these bogs in order to halt the loss of water from the sites. Dams were installed depending on the topography of the bog with a dam being installed for every 10cm change in level on the site (Farrell, 2007; Mc Donagh, 1997). These sites were re-surveyed in 2013 and Clara bog was reported to have lost some areas of active raised bog due to impacting activities while Raheenmore was considered to be improving in condition (Fernandez *et al*., 2013).

In another study, Hannigan *et al*. (2011) monitored two blanket bog sites in Wicklow, one of which had been subjected to drain blocking (similar to that carried out in Clara Bog) 15 years previous, the other study site was an intact blanket bog. This study compared the macroinvertebrate and microcrustacean communities in open-water habitats of the intact and a restored mountain blanket bog. The restoration measures that had been carried out resulted in an aquatic habitat and macroinvertebrate assemblages similar to the intact blanket bog site (Hannigan *et al*., 2011). Such studies show how restoration works can repair some of the damage that has been inflicted on these habitats.

1.13.2 Bord na Móna peatland rehabilitation

Rehabilitation is required to be carried out after production ceases and Bord na Móna operates under IPPC Licence issued and administered by the EPA to extract peat across Ireland. In the early 1990s the first attempts to create wetlands were undertaken on industrial cutaway in Ireland by Bord na Móna. A number of wetlands have since been created by drain blocking and berm construction in order to hold water on the site. These wetlands have stabilised the former production areas while also providing valuable wildlife habitat (Egan, 1994).

Some notable examples of wetlands created on Bord na Móna industrial cutaway peatlands can be seen at the Lough Boora Parklands and Drinagh Bog in Co. Offaly. The Lough Boora Parklands is a multi-functional site with biodiversity and amenity aspects (Bord na Móna, 2013) while targeted rehabilitation work at Drinagh Bog focused on creating suitable habitat for breeding waders (McCorry *et al.,* 2012). Further work on peatland rehabilitation by Bord na Móna includes trials on the establishment of reed-beds along with peat stabilisation trials using fertilisers and nurse crops. This work is outlined in the Bord na Móna Biodiversity

Action Plan (2010-2015) (Bord na Móna, 2010). Work carried out by Bord na Móna also includes restoration of raised bog sites including Abbeyleix Bog (2009) in Laois, Cuckoo Hill Bog (2011) in Roscommon and Moyarwood (2012) in Galway. The methodology for these works follows that developed by the NPWS for Clara Bog SAC (McDonagh, 1997).

1.13.3 Coillte projects

The Irish semi-state forestry company, *Coillte*, has also undertaken extensive bog restoration projects on land (former blanket and raised bog sites) originally planted for commercial forestry in the 1980s as these plantations proved to be financially and environmentally unsustainable. Restoration projects were initiated in 2004 and in 2011 on afforested raised bog sites in Coillte ownership. The projects aimed to restore 571.2ha of raised bog on 14 sites to a favourable conservation status. Other restoration work was carried out on blanket bog sites between 2002 and 2007. The key feature in these projects, was the removal of poor-growing pine trees and blocking drains, usually by means of plastic sheathing inserted along bog drains, monitoring on these sites is ongoing but initial results show that the water tables have risen and *Sphagnum* mosses are increasing (Coillte, 2013; Delaney *et al*., 2012).

1.14 North American approach to rehabilitation and restoration of peatlands

A significant body of work has been conducted in relation to the rehabilitation and restoration of former industrial peatlands in Canada. North American peat production is carried out primarily to supply the horticultural market with peat for use as a growing medium. The peat for this end product is harvested from the ombrotrophic section of the bog where the peat is less humified and is of an acidic nature.

Conditions present in post-production peatlands differ considerably in North American situations than those encountered in a similar Irish situation. These differences include:

Only the top acidic peat layer is removed in North American production peatlands (in general, in Ireland peat production extracts to the lower fen layers of peat).

Climate – North American peatlands are subject to extreme weather conditions. Summer conditions are hot and dry while winter conditions may be below freezing leading to frost heave. These climatic conditions lead to pioneer plant mortality.

These factors make it difficult for plant species to naturally colonise former peat production bogs in North America, as opposed to Irish cutaways. In order to counter act these difficulties a unique approach to restoring former peat production areas is required. Price (1998) describes how a combination of rehabilitation or restoration actions works best. The main guideline in North America for bog rehabilitation is Quinty and Rochefort (2003). Drain blocking, pumping water back onto the site in order to further re-wet the site and using straw mulch to provide establishing plants with suitable protection from the elements are the main features. Quinty and Rochefort (2003), caution against allowing deep water to develop as wave action can inhibit the development of some vegetation communities, and recommend using berms in order to develop shallow water throughout the site. Plant fragments can be spread over the site in order to speed up the re-vegetation of restoration sites if natural re-colonisation is not effective (Quinty and Rochefort 2003). The methods described by Quinty and Rochefort (2003) have been recognised as being very successful and have been adopted by a significant number of peat producers in Canada as part of a certification process (Cleary *et al*., 2005). *Restoration* of peatlands is therefore generally an attainable option of post-industrial production peatlands in North America given that acidic peat layers remain post production. For the purpose of restoration, a suitable *Sphagnum* moss (*S. fuscum* and *S. rubellum*) dominated habitat is considered a successful outcome (Quinty and Rochefort, 2003).

1.15 Case studies –Europe

Approximately 60% of European peatlands have been altered from their original natural state, (Joosten and Clarke, 2002). Human changes to peatlands include approximately 50% for agriculture, 30% for forestry and 10% for peat extraction (Joosten, 1997). A number of projects have been carried out across Europe and the details of the projects are contained in the following sections.

1.15.1 Belarus

In Belarus, 28,208ha of former peat production bogs have been rehabilitated since 2002 by the Government of Belarus. The main method of rehabilitation was re-wetting. This method involved building berms and blocking drains in order to allow shallow flooding of the former peat production areas. Natural regeneration of wetland species followed the rehabilitation works. Fires had been widespread in former production areas and re-wetting has dramatically reduced the incidence of fire (Tanneberger and Wichtmann, 2011).

The rehabilitated peatlands fulfil a number of services such as biomass production (where crops including *Phragmites australis* are harvested in winter when freezing conditions allow for such work), tourism, enrichment of biodiversity and carbon sequestration. The focus of the project for the Belarusian government was carbon sequestration in order to obtain carbon credits for the work that has been carried out on the peatlands. Following on from the 1986 disaster in the Chernobyl nuclear power plant large areas of peatland close to the power plant were also re-wetted to reduce radionuclide release from the soil (Tanneberger and Wichtmann, 2011).

1.15.2 Northern Europe (Estonia, Sweden and Finland)

Peatlands are abundant in Northern Europe, especially Estonia, Sweden and Finland due to suitable climatic conditions. Finland has the highest proportion of peatlands in relation to its size than any other country on earth (Foss and O'Connell, 1996). Peatlands have been exploited in these countries for a number of reasons particularly agriculture, forestry and energy. Rehabilitation works on peatlands has only occurred deliberately since 1996, however many active peatlands in the past contained excavated pits that were allowed to flood as a water source for fire fighting (Vasander *et al*., 2003). These water pits in many instances re-vegetated naturally. In the period 2002 to 2005 approximately 300ha of degraded peatlands had been planned for rehabilitation works (Vasander *et al*., 2003). There is limited information available on these rehabilitation works however this section gives an overview of some of the work undertaken.

In Finland, environmental management of peatlands, landscape ecology and protection of key biotopes have created needs and pressure to restore drained peatlands to natural mire ecosystems (Vasander *et al*., 2003). The Finnish Government has prepared a National Strategy for mires and peatlands that seeks to develop sustainable and responsible uses of peatlands (Silpola, 2011). This includes responsible management of industrial sites.

In Sweden and Finland, one of the main uses of peatlands has been forestry. In order to establish plantations on peatlands extensive drainage works must be carried out. Swedish and

Finnish rehabilitation works have focused on reinstating a high water table in these areas. Rehabilitation of peatlands in Sweden has been on-going since the early 1980s and results of the work indicated that it may take several centuries for all signs of peat excavations to disappear (Vasander *et al*., 2003).

In Estonia, peat harvesting has legislation that requires restoration or preparation for after-use once peat harvesting has ceased (Vasander *et al.,* 2003).

1.15.3 Germany

The vast majority of German peatlands are found in Northern Germany and Bavaria, with the total area exceeding 1,419,000ha (Jensen *et al*., 2011). Over 95% of German peatlands have been drained and degraded; mainly for use as agricultural areas. Each federal state in Germany has its own responsibility regarding peatlands. A range of restoration and rewetting projects have begun in recent years with the aim of re-establishing peatland functions (Witzel, 2012). Projects include *Sphagnum* farming and peatland rewetting (Osterloch *et al*., 2012 and Albrecht, 2012).

The German Government put in place a '*Peatland Action Plan'* in 2002. This document aimed to rehabilitate peatlands in order to improve their potential to enhance the status of water quality as well as creating suitable habitats for endangered species. The '*Peatland Action Plan 2002*' clearly stated its goals and intends to achieve them through the development of a state wide GIS-based peatland information system. This allows information relating to each peatland to be gathered in order to facilitate targeted rehabilitation plans specific to each site (Trepel, 2007).

1.16 Tropical peatlands

Peatlands in tropical regions are also being developed on an industrial scale for palm oil production, this can have impacts on carbon and is of growing global concern. Several restoration works are currently being implemented in tropical areas (Rieley, 2012 and Applegate *et al*., 2012).

Chapter 2 Study Area

2.1 Study Area (climate, geology and location within Ireland)

Bellacorick is located in North West Mayo approximately 13.6 km east of the town of Bangor Erris in Co. Mayo. Bellacorick Village is central to the Bellacorick Bogs (5840 ha) and the Bord na Móna Oweninny Works. The study site comprises an area of industrial cutaway Atlantic blanket bog and stretches from the townlands of Tawnaghmore and Sheskin in the west to the townlands of Doobehy and Corvoderry to the East. The central grid reference for the site is F96882 320038.

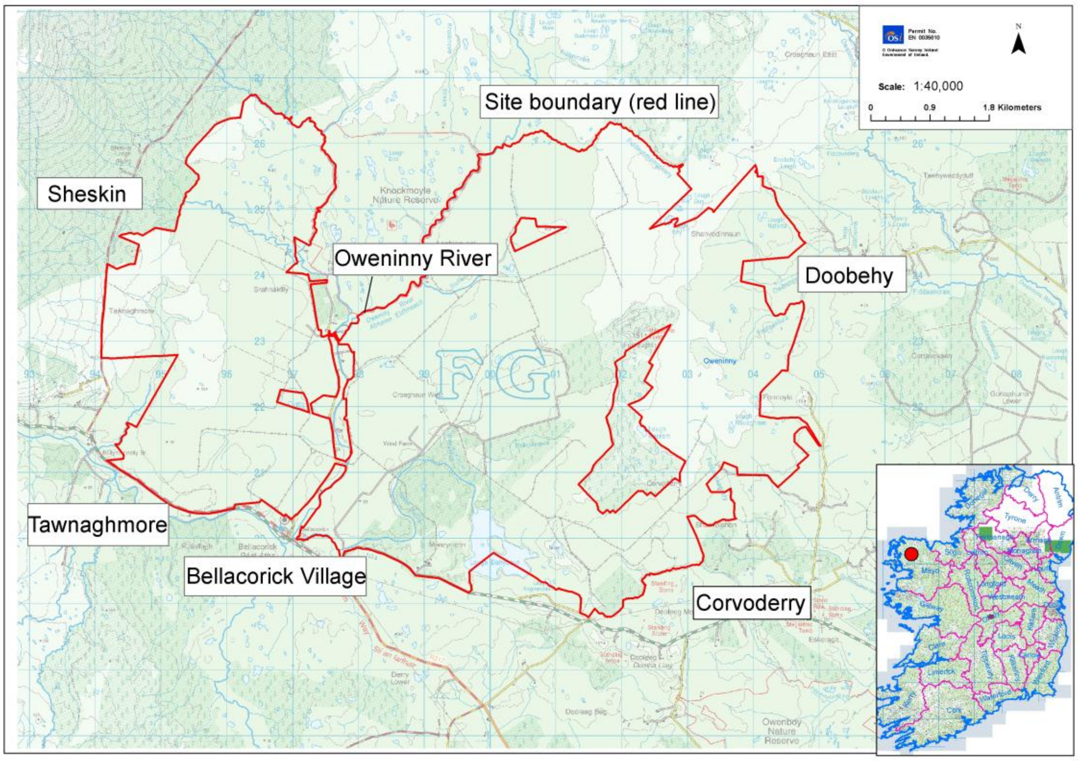


Figure 2.1 The Bellacorick site (red boundary line) and surrounding town lands

The Bellacorick bogs are situated on a lowland area (80m to 133m above sea level) north of the Nephin Beg mountain range (806m above sea level) and south of Slieve Fyagh (335m above sea level). The western section of the site is drained by the Oweninny and Muing Rivers. These rivers are tributaries of the Owenmore River that runs west of Bellacorick into Tullaghan Bay at Blacksod. Tributaries of the north-eastern flowing Owenmore and Cloonaghmore Rivers drain the north-eastern sections while tributaries of the Eskeragh River drains the eastern section of the site.

Prior to the site being used for the production of peat, Bellacorick comprised an extensive area of Atlantic Blanket bog which in turn encompassed a complex of peatland habitats including a number of lakes which were dotted across the landscape. Areas of former production bog located within the site are low lying with the highest point on the site, Furnought Hill, reaching a height of O.D. 151m, National Grid Reference: G022 232 (Farrell, 2001).

2.2 Conservation value of the site

A number of designated sites lie both within and adjacent to the Bellacorick site, these include lake, bog, flush and fen habitats. The designated sites are listed below in Table 2.1 and are shown in Figure 2.2.

Table 2.1 Designated areas within or adjacent to the Bellacorick site

Site name	**Designation**	**NPWS site code**	**Features of interest (NPWS, 2013)**
Bellacorick Iron Flush	SAC	000466	-Marsh saxifrage (*Saxifraga hirculus)*
Lough Dahybaun	SAC	002177	- Slender naiad (Najas flexilis) - Oligotrophic waters containing very few minerals of sandy plains (Littorelletalia uniflorae) - Blanket bog
Bellacorick bog complex	SAC/pNHA	001922	- *Vertigo geyeri* - Marsh saxifrage (*Saxifraga hirculus*) - Natural dystrophic lakes and ponds - Northern Atlantic wet heaths with *Erica tetralix* - Blanket bog - Depressions on peat substrates of the Rhychosporion - Alkaline fens
Carrowmore Lake Complex	SAC/pNHA	000476	- Shining sickle moss (*Drepanocladus vernicosus*) -Marsh saxifrage (*Saxifraga hirculus*)

			-Blanket bog -Depressions on peat substrates of the Rhychosporion
Owenduff/Nephin Complex	SAC/pNHA	000534	- Salmon (*Salmo salar*) - Otter (*Lutra lutra*) - Shining sickle moss (*Drepanocladus vernicosus*) - Marsh saxifrage (*Saxifraga hirculus*) - Oligotrophic waters containing very few minerals of sandy plains (Littorelletalia uniflorae) -Oligotrophic to mesotrophic standing waters - Natural drystrophic lakes and ponds - Water courses of plain to montane levels with the Ranunculion fluitantis and Callitricho-Batrachion vegetation - Northern Atlantic wet heaths with *Erica tetralix* - Alpine and Boreal heaths - *Juniperus communis* formations on heaths or calcareous grasslands - Blanket bog - Transition mires and quaking bogs

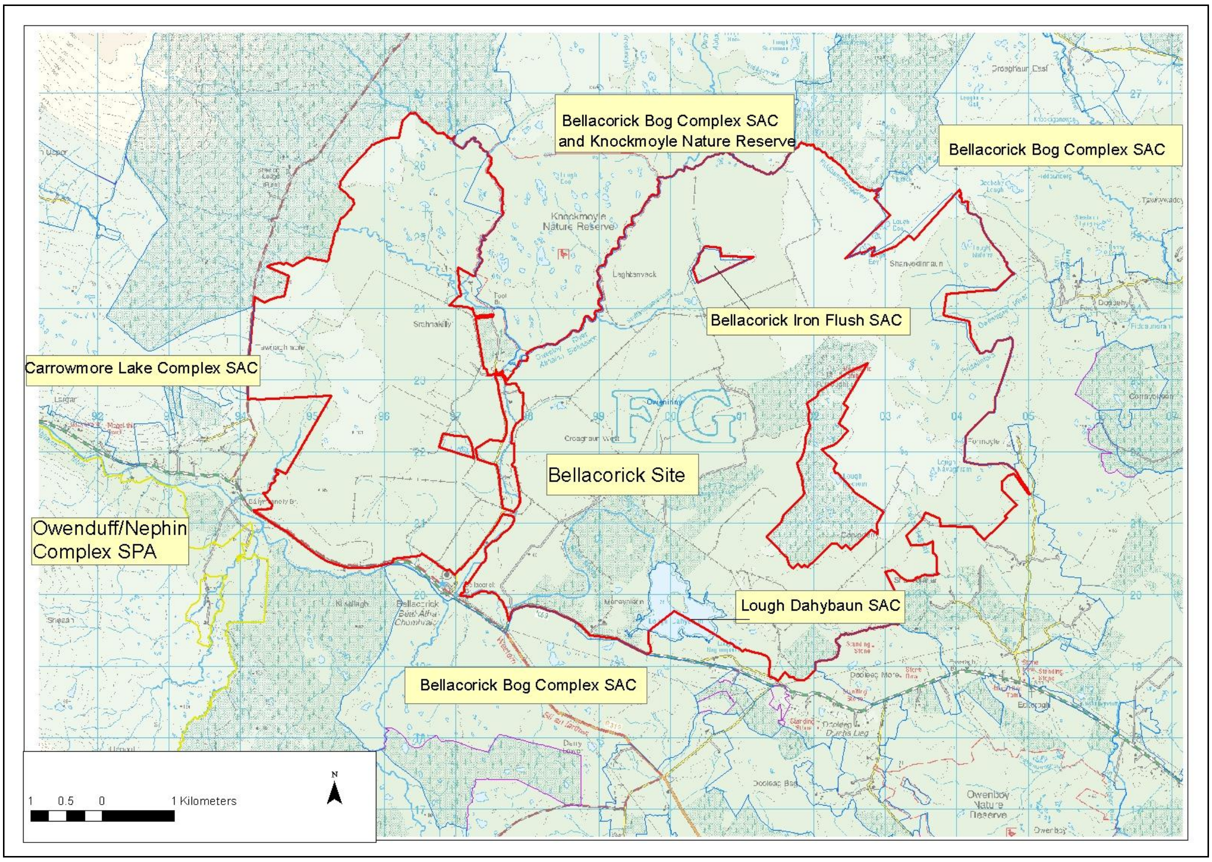


Figure 2.2 Designated sites surrounding and within the Bellacorick Site

2.3 Geology of Bellacorick

The former production areas at the Bellacorick site are underlain by carboniferous sandstone of the Downpatrick Formation (Gardiner and Radford, 1980). During the Holocene Quaternary Period (10,000BP to present), the Carboniferous sandstone was overlain with glacial till (Irish Quaternary Association, 2013). During the last ice age, glaciers to the north of Nephin covered the lowland areas of Bellacorick and the melting ice deposited sand and gravel (Long *et al*., 1992). This process resulted in a landscape of mounds and ridges of stratified sand and gravel (kames) once the ice had receded. Peat began to develop approximately 9,000BP (Doyle and Ó Críodáin, 2003) in the poorly drained areas and eventually spread over the Bellacorick area (and much of North West Mayo). As peat production removed the peat of the Bellacorick bogs, these gravel mounds and ridges were once again exposed (Farrell, 2001).

The mineral soil that is located beneath the peat at the Bellacorick site is strongly podsolised glacial till with a well developed impervious iron-humus pan located at varying depths from 20cm to 190cm below the surface (Farrell, 2001; Doyle, 1982) (Figure 2.3).

Figure 2.3 Soil profile of cutaway bog at Bellacorick

2.4 Climate of North West Mayo

The climate at Bellacorick is oceanic, typical of the western seaboard of Ireland. The annual level of precipitation was recorded at 1632mm during the period 1981-2010 (Met Eireann, 2013).

The temperature is considered mild with average July temperatures of 15°C and average January temperatures of 5.5°C. Due to warm temperatures prevailing in winter, North West Mayo does not undergo any considerable periods of frost and snow. Humidity is reported as being high, resulting in low levels of surface evaporation. The ratio of precipitation is 2:1, a condition that results in permanent waterlogging of the soils (Doyle and Moore, 1980).

The Bellacorick site is subjected to a strong, steady wind regime. Ireland's first commercial wind farm has been installed at the Bellacorick since 1992 (Farrell, 2001).

2.5 The landscape of North West Mayo

Peatlands dominate the landscape of North West Mayo. Since Bord na Móna ceased peat operations in North West Mayo there has been no further industrial peat production in the area, however domestic sod peat production is common in the bogs surrounding the Bellacorick site.

Agriculture is extensively practised throughout the region and the most common type of agriculture is a mixture of extensive sheep and cattle grazing. Fertile agricultural lands are located along the flood plains of the many rivers in the area and these areas are the most productive in agricultural terms. Over-grazing has proven problematic in some of the blanket peats of the upland areas, due mainly to high numbers of sheep in these areas (Farrell, 2001). 'Re-claimed land' is the method by which wetlands are drained in an attempt to convert these areas into productive agricultural lands. These areas can initially produce grazing areas but rapidly become colonised by *Juncus effusus* (Farrell, 2001).

Cattle and sheep from adjoining farms are commonly encountered within the Bellacorick site where they graze primarily along former railway embankments and the riparian zones. Red Deer (*Cervus elaphus*) are also commonplace within the Bellacorick site. These animals form part of the wild herd in the area and were released in the area in the late 1990s.

Commercial forestry is also widespread in North West Mayo with large tracts of land given over to this land use. Commercial plantations, dominated by sitka spruce (*Picea sitchensis*) and lodgepole pine (*Pinus contorta*), have been planted in large blocks over peat soils in the west of Ireland. Ireland's state owned forestry company, *Coillte*, is a major land owner in North West Mayo.

2.6 Peat production in North West Mayo

In the 1940s Bord na Móna acquired approximately 6,500 hectares of Atlantic Blanket Bog in North West Mayo (Oweninny). The bogs are split between the Bellacorick site and a site 8km away in Bangor. Bog drainage work began in 1951 and working conditions were described as being considerably more difficult than those encountered on the midland raised bogs. This was largely due to the undulating topography of the Oweninny bogs along with the fact that North West Mayo receives approximately twice the amount of rainfall in a year than the midlands. An engineer working in the area at the time noted that "*if you can see Nephin it's going to rain and if you can't it's already raining*" (Clarke, 2010).

Prior to peat production at the Bellacorick site the average peat depth was four metres (Farrell, 2001; Richard Cosgrove, Oweninny works manager, pers.comm). Drainage was necessary for production to begin and this work began by installing drains at 15 metre intervals. The surface vegetation was removed and the peat was then milled from the resulting peat fields. Milling involves using machinery to harvest the top 15mm to 20mm following solar drying (Figure 2.4). This harvested peat is then gathered and stored in stockpiles that run parallel to the peat fields. A network of narrow gauge railways was installed on the site and used to transport the peat to the peat fired electricity station at Bellacorick village.

Peat production took place during the driest times of the year (summer months) and generally continued in any given area until the underlying substrate was exposed, a layer of fossil timber was exposed or drainage was no longer possible (Farrell, 2001). Peat fields were withdrawn from production on a permanent basis and cutaway areas gradually emerged as scattered fragments within the wider production landscape. This resulted in a mosaic of peat fields along with exposed gravel hills and ridges as peat harvesting continued in the surrounding deeper peat areas.

Figure 2.4 Peat harvesting on a Bord na Móna industrial peatland site in the midlands illustrating the mechanical harvesting of peat.

Figure 2.5 Cutaway peat field (on right) adjacent to active production field (to left); rushes line the drain and quickly spread onto the cutaway.

Figure 2.5 shows a typical cutaway peat field with vegetation developing in the old field drains before spreading onto the former production area. *Juncus* spp. are often the first species to colonise the bare cutaway peat fields.

2.7 After use of industrial peatlands at Bellacorick

Once peat fields emerge from peat production, they are termed cutaway. Four main after uses of industrial cutaway have been trialled at the Bellacorick site, namely agricultural use, biomass, commercial forestry and wind-farm development.

Bord na Móna attempted to establish agricultural lands on a section of cutaway at the Bellacorick site. Trials initiated in the 1980s were subsequently abandoned due to inclement weather conditions and problems with mineral deficiencies for grazing animals (Gerry McNally, Bord na Móna Land Development Manager 1960s to 2012, pers.comm).

Willow (*Salix* sp.) was planted as part of a biomass trial (in the 1980s) on a small area of cutaway but this also failed to produce a viable crop. Lodgepole Pine (*Pinus contorta*) and Sitka Spruce (*Picea sitsenchis*) plantations were also established on an area of cutaway in Bellacorick in the 1980s. Forestry, although still present on the site, has not been deemed to be commercial due to poor tree growth and development (Gerry McNally pers.comm)

None of these options, agriculture, forestry or biomass, proved commercially viable. In the early 2000s it was agreed that the only viable options were to allow the area to stabilise naturally through natural regeneration (Farrell, 2001) coupled with the existing and future potential for development of wind energy generation. A wind farm constructed in 1992 is still operational in the Bellacorick site and consists of 21 wind turbines. There are currently plans to increase the scale of the wind farm at Bellacorick and this is subject to planning (Planning permission was applied for in 2013).

In 2001, Farrell classified the various '*land uses'* at the Oweninny Works and Bangor sites as a mosaic of active production bog, cutaway bog, drained blanket bog, forestry and agricultural trials (Table 2.2).

Table 2.2 Bord na Móna holdings and land-use at Bellacorick in 2001 (Farrell, 2001)

Land-use	**Area**
Production bog (2001)	2,400ha
Cutaway bog	1,780ha
Biomass trial areas	110ha
Conifer plantation areas	650ha
Agricultural areas	90ha
Under development for production (drainage works)	810ha
Total area of Bord na Móna holdings at the Bellacorick site in 2001	5,840ha*

* this figure includes the Bangor site which was not included in this study

2.8 Rehabilitation of the Bellacorick cutaway

Farrell (2001) identified eleven plant communities establishing on the industrial cutaway fields at the Bellacorick site. These communities included *Juncus effusus*, *Juncus bulbosus* and *Eriophorum angustifolium* pioneer communities along with rudimentary forms of Sphagneto-Juncetum effusi, *Sphagnum cuspidatum-Eriophorum angustifolium*, *Juncus bulbosus-Sphagnum cuspidatum* pools, Calluno-Ericetum, Caricetum paniculatae, Typhetum latifoliae, Tussilaginetum and Centaureo-Cynosuretum communities. These plant communities have been linked with the Bord na Móna pioneer plant communities and are explained in more detail in Chapter 4.

The plant communities present at the Bellacorick site in 2001 were largely dominated by the *Juncus effusus* pioneer community with extensive bare peat covering 53% of site. With this work and a number of small scale rehabilitation trials completed, it was possible to draw up a rehabilitation plan for the site (Farrell, 2008).

The aims of the rehabilitation of the Oweninny Works were:

- Stabilisation of the peat production areas through revegetation and
- In turn, mitigation of potential peat run-off from the site and
- Re-establishment of peat-forming plant communities where possible

Rehabilitation of the cutaway was considered successful when the remaining peat of the cutaway fields had been stabilised, which involved the establishment of vegetation cover. Revegetation was therefore the primary objective of the rehabilitation programme. While revegetation occured with minimal active rehabilitation management on flat fields, rewetting of production areas resulted in more extensive development of replacement peat-forming communities. Therefore, the secondary rehabilitation objective for the cutaway bog was to promote the establishment of peat-forming communities, where possible (Farrell, 2008). Sloping areas on the Bellacorick site appeared to be slow to revegetate and needed a different rehabilitation approach than the flatter areas.

Initial small-scale rehabilitation trials were established between 1996 and 2002, and large-scale rehabilitation commenced in 2003 with the cessation of peat production at the Oweninny Works (Farrell, 2008).

The general approach to the rehabilitation of the site required initial active rehabilitation work (blocking drains, etc.) followed by monitoring of effectiveness of this work. The basic rehabilitation management methods were:

<u>Rewetting</u>: Blocking drains and preventing water-run-off by means of peat ridges and peat berms; this work was carried out by Bord na Móna dozers and excavators

<u>Ploughing</u>: Disturbance and ploughing of gravel and/or peat-covered slopes to stabilise peat and increase vegetation establishment in areas that were otherwise slow to colonise. This rehabilitation measure was appropriate for up to 20% of the Oweninny peatlands (Farrell, 2008) due to the variable sub-peat topography.

Most of the work was completed by January 2005, with the remainder largely completed by September 2006 (Farrell, 2008). The rehabilitation monitoring is ongoing.

2.9 Green House Gas (GHG) monitoring at Bellacorick

The '*Carbon Restore'* project has been monitoring a section of the rewetted industrial cutaway within the site with the aim of gaining an understanding of the Green House Gas (GHG) regime of the site. This project is financed by Bord na Móna and the Environmental Protection Agency of Ireland (EPA). Gas measurements have been recorded on the site (Figure 2.6) since November 2008 using static chamber measuring devices. The GHG monitoring stations were set up within three habitats (bare peat was also monitored) –

- *Juncus effusus-Sphagnum cuspidatum* dominated communities
- *Sphagnum cuspidatum*-dominated communities
- *Eriophorum angustifolium*-dominated communities

Some of the results from this work are highlighted in Chapter 6 (Wilson *et al*. 2013).

Figure 2.6 GHG monitoring site at Bellacorick

Chapter 3 Materials and Methods

3.1 Fieldwork

Fieldwork was carried out over two field seasons. The first season was between May 2011 and August 2011 and was used to conduct a walkover vegetation survey of the entire site. Aerial photos (2008) from the Ordinance Survey Ireland (OSI), were used to facilitate the development of site habitat maps. The second season of field work was carried out in May 2012 and involved the establishment of permanent quadrats across the site in order to monitor vegetation change.

3.2 Vegetation classification

Prior to the walkover vegetation survey, a Bord na Móna Habitat Scheme was devised to account for the range of vegetation types occurring at the Bellacorick site. This was necessary as the site comprises largely pioneer vegetation types which are not represented accurately by the habitat classes used by The Heritage Council Habitat Classification Scheme (Fossitt, 2000), which is the most widely used habitat classification scheme in Ireland. Following on from Farrell (2001) who based her work on the Braun-Blanquet classification system (Braun-Blanquet and Tüxen, 1952), work by Rowlands (2001) and further vegetation survey of the Bord na Móna midlands bogs (2009-2012), a more detailed habitat scheme was developed by the Bord na Móna ecology team, to account for the variation within cutaway bogs. This has been called the Bord na Móna Habitat Scheme and is only used on Bord na Móna cutaway peatland sites. The vegetation survey carried out as part of this study follows the Bord na Móna Habitat Scheme and are aligned with Fossit (2000) habitat categories where possible (Table 3.1.).

The Bord na Móna Habitat Scheme divides the pioneer vegetation of industrial cutaway bogs into 110 habitat types and also includes un-vegetated habitat types such as bare peat, bog timber, bare gravel/subsoil, etc. The Bord na Móna Habitat Scheme is tailored to cutaway habitats and the nomenclature for habitats uses the latin name of the dominant species first. An example is the habitat pEang, whereby the p indicates that the habitat is a pioneer habitat, and the Eang indicates *Eriophorum angustifolium* is the dominant species. The habitat pEang/pJeff is the code for pioneer *E. angustifolium* habitat (dominant species first) with *Juncus effusus* also present in the vegetation.

This study aligns the Bord na Móna Habitat Scheme with the Heritage Council scheme and the Braun-Blanquet approach used by Farrell, 2001.

Table 3.1 Bord na Móna Habitat Scheme

Bord na Móna Habitat Scheme code	Habitat number (for GIS use)	Habitat descriptions
BP	1	Bare peat
Rip	80	Riparian areas (streams or drains with fringing habitats)
Acc	81	Access (tracks or railways with associated habitats)
Silt	82	Silt ponds (artificial ponds with associated fringing habitats)
Bog timber	199	Fossil timber uncovered by peat operations
Gravel	207	Bare gravel/subsoil (underlying substrate)
PB3d	302	Degraded lowland blanket bog (PB3)
PB3r	303	Lowland blanket bog (PB3) (rehabilitated, drains blocked)
PF2d	304	Degraded poor fen and flush (PF2)
pJeff	305	Pioneer *Juncus effusus*-dominated poor fen
pEang	307	Pioneer *Eriophorum angustifolium*-dominated vegetation
pJeffM	308	Pioneer *Juncus effusus*-dominated (moss-rich) poor fen
pJeffMS	309	Pioneer *Juncus*-dominated poor fen, moss-rich with some *Sphagnum* cover 5-25%
pJeffS	310	Pioneer *Juncus effusus*-dominated, *Sphagnum*-rich poor fen (*Sphagnum* cover > 25%)
pJeffG	311	Pioneer *Juncus effusus*-dominated poor fen, grass species.-rich
pJeffM/pEq	312	Pioneer *Juncus effusus*-dominated poor fen, moss-rich with more calcareous indicators (*Equisetum* spp./*Calliergon* spp.)
pRosPan	313	Pioneer *Eriophorum angustifolium with Carex rostrata*-dominated poor fen with *Carex paniculata*
pEangS	314	Pioneer *Eriophorum angustifolium with Sphagnum*
Sphagnum (S)	315	*Sphagnum*-dominated pool
OW/S	316	Pools and open water with *Sphagnum* spp.
dHeath	317	Pioneer *Calluna*-dominated dry heath
pTyph	320	Pioneer *Typha*-dominated vegetation
eWill	321	Emergent willow-dominated scrub (young trees, low growing)
oWill	322	Open willow-dominated scrub (medium cover, similar to thicket stage)
ePine	323	Emergent pine-dominated scrub
oPine	324	Open pine-dominated scrub
DisTuss	325	Pioneer *Tussilago*-dominated vegetation
gMol-Arr	326	Pioneer dry grassland vegetation
BP/pJeff	327	Mosaic of bare peat and pioneer *Juncus effusus*-dominated poor fen
BP/pJeffM	328	Mosaic of bare peat and pioneer *Juncus effusus*-dominated poor fen (moss-rich)

BP/pCamp	329	Mosaic of bare peat and pioneer *Campylopus*-dominated poor fen
BP/pCamp/pJeff	330	Mosaic of bare peat, pioneer *Campylopus*-dominated and pioneer *Juncus effusus*-dominated poor fen
gravel/pJeff	331	Mosaic of exposed gravel and pioneer *Juncus effusus*-dominated poor fen
gravel/pJeffM	332	Mosaic of gravel and pioneer *Juncus effusus*-dominated poor fen (moss-rich)
gravel/pJeffM/pJeff	333	Mosaic of exposed gravel, pioneer *Juncus effusus*-dominated poor fen (moss-rich) and pioneer *Juncus effusus*-dominated poor fen
gravel/BP/pJeff	334	Mosaic of exposed gravel, bare peat and pioneer *Juncus effusus*-dominated poor fen
gravel/BP/pJeff/pEang	335	Mosaic of gravel, bare peat, pioneer *Juncus effusus*-dominated and pioneer *Eriophorum angustifolium*-dominated vegetation
gravel/fossiltimber	336	Mosaic of exposed gravel and fossil timber
gravel/fossiltimber/pJeff/pEang/BP	338	Mosaic of exposed gravel, fossil timber, pioneer *Juncus effusus*-dominated, *Eriophorum angustifolium*-dominated vegetation and bare peat
OW/pEangS	339	Mosaic of open water, *Eriophorum angustifolium* and *Sphagnum*-rich -dominated vegetation
pJeffM/OW/pEangS	340	Mosaic of pioneer *Juncus effusus*-dominated poor fen (moss-rich), open water and pioneer *Eriophorum angustifolium*-dominated vegetation (*Sphagnum*-rich)
pJeffM/eWill	341	Mosaic of pioneer *Juncus effusus*-dominated poor fen (moss-rich) and emergent willow-dominated scrub
pJeffM/oWill	342	Mosaic of pioneer *Juncus effusus*-dominated poor fen (moss rich) and open willow-dominated scrub
pJeff/ePine	343	Mosaic of pioneer *Juncus effusus*-dominated poor fen and emergent pine-dominated scrub
pJeff/oPine	344	Mosaic of pioneer *Juncus effusus*-dominated poor fen and open pine-dominated scrub
pJeffM/ePine	345	Mosaic of pioneer *Juncus effusus*-dominated poor fen (moss rich) and emergent pine-dominated scrub
pJeffM/oPine	346	Mosaic of pioneer *Juncus effusus*-dominated poor fen (moss rich) and open pine-dominated scrub
pJeffS/ePine	347	Mosaic of pioneer *Juncus effusus*-dominated poor fen (*Sphagnum*-rich) and emergent pine-dominated scrub
pJeffS/oPine	348	Mosaic of pioneer *Juncus effusus*-dominated poor fen (*Sphagnum*-rich) and open pine-dominated scrub
pJeffG/ePine	349	Mosaic of pioneer *Juncus effusus*-dominated poor fen (grass-rich) and emergent pine-dominated scrub
pJeffG/oPine	350	Mosaic of pioneer *Juncus effusus*-dominated poor fen (grass

		species-rich) and open pine-dominated scrub
DH/ePine	351	Mosaic of pioneer dry *Calluna*-dominated heath and emergent pine-dominated scrub
DH/oPine	352	Mosaic of pioneer dry *Calluna*-dominated heath and open pine-dominated scrub
pJeffS/pEangS	353	Mosaic of pioneer *Juncus effusus*-dominated poor fen (*Sphagnum*-rich) and pioneer *Eriophorum angustifolium*-dominated vegetation (*Sphagnum*-rich)
pJeffM/pEang	354	Mosaic of pioneer *Juncus effusus*-dominated poor fen (moss-rich) and pioneer *Eriophorum angustifolium*-dominated poor fen vegetation
pJeff/pCamp	355	Mosaic of pioneer *Juncus effusus*-dominated poor fen and pioneer *Campylopus*-dominated poor fen
pJeff/dHeath	356	Mosaic of pioneer *Juncus effusus*-dominated poor fen and dry *Calluna*-dominated heath
pJeff/pEang/pRos	357	Mosaic of pioneer *Juncus effusus*, *Eriophorum angustifolium* and *Carex rostrata* -dominated poor fen
OW	359	Open water
pJeffM/pJeffS	360	Mosaic of pioneer *Juncus effusus*-dominated poor fen (moss-rich) and pioneer *Juncus effusus*-dominated poor fen (*Sphagnum*-rich)
OW/pJeffM	361	Mosaic of open water and pioneer *Juncus effusus*-dominated poor fen (moss-rich)
gravel/pJeff/dHeath	362	Mosaic of exposed gravel, *Juncus effusus*-dominated poor fen and pioneer dry heath
pJeff/pJeffM	363	Mosaic of pioneer *Juncus effusus*-dominated poor fen and pioneer *Juncus effusus*-dominated poor fen (moss-rich)
BP/pJeff/pEang	364	Mosaic of bare peat, pioneer *Juncus effusus*-dominated poor fen and pioneer *Eriophorum angustifolium*-dominated vegetation
pJeff/pEang	365	Mosaic of pioneer *Juncus effusus*-dominated poor fen and *Eriophorum angustifolium*-dominated vegetation
OW/pTyph	366	Mosaic of open water and pioneer *Typha*-dominated vegetation
BP/pEang	367	Mosaic of bare peat and pioneer *Eriophorum angustifolium*-dominated vegetation
BP/gravel	368	Mosaic of bare peat and exposed gravel
BP/pJeffS	369	Mosaic of bare peat and pioneer *Juncus effusus*-dominated poor fen (*Sphagnum*-rich)
OW/pJeffS	370	Mosaic of open water and pioneer *Juncus effusus*-dominated poor fen (*Sphagnum*-rich)
pPhrag	371	*Pioneer Phragmites*-dominated reedbed
Pschon	372	Pioneer rich fen vegetation with *Schoenus nigricans* (rudimentary rich fen)
gMol	375	Pioneer dry *Molinia*-dominated grassland

BP/dHeath/pJeff	376	Mosaic of bare peat, pioneer dry heath and pioneer *Juncus effusus*-dominated poor fen vegetation
OW/pEangS/pJeffS	377	Mosaic of open water, pioneer *Eriophorum angustifolium*-dominated vegetation (*Sphagnum*-rich) and pioneer *Juncus effusus*-dominated poor fen
Gravel/dHeath/BP/pJeff	379	Mosaic of exposed gravel, *Calluna* dominated heath, bare peat and pioneer *Juncus effusus*
dHeath/pJeff/pEang	380	Mosaic of *Calluna*-dominated heath with pioneer *Juncus effusus* and pioneer *Eriophorum angustifolium*
dHeath/Sphagnum/pEang	381	Mosaic of *Calluna*-dominated dry heath with *Sphagnum* and pioneer *Eriophorum angustifolium*
BP/dHeath/pEang	383	Mosaic of bare peat, pioneer *Calluna* dominated heath and pioneer *Eriophorum angustifolium*-dominated vegetation
BP/gMol	384	Mosaic of bare peat and pioneer *Molinia*-dominated grassland
OW/pJeff/pBulb	385	Mosaic of open water, pioneer *Juncus effusus* and pioneer *Juncus bulbosus*-dominated pioneer poor fen vegetation
Gravel/pJeff/oPine	386	Mosiac of exposed gravel, pioneer *Juncus effusus*-dominated poor fen and open pine-dominated scrub
BP/pJeff/oPine	388	Mosaic of bare peat, pioneer *Juncus effusus*-dominated poor fen and open pine-dominated scrub
dHeath/gMol	390	Mosaic of pioneer dry heath and pioneer *Molinia*-dominated grassland
Gravel/BP/pEang	391	Mosaic of exposed gravel, bare peat and *Eriophorum angustifolium*-dominated vegetation
pRos	392	Pioneer *Carex rostrata*-dominated poor fen
pEang/pRos	393	Mosaic of pioneer *Eriophorum angustifolium*-dominated vegetation and pioneer *Carex rostrata*-dominated poor fen
BP/Equ	394	Mosaic of bare peat and poor fen with calcareous indicators (*Equisetum* spp./*Calliergon* spp.)
gMol/oWill	395	Mosaic of pioneer dry *Molinia*-dominated grassland and open willow-dominated scrub
pJeffG/dHeath/oPine	396	Mosaic of pioneer *Juncus effusus*-dominated poor fen (grass species-rich), *Calluna*-dominated dry heath and emergent pine-dominated scrub
pEang/pJeff/oPine	397	Mosaic of pioneer *Eriophorum angustifolium*-dominated vegetation, pioneer *Juncus effusus*-dominated poor fen and emergent pine-dominated scrub
pEang/pJeff/pRos	401	Mosaic of pioneer *Eriophorum angustifolium*-dominated vegetation, pioneer *Juncus effusus*-dominated poor fen and pioneer *Carex rostrata*-dominated poor fen
pJeff/pTyph	402	Mosaic of pioneer *Juncus effusus*-dominated poor fen and pioneer *Typha*-dominated vegetation
OW/pTyph/S	403	Mosaic of open water, pioneer *Typha*-dominated vegetation and

		Sphagnum-dominated pools
GS4/oPine	404	Mosaic of wet grassland (GS4) and open pine-dominated scrub
Gravel/pJeff/oPine/M/S	405	Mosaic of exposed gravel, pioneer *Juncus effusus*-dominated poor fen and open pine-dominated scrub (moss and *Sphagnum*-rich)
BP/pCamp/pEang	406	Mosaic of bare peat, pioneer *Campylopus*-dominated poor fen and pioneer *Eriophorum angustifolium*-dominated vegetation
BP/pJbulb	408	Mosaic of bare peat and pioneer *Juncus bulbosus*-dominated poor fen
gravel/gMol	409	Mosaic of exposed gravel and pioneer dry *Molinia*-dominated grassland
OW/BP/pJeff	411	Mosaic of open water, bare peat and pioneer *Juncus effusus*-dominated poor fen
dHeath/pJeffM	413	Mosaic of pioneer *Calluna*-dominated dry heath and pioneer *Juncus effusus*-dominated poor fen (moss-rich)
BP/dHeath/pJeffM	415	Mosaic of bare peat, *Calluna*-dominated dry heath and pioneer *Juncus effusus*-dominated poor fen (moss-rich)
BP/gMol/pEangM	416	Mosaic of bare peat, pioneer dry *Molinia*-dominated grassland and pioneer *Eriophorum angustifolium*-dominated vegetation (moss-rich)
OW/Gravel/BP/M	417	Mosaic of open water, exposed gravel, bare peat and fragmented moss cover
pJeff/pEang/eWill	418	Mosaic of pioneer *Juncus effusus*-dominated poor fen, pioneer *Eriophorum angustifolium*-dominated vegetation and emergent willow-dominated scrub
gMol/oPine/pEqu	419	Mosaic of pioneer *Molinia*-dominated grassland, open pine-dominated scrub with *Equisetum* spp
pJeff/oPine/eWill/S	420	Mosaic of pioneer *Juncus effusus*-dominated poor fen, open pine-dominated scrub, emergent willow scrub (*Sphagnum*-rich)
OW/pTyp/pRos	421	Mosaic of open water, *Typha*-dominated vegetation and pioneer *Carex rostrata*-dominated poor fen
BP/pEang/pTrig	422	Mosaic of bare peat, pioneer *Eriophorum angustifolium*-dominated vegetation and pioneer *Triglochin*-dominated poor fen
BP/pJeff/pEang/S	423	Mosaic of bare peat, pioneer *Juncus effusus*-dominated poor fen and pioneer *Eriophorum angustifolium*-dominated vegetation (*Sphagnum*-rich)

Within the Bellacorick site, areas not subjected to industrial peat cutting (riparian areas, bog remnants, conifer plantations etc), were classified according to Fossit (2000) and are shown in Table 3.2. In this catogery, cutover bog refers to areas around the boundary of the

Bellacorick site that have been used for domestic sod peat production in the past while bare ground refers to areas that were used for machinery storage, workshops and hard stand areas.

Table 3.2 Habitats at the Bellacorick site according to Fossit (2000)

Fossit (2000) code	**Code for GIS**	**Habitat description**
PB3	101	Lowland blanket bog
PB4	102	Cutover bog
PF2	104	Poor fen and flush
WN6	110	Wet Willow-Alder-Ash woodland
WD1	113	Mixed broad-leaved woodland
WD4	115	Conifer plantation
WS1	116	Scrub
WS2	119	Recently-planted woodland
WS5	123	Recently-felled woodland
WL2	125	Treeline
GA1	126	Improved grsld
GS1	128	Dry calcareous and neutral grsld
GS2	129	Dry meadows and grassy verges
GS3	130	Dry-humid acid grsld
GS4	131	Wet grsld
HH1	133	Dry heath
HH3	135	Wet heath
HD1	136	Dense Bracken
ED2	138	Spoil and bare ground
ED3	139	Recolonising bare ground
BL3	148	Buildings and artificial surfaces
FS1	154	Reed and large sedge swamps
FW1	300	Eroding Rivers
FL1	301	Dystrophic lakes

The habitats described in Table 3.2 have been aligned to the Farrell (2001) study which uses the Braun-Blanquet classification system, these are described further in Chapter 4.

3.3 Field survey and habitat mapping

The habitat survey was carried out in accordance with the Heritage Councils 'Best Practice Guidance for Habitat Mapping and Survey' (Smith *et al.*, 2010). Prior to the survey beginning, the minimum habitat unit size for the survey was set at 0.5ha, based on the time and recourses available (all figures for vegetation cover within the results chapter are given to two decimal places which equals 0.5ha unit of vegetation). The main vegetation and habitat mapping survey was carried out in the summer of 2011.

The 2001 habitat map was compiled using 2001 aerial photos (1:6,000 scale) and data from Farrell (2001).

For the 2011 survey, 2008 aerial photos (colour) at a scale of 1:6,000 were used as a base map. The site was walked and pioneer habitat classifications (Table 3.1) and habitats according to Fossit (2000) (Table 3.2) were applied to the vegetation on site using the aerial photos as a guide. Information was recorded using the field card (Figure 3.3). Features on the ground such as vegetation, watercourses and roads were also noted. Once the field work was completed, work began on digitising habitat maps.

3.3.1 Habitat mapping of the Bellacorick site

Maps were digitised using Arc Map 10 GIS. This GIS package allows every unit (in this case vegetation communities, open water, roads etc) to be mapped digitally. Guidelines outlined by Smith *et al.* (2011) were followed in this work.

Initially, shapefiles (digital files used in GIS) are created. The shapefiles contain information pertaining to the site and within the shapefile separate polygons are created, which relate to different units of habitats which are accordingly detailed in an attributes table. The shapefile is used as a layer and this layer can be overlain on other layers, such as an aerial photograph or another map, with each layer adding an extra layer of information, enabling detailed maps to be created.

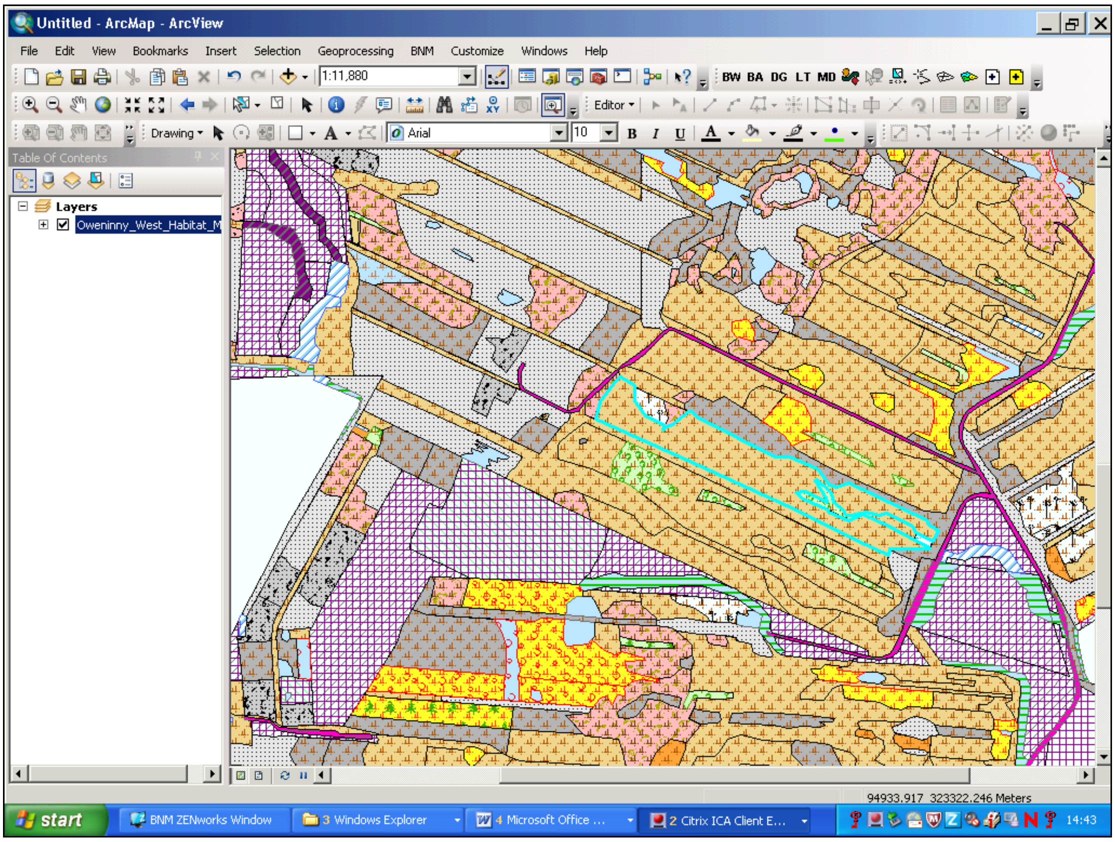
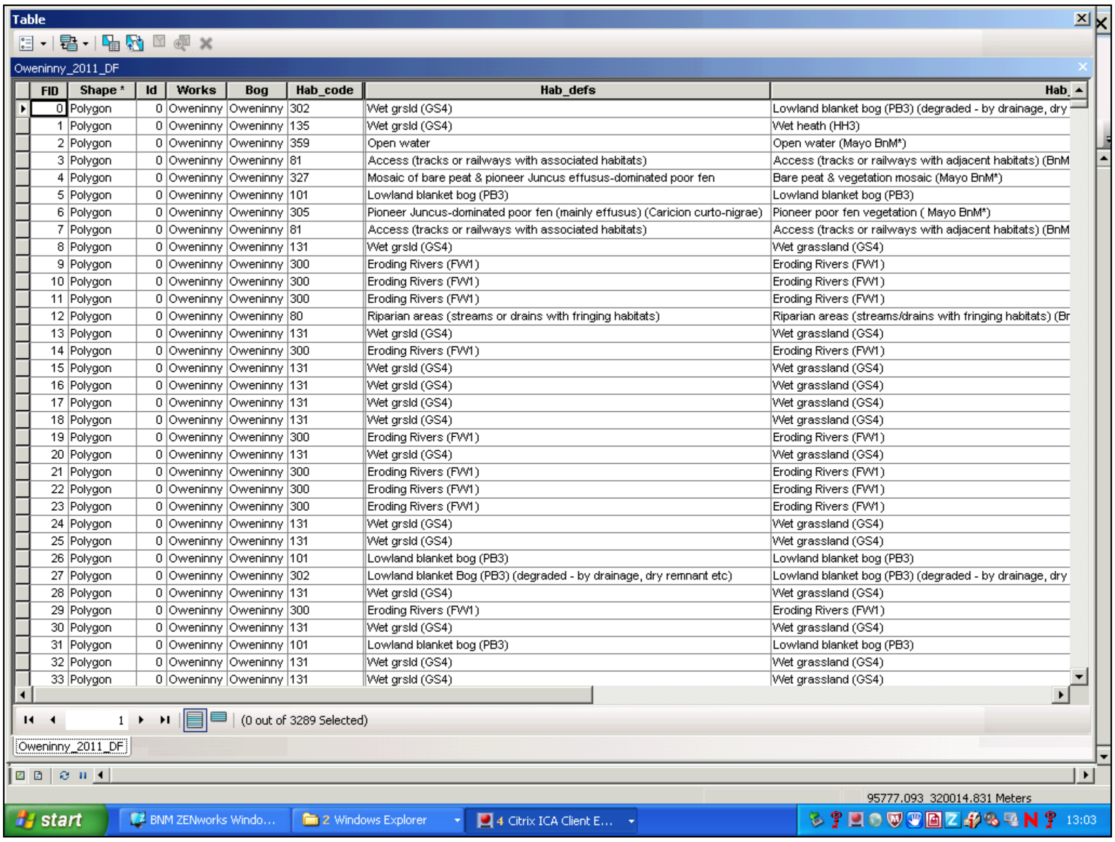


Figure 3.1 Screen grab of Arc Map – showing polygons within a shapefile

Each unit (feature of the site) within the shapefile was registered as a separate polygon. A polygon is a unit within the mapped area that has been assigned a specific code as described in the Bord na Móna Habitat Scheme (Chapter 3). The 2011 habitat map in this thesis contains 3,288 polygons. Using the attributes table in ArcMap GIS, each polygon can be assigned information that is relevant to that area such as vegetation type, rehabilitation measures carried out etc. Figure 3.2 demonstrates an example of an attributes table used for the mapping of the Bellacorick site.



FID	Shape *	Id	Works	Bog	Hab_code	Hab_defs	Hab_
0	Polygon	0	Oweninny	Oweninny	302	Wet grsld (GS4)	Lowland blanket bog (PB3) (degraded - by drainage, dry
1	Polygon	0	Oweninny	Oweninny	135	Wet grsld (GS4)	Wet heath (HH3)
2	Polygon	0	Oweninny	Oweninny	359	Open water	Open water (Mayo BnM*)
3	Polygon	0	Oweninny	Oweninny	81	Access (tracks or railways with associated habitats)	Access (tracks or railways with adjacent habitats) (BnM
4	Polygon	0	Oweninny	Oweninny	327	Mosaic of bare peat & pioneer Juncus effusus-dominated poor fen	Bare peat & vegetation mosaic (Mayo BnM*)
5	Polygon	0	Oweninny	Oweninny	101	Lowland blanket bog (PB3)	Lowland blanket bog (PB3)
6	Polygon	0	Oweninny	Oweninny	305	Pioneer Juncus-dominated poor fen (mainly effusus) (Caricion curto-nigrae)	Pioneer poor fen vegetation (Mayo BnM*)
7	Polygon	0	Oweninny	Oweninny	81	Access (tracks or railways with associated habitats)	Access (tracks or railways with adjacent habitats) (BnM
8	Polygon	0	Oweninny	Oweninny	131	Wet grsld (GS4)	Wet grassland (GS4)
9	Polygon	0	Oweninny	Oweninny	300	Eroding Rivers (FW1)	Eroding Rivers (FW1)
10	Polygon	0	Oweninny	Oweninny	300	Eroding Rivers (FW1)	Eroding Rivers (FW1)
11	Polygon	0	Oweninny	Oweninny	300	Eroding Rivers (FW1)	Eroding Rivers (FW1)
12	Polygon	0	Oweninny	Oweninny	80	Riparian areas (streams or drains with fringing habitats)	Riparian areas (streams/drains with fringing habitats) (Br
13	Polygon	0	Oweninny	Oweninny	131	Wet grsld (GS4)	Wet grassland (GS4)
14	Polygon	0	Oweninny	Oweninny	300	Eroding Rivers (FW1)	Eroding Rivers (FW1)
15	Polygon	0	Oweninny	Oweninny	131	Wet grsld (GS4)	Wet grassland (GS4)
16	Polygon	0	Oweninny	Oweninny	131	Wet grsld (GS4)	Wet grassland (GS4)
17	Polygon	0	Oweninny	Oweninny	131	Wet grsld (GS4)	Wet grassland (GS4)
18	Polygon	0	Oweninny	Oweninny	131	Wet grsld (GS4)	Wet grassland (GS4)
19	Polygon	0	Oweninny	Oweninny	300	Eroding Rivers (FW1)	Eroding Rivers (FW1)
20	Polygon	0	Oweninny	Oweninny	131	Wet grsld (GS4)	Wet grassland (GS4)
21	Polygon	0	Oweninny	Oweninny	300	Eroding Rivers (FW1)	Eroding Rivers (FW1)
22	Polygon	0	Oweninny	Oweninny	300	Eroding Rivers (FW1)	Eroding Rivers (FW1)
23	Polygon	0	Oweninny	Oweninny	300	Eroding Rivers (FW1)	Eroding Rivers (FW1)
24	Polygon	0	Oweninny	Oweninny	131	Wet grsld (GS4)	Wet grassland (GS4)
25	Polygon	0	Oweninny	Oweninny	131	Wet grsld (GS4)	Wet grassland (GS4)
26	Polygon	0	Oweninny	Oweninny	101	Lowland blanket bog (PB3)	Lowland blanket bog (PB3)
27	Polygon	0	Oweninny	Oweninny	302	Lowland blanket Bog (PB3) (degraded - by drainage, dry remnant etc)	Lowland blanket bog (PB3) (degraded - by drainage, dry
28	Polygon	0	Oweninny	Oweninny	131	Wet grsld (GS4)	Wet grassland (GS4)
29	Polygon	0	Oweninny	Oweninny	300	Eroding Rivers (FW1)	Eroding Rivers (FW1)
30	Polygon	0	Oweninny	Oweninny	131	Wet grsld (GS4)	Wet grassland (GS4)
31	Polygon	0	Oweninny	Oweninny	101	Lowland blanket bog (PB3)	Lowland blanket bog (PB3)
32	Polygon	0	Oweninny	Oweninny	131	Wet grsld (GS4)	Wet grassland (GS4)
33	Polygon	0	Oweninny	Oweninny	131	Wet grsld (GS4)	Wet grassland (GS4)

Figure 3.2 Attributes table in ArcMap GIS

Each polygon is then colour coded based on the assigned habitat code. This assigns a colour or specific shading to the polygon according to the habitat that was present. In this way, each habitat within the site is marked with its own colour and this allows the habitat maps to be easily interpreted.

A general and more simplified vegetation cover system was then developed to further aid interpretation of the major changes on the site. ArcMap was used to produce simplified vegetation cover maps for both 2001 and 2011 by assigning the Bord na Móna habitat-types into the 9 different categories. The nine different simplified vegetation categories for the Bellacorick site (according to Farrell, 2001) are shown in Table 3.3. These highlight the main vegetation features across the site from pioneer vegetation to more established poor fen, bog pool communities, dry heath and bare peat and exposed gravel.

Table 3.3 Simplified vegetation land cover categories for the Bellacorick site

Simplified vegetation land cover categories
Juncus effusus pioneer community
Juncus bulbosus pioneer community
Eriophorum angustifolium pioneer community
Sphagneto-Juncetum effusi community
Sphagnum cuspidatum-Eriophorum angustifolium community
Juncus bulbosus-Sphagnum cuspidatum pools
Calluno-Ericetum community
Bare peat
Exposed gravel

3.4 Vegetation monitoring (composition and cover)during the 2012 field season

Vegetation monitoring can be used to give a picture of the vegetation composition and cover across any given site and outline the changes in vegetation over time. Permanent monitoring stations (quadrats) were established within the Bellacorick cutaway habitats identified during the vegetation survey in 2012.

Stratified random sampling is the chosen method for the placement of permanent quadrats to monitor future changes in the vegetation of the Bellacorick site. Rowlands (2001) used this method while surveying cutaway industrial peat production areas in Offaly and this method allows for randomly placed survey points to record information about the site. The information gathered is then used to gain a clear picture of the vegetation at the Bellacorick site.

The quadrats were placed randomly across these vegetation types. The proportional area of the site that each vegetation type occupied was used to allocate quadrats between land cover types, with quadrat number per type weighted by area (Table 3.4). The location of each quadrat was chosen using the habitat maps that had been developed on the site using the field data collected in 2011. The quadrats were placed randomly across these vegetation habitats. This ensures that each vegetation community was weighted with an appropriate percentage of quadrats. The proportional area of the site that each vegetation community occupies was used to allocate an appropriate number of the 57 quadrats. This number of quadrats was chosen as the appropriate number needed to cover each vegetation type given the resources available.

Quadrats of 2m x 2m dimension were chosen using the two nested quadrat design (Wheater *et al*., 2011). This method involved sampling trial areas on the site. Small quadrats of 0.5m x 0.5m were used first, the quadrats were doubled in size and the numbers of plant species encountered were recorded. With each doubling of the quadrat size the number of plant species increased until the 2m x 2m quadrat size was incorporated. A 3m x 3m quadrat did not reveal any new plant species. It was concluded that 2m x 2m was optimal quadrat size for monitoring the vegetation at the Bellacorick site.

In order to avoid ecotones/edge effect, a 3 metre buffer from the boundary of each habitat type was observed when setting up the quadrats. The number of quadrats in each habitat type is outlined in Table 3.4. Information recorded from each quadrat allows for the ordination of the information to determine linkages between species, presence/absence, indicator species and measurable environmental variables such as peat depth, vegetation height and water depth.

Table 3.4 Simplified vegetation categories and the number of permanent quadrats allocated for monitoring

Habitat	**Number of quadrats**	**% of the site in 2011**
Juncus effusus pioneer community	30	41.23
Juncus bulbosus pioneer community	3	0.07
Eriophorum angustifolium pioneer community	3	2.85
Sphagneto-Juncetum effusi	6	6.21
Sphagnum cuspidatum-Eriophorum angustifolium community	3	0.15
Juncus bulbosus-Sphagnum cuspidatum pools	3	0.31
Calluno-Ericetum cinereae	3	1.78
Bare peat	3	11.75
Exposed gravel	3	0.52
Total	**57**	**64.87**

Cover of each species within a quadrat was estimated using the Domin scale (Table 3.5) (Kent and Coker, 1992).

Table 3.5 Domin cover scale

Domin	Value
A single individual. No measurable cover	+
1-2 individuals. No measurable cover. Individuals with normal vigour	1
Several individuals but less than 1% cover	2
1-4% cover	3
4-10% cover	4
11-25% cover	5
26-33% cover	6
34-50% cover	7
51-75% cover	8
76-90% cover	9
91-100% cover	10

The location of each quadrat was recorded using a hand held GPS (Garmin GPSmap 60CSx) unit and the corners of the quadrat were marked using bamboo canes. A timber stake was also used to mark each quadrat in order to aid the finding of each quadrat in the future. Information recorded from inside the quadrat included the following –

- Species list (vascular plants and bryophytes)
- Total percentage cover of vegetation cover including both vascular and bryophyte species
- Percentage of bare peat
- Percentage of exposed gravel
- Percentage of open water

A photo point of each quadrat was also taken. Photo points allow for an effective qualitative record to be taken from each quadrat. The setting up of photo points at each quadrat creates a permanent visual record, allowing factors and changes to be evaluated that might not have been considered when the monitoring was initially established (Elzinga, 2001). Each photograph was taken 1.5m to the south of the quadrat and half way between the two most southerly corners of the quadrat. The camera was pointed in a true north direction. The camera was at eye level (1.2m) for each photograph. A Panasonic Lumix DMC-FS62 10 mega pixels digital camera was used for each photograph.

A field recording card was devised using parameters set out by Weekes and Fitzpatrick (2010). A recording sheet is shown in Figure 3.3.

<table>
<tr><td colspan="2">Quadrat number –
Habitat type -</td><td colspan="2">GPS -</td><td>Date -</td></tr>
<tr><td>% bare peat-</td><td colspan="2">% open water-</td><td>% ex. gravel-</td><td>max. ht. of veg.-
max. ht of moss-</td></tr>
<tr><td colspan="5">Species list and % of each species within quadrat (domin scale)</td></tr>
<tr><td colspan="5">Management notes – grazing, recent fire, disturbance</td></tr>
</table>

Figure 3.3 Field recording sheet (reduced in size)

Nomenclature for vascular plants follows Parnell and Curtis (2012). Nomenclature for bryophytes follows Atherton *et al*. (2010) with lichens following Whelan (2011).

3.5 Data Analysis

3.5.1 Non-Metric Multidimensional Scaling (NMS) Ordination

NMS ordination using Sorensens distance measure and NMS autopilot was carried out using PCORD v.6 to determine the relationship between plant community composition and the measured environmental variables. Ordination provides a means of viewing data in high dimensional space by seeking and displaying the strongest structure, thus extracting dominant patterns from an infinite number of possibilities (McCune and Grace, 2002). It takes a large number of variables (species) for each quadrat and distils them down in a number of composite varaibles (axes in ordination). The resulting distance between the points (quadrats) in the ordination diagram is approximately proportional to the dissimilarity in their species composition (McCune and Grace, 2002).

3.5.2 Cluster analysis and indicator species analysis

The information obtained from the quadrats was organised into two matrices, matrix 1- species data and matrix 2- environmental variables for each quadrat. Two habitats, bare peat and exposed gravel were not included in the matrices as they had no species present. Cluster analysis was then carried out on the data from the permanent quadrats using PC ORD v. 6 with the Sorensen distance and Flexible Beta linkage method. Indicator species analysis was carried out to determine objectively where to prune the cluster analysis dendrogram (McGune and Grace, 2002).

Chapter 4 Results

4.1 Maps of the Bellacorick peatlands

4.1.1 Introduction

Following the baseline vegetation survey of the site in 2011 habitat maps were developed for the Bellacorick site. These are outlined here and provide the back-drop for further discussion relating to the changes in vegetation cover and habitat types on the Bellacorick site between 2001 and 2011. They include:

- Detailed habitat (Fig. 4.1) and simplified habitat maps 2001 (Fig. 4.3). Using the 2001 aerial photographs, site records and hand recorded habitat maps from Farrell (2001), a habitat map was produced to show the extent of vegetation cover and the main habitat types present on the site in 2001.

- Detailed habitat (Fig. 4.2) and simplified habitat map 2011 (Fig. 4.4). Using the 2010 aerial photographs, a habitat map was produced to show the extent of vegetation cover and the main habitat types present on the site in 2011.

Using the habitat maps and simplified vegetation maps of Bellacorick for both 2001 and 2011, it is possible to

- Compare the spread of vegetation across the Bellacorick site over the ten year period 2001-2011.

- Outline and compare the main habitats on the Bellacorick cutaway in 2001 and 2011.

- Determine trends in vegetation succession across the site and compare the rates of change between areas.

- Highlight any areas that have been slow to re-vegetate and areas that have already re-vegetated; following from the variation in vegetation cover and spread, the success of rehabilitation measures across the entire site can be assessed.

4.2 Description of habitat maps

The habitats present in 2001 and 2011 (Figures 4.1 and 4.2 respectively) were mapped using the Bord na Móna Habitat Scheme (outlined in section 3.1). Larger versions of these maps are available in Appendix I and II. In 2001 a total of 46 Bord na Móna habitat types were recorded. In 2011, 110 Bord na Móna habitat types were recorded.

4.2.1 Habitat map of the Bellacorick site (2001)

Figure 4.1 shows extensive bare peat areas, as peat production was still ongoing at the Bellacorick site at this time. There are some vegetated cutaway areas emerging and these are characterised by pioneer poor fen vegetation. Other habitats present include open water, scrub and dry heath. Also obvious are the remnant bog areas, which cover 919.41 ha, between the production areas and riparian zones. The largest remnant area is to the north west of the site and accounts for approximately 300ha of the total area. Areas of exposed gravel and subsoil are scattered across the site. Coniferous forestry that occupies areas within the site are also mapped (Figure 4.1).

4.2.2 Habitat map of the Bellacorick site (2011)

Figure 4.3 details the habitat types found on the site in 2011 using the Bord na Móna habitat types. The main changes at the site between 2001 and 2011 based on the habitat mapping are as follows:

- The map shows a notable increase in vegetation cover between 2001 and 2011, with corresponding reductions in the areas of bare peat.
- Poor fen and rudimentary versions of poor fen are the main vegetation types emerging across the site in 2011.
- Bare gravel hills are still a feature but are slowly colonising with dry heath and poor fen (rudimentary types).
- Pine scrub is establishing in areas of poor fen particularly on eastern side of the site.
- There is an increase in open water and ponds across the site.
- Bog remnants are still present with some areas rehabilitated (drain blocking).
- There is a notable increasing trend in *Sphagnum*-rich poor fen areas (highlighted in yellow) (Fig. 4.3).

The aim of generating two habitat maps, ten years apart, is to allow a quick visual assessment of how the site has changed, vegetatively, over that period of time. The complexities of both maps highlight the variation across the site. The main habitats along with the vegetation changes over the period 2001 -2011 are outlined in Table 4.1.

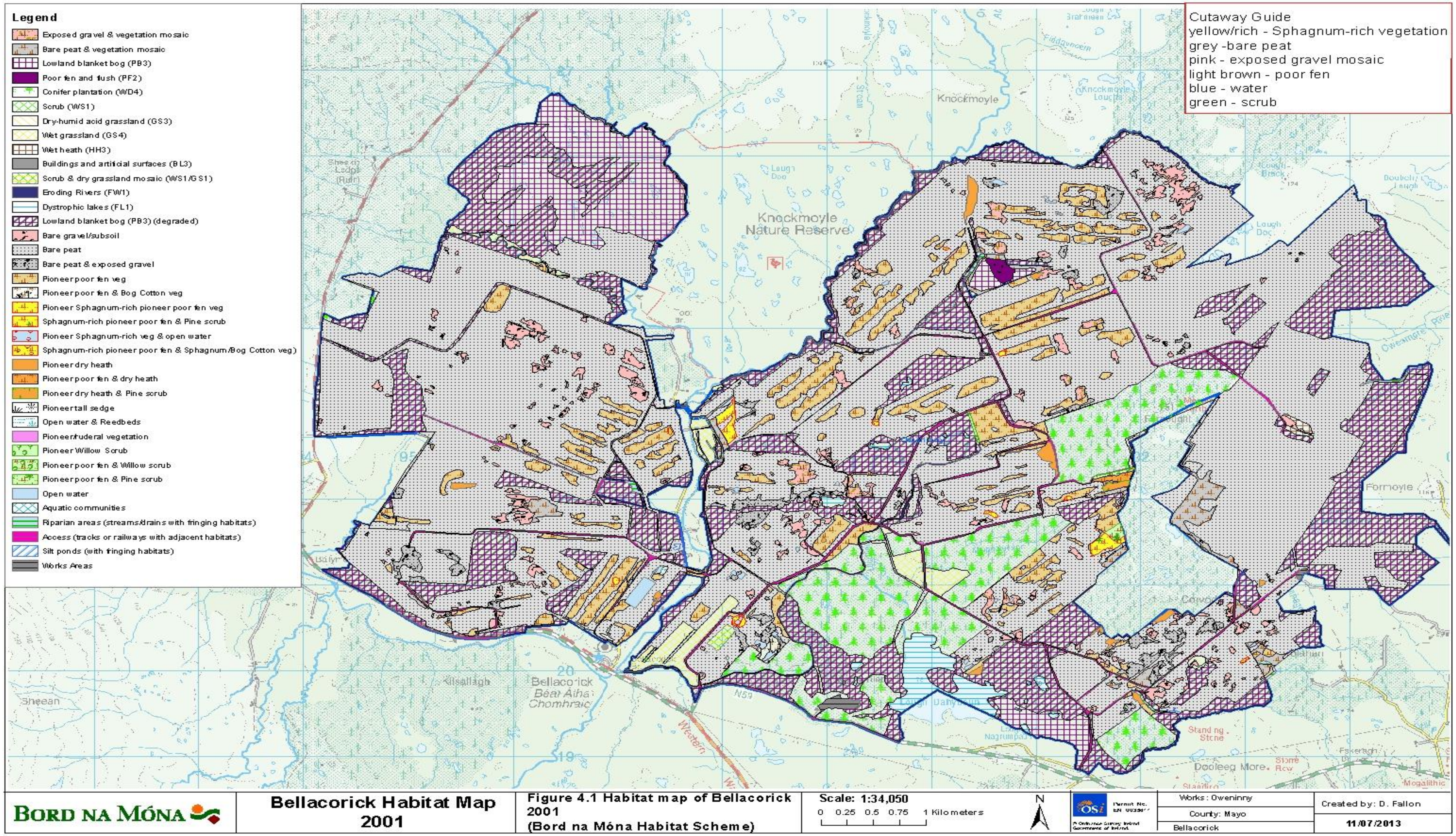


Figure 4.1 Habitat map of Bellacorick 2001 (Bord na Móna Habitat Scheme)

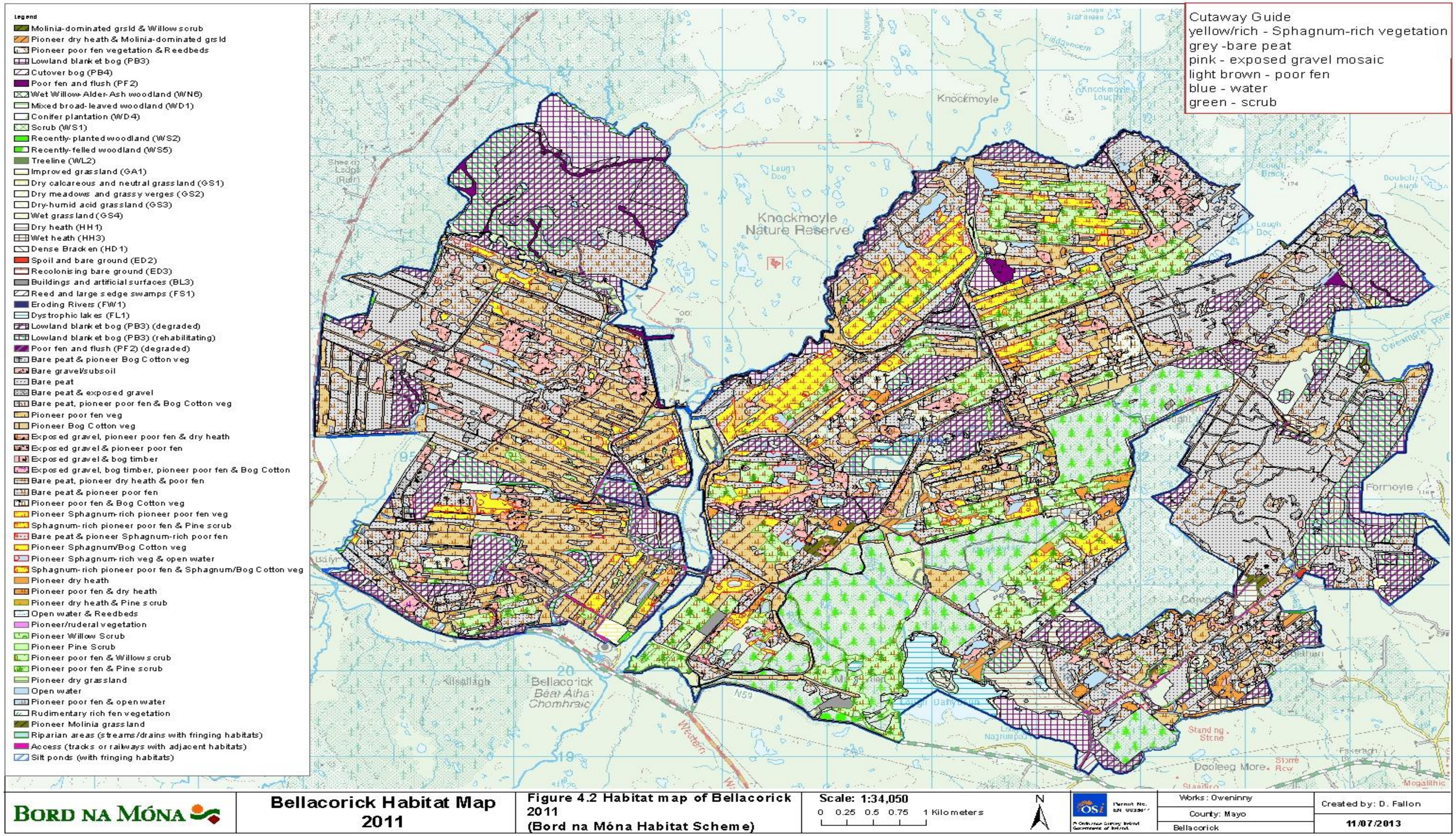


Figure 4.2 Habitat map of Bellacorick 2011 (Bord na Móna Habitat Scheme)

Table 4.1 Overall habitat changes in Bellacorick between 2000 and 2011. (The figures shown in bold show some of the largest changes over the ten year period)

	Bellacorick 2001		**Bellacorick 2011**		
Bord na Móna Habitat Scheme and Heritage Council classifications (denoted in brackets)	**Area (Ha)**	**% cover**	**Area (Ha)**	**% cover**	**% change (2011-2001)**
Access (tracks or railways with adjacent habitats)	81.94	1.58	44.90	0.86	-0.71
Bare gravel/subsoil	124.99	2.41	27.03	0.52	-1.89
Bare peat and exposed gravel	64.38	1.24	19.10	0.36	-0.87
Bare peat and pioneer *Sphagnum*-rich poor fen	0	0	6.83	0.13	0.13
Bare peat and vegetation mosaic	**15.82**	**0.30**	**904.74**	**17.47**	**17.17**
Bare peat	**2758.78**	**53.29**	**608.39**	**11.75**	**-41.50**
Bog timber	0	0	0.58	0.01	0.01
Buildings and artificial surfaces (BL3)	5.30	0.10	14.07	0.27	0.16
Conifer plantation (WD4)	478.39	9.24	420.07	8.11	-1.12
Cutover bog (PB4)	0	0	5.85	0.11	0.11
Dense bracken (HD1)	0.97	0.01	1.12	0.02	0.02
Dry calcareous and neutral grassland (GS1)	0	0	0.63	0.012	0.01
Dry heath (HH1)	1.97	0.03	47.02	0.90	0.87
Dry meadows and grassy verges (GS2)	0	0	0.86	0.01	0.01
Dry-humid acid grassland (GS3)	3.25	0.06	12.65	0.24	0.18
Dystrophic lakes (FL1)	49.32	0.95	52.72	1.018	0.06
Eroding rivers (FW1)	22.17	0.42	15.35	0.29	-0.13
Exposed gravel and vegetation mosaic	24	0.46	230.17	4.44	3.98
Improved grassland (GA1)	0	0	7.22	0.139	0.13
Lowland blanket bog (PB3)	128.80	2.48	122.11	2.35	-0.12
Lowland blanket Bog (PB3), degraded - by drainage, dry remnant etc	836.25	16.15	603.06	11.64	-4.50
Lowland blanket bog (PB3) (rehabilitating)	0	0	194.25	3.75	3.75
Mixed broad-leaved woodland (WD1)	0	0	0.12	-	-
Molinia-dominated grassland and willow scrub	3.6	0.06	0.45	0.00	-0.06
Open water and reedbeds	0	0	0.67	0.01	0.01
Open water	**12.45**	**0.24**	**64.66**	**1.24**	**1.00**
Pioneer dry grassland	0	0	0.71	0.01	0.01
Pioneer dry heath and molinia-dominated grassland	0	0	8.25	0.15	0.15
Pioneer dry heath and pine scrub	0	0	4.95	0.09	0.09
Pioneer dry heath	14.30	0.27	14.99	0.28	0.01
Pioneer Molinia grassland	0	0	10.75	0.20	0.21

Pioneer ombrotrophic vegetation	0	0	21.24	0.41	0.41
Pioneer pine scrub	**0**	**0**	**18.91**	**0.36**	**0.36**
Pioneer poor fen and bog cotton vegetation	0	0	4.96	0.095	0.09
Pioneer poor fen and dry heath	**0**	**0**	**29.33**	**0.56**	**0.56**
Pioneer poor fen and open water mosaic	0.66	0.01	25.70	0.49	0.48
Pioneer poor fen and pine scrub	0	0	308.20	5.95	5.95
Pioneer poor fen and willow scrub	0	0	25.15	0.48	0.48
Pioneer poor fen vegetation and reedbeds	0.54	0.01	3.31	0.06	0.05
Pioneer poor fen vegetation	**333.04**	**6.43**	**958.61**	**18.51**	**12.08**
Pioneer *Sphagnum*-rich poor fen vegetation	**0**	**0**	**38.20**	**0.73**	**0.73**
Pioneer willow scrub	0.87	0.01	0.22	0.00	-0.01
Pioneer/ruderal vegetation	0.12	0.00	0.80	0.01	0.01
Poor fen and flush (PF2)	71.99	1.39	21.24	0.41	-0.98
Poor fen and flush (PF2) (degraded - drainage etc)	7.65	0.15	3.09	0.05	-0.08
Recently-felled woodland (WS5)	0	0	4.15	0.08	0.08
Recently-planted woodland (WS2)	0	0	1.7	0.03	0.03
Recolonising bare ground (ED3)	0	0	0.82	0.01	0.01
Reed and large sedge swamps (FS1)	0	0	3.56	0.06	0.06
Riparian areas (streams/drains with fringing habitats)	16.89	0.32	52	1.00	0.67
Rudimentary rich fen vegetation	0	0	4.93	0.09	0.09
Scrub (WS1)	6.65	0.12	11.7	0.22	0.10
Silt ponds (with fringing habitats)	4.80	0.09	19.42	0.37	0.28
Pioneer poor fen (*Sphagnum*-rich) and pine scrub, *Sphagnum*-rich	**0**	**0**	**32.84**	**0.63**	**0.63**
***Sphagnum*-rich vegetation and open water**	**0**	**0**	**13.77**	**0.26**	**0.26**
Sphagnum-rich vegetation	0.40	0.00	8.32	0.16	0.15
Spoil and bare ground (ED2)	0	0	0.58	0.01	0.01
Treeline (WL2)	0	0	0.42	0.00	0.00
Wet grassland (GS4)	90.35	1.74	72.59	1.40	-0.33
Wet heath (HH3)	15.40	0.29	43.88	0.84	0.55
Wet willow-alder-ash woodland (WN6)	0	0	2.97	0.05	0.05
Total area	**5177**		**5177**		

The most notable changes are illustrated in Table 4.1 and are:

- Vegetation cover has increased across the site, bare peat occupied 53.3% of the site in 2001, and by 2011 this had reduced to 11.7%.
- Pioneer poor fen vegetation has increased by 44.4% since 2001; pioneer poor fen habitats occupied an area of 333ha in 2001, however this area increased to 2,630ha in 2011.

- *Sphagnum* cover has increased across the site. *Sphagnum*-rich poor fen habitats (>50% *Sphagnum* cover) have increased from less than 1% of the site in 2001 to approximately 7% in 2011.
- There is a 7% increase in *Pinus contorta* dominated habitats since 2001.
- Areas of the site with exposed gravel (bare peat and exposed gravel, exposed gravel and exposed gravel and vegetation mosaic) have increased by 1.8% of the site in the period between 2001 and 2011; Figure 4.2 (2011 habitat map) shows that the slopes and exposed hills on the site are slower to establish vegetation.
- The 2011 habitat map reveals that low lying areas within the site, where water is retained have vegetated.

4.2.3 Simplified habitat maps

In order to illustrate the habitat cover changes on the site between 2001 and 2011, simplified habitat cover maps (Figure 4.3 and 4.4) were produced. These maps illustrate the 110 habitats of the Bord na Móna Habitat Scheme amalgamated into 9 simplified habitat types. The maps illustrate clearly changes in the following broad categories.

- Bare peat – 53% cover in 2001 decreased to 12% cover in 2011
- Total vegetation cover has increased from 9% in 2001 to approximately 54% in 2011
- Bare peat with emerging vegetation – approximately 17% cover in 2011 compared to <1% cover in 2001

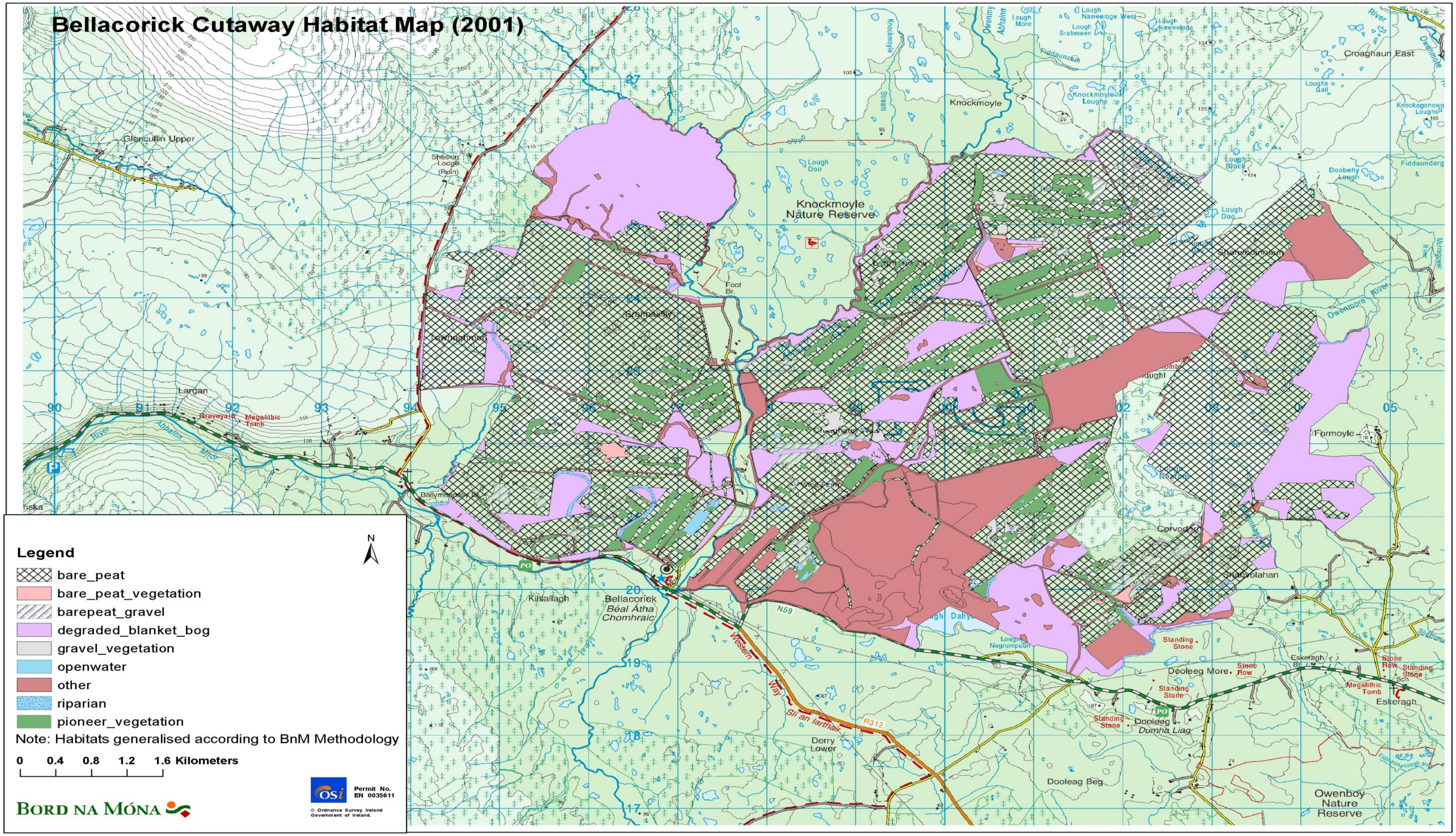


Figure 4.3 Simplified land cover map of Bellacorick 2001

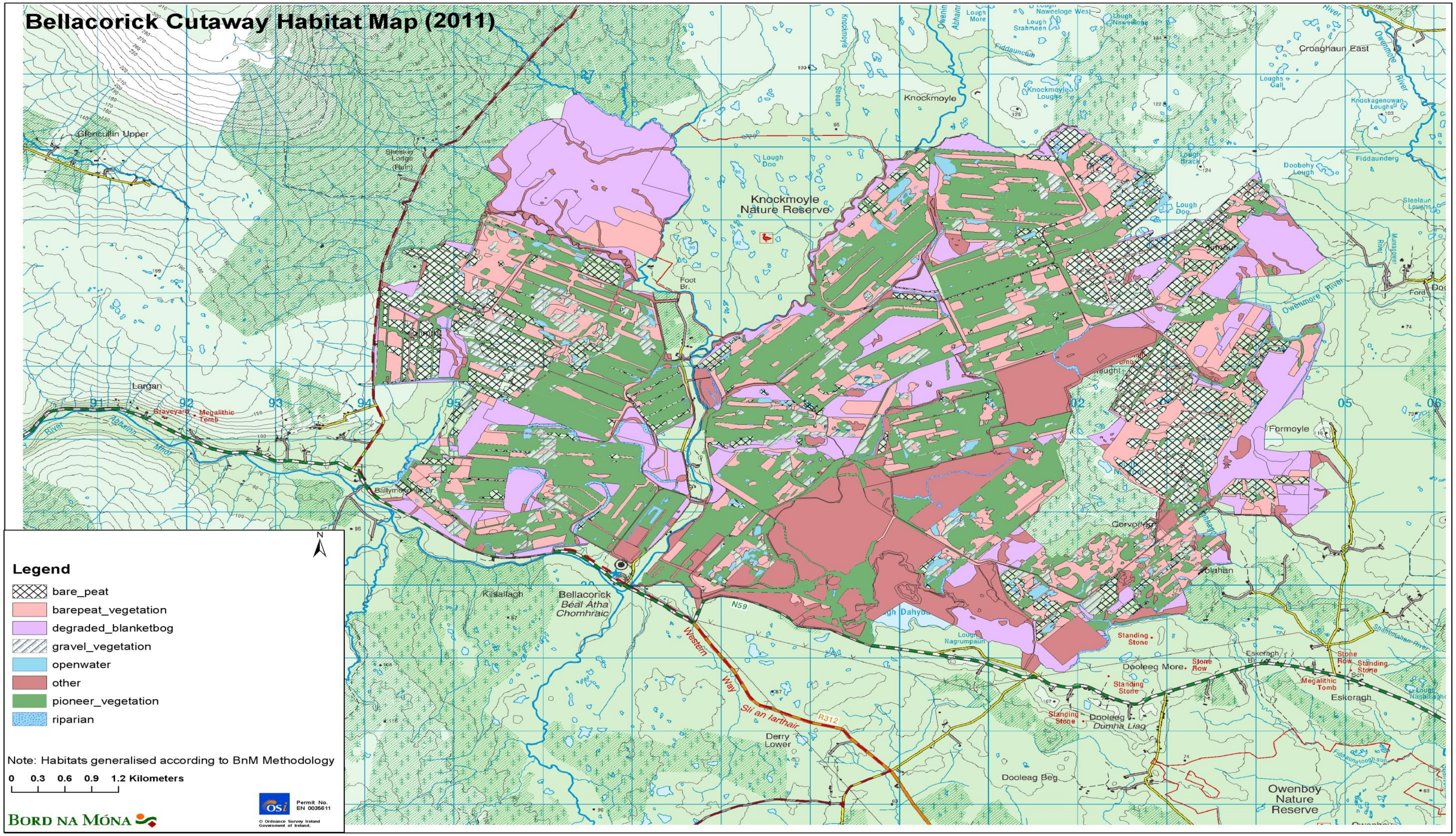


Figure 4.4 Simplified land cover map of Bellacorick 2011

4.3 Habitats and vegetation cover recorded at the Bellacorick site in 2011

In 2001 Farrell described the vegetation at Bellacorick using the Braun-Blanquet system (Braun-Blanquet and Tüxen, 1952) and described eleven vegetation types on the cutaway peatlands at the Bellacorick site.

- *Juncus effusus* pioneer community
- *Juncus bulbosus* pioneer community
- *Eriophorum angustifolium* pioneer community
- Sphagneto-Juncetum effusi community
- *Sphagnum cuspidatum-Eriophorum angustifolium* community
- *Juncus bulbosus-Sphagnum cuspidatum* pools
- Calluno-Ericetum community
- Caricetum paniculatae community
- Typhetum latifoliae community
- Tussilaginetum community
- Centaureo-Cynosuretum community

The following sections (4.3.1 to 4.3.11) describe the extent of these plant communities in 2011 and their affinity to the Bord na Móna Habitat Scheme.

4.3.1 *Juncus effusus* pioneer community

Farrell (2001) classified this community – '*Juncus effusus* pioneer community' and reported that it was found in cutaway areas of shallow peat where broad fluctuations of the water table occur.

The Bord na Móna Habitat Scheme outlines 41 habitat types that correspond to this community which is essentially a pioneer stage of poor fen habitat. The habitat is largely characterised by the presence of *J. effusus*, which forms the main vegetation component. Those 32 types with *J. effusus* dominant align with the Farrell (2001) description due to the fact that the main vegetation component is comprised of patchy to open cover of *J. effusus* usually in the form of tussocks.

Both the Farrell (2001) descriptions and the Bord na Móna Habitat Scheme are considered as rudimentary forms within the Heritage Council habitat – PF2 – Poor fen and flush (Fossitt 2000) where the dominant vegetation type comprises *J. effusus*, but generally with a well developed moss layer.

Figure 4.5 **Juncus effusus** ***pioneer community***

The vegetation composition can vary widely within stands. The tussocks of *J. effusus* can range from 40cm to 120cm in height and can be densely clumped together or form a more open sward. Other plant species emerging commonly include the sedge *Eriophorum angustifolium,* grasses such as *Agrostis stolonifera,* herbs such as *Rumex acetosella,* and emerging shrubs and trees such as *Pinus contorta.* A bryophyte layer may also be present and is commonly comprised of *Campylopus introflexus* and *Polytrichum commune*.

Table 4.2 lists all of the Bord na Móna habitats that are included in this vegetation community and illustrates the relationship with the habitats described by Farrell (2001) and how they relate to the poor fen and flush (PF2) habitat (Heritage Council classification system). The most common habitat types are shown in bold.

Table 4.2 *Juncus effusus* pioneer community

Heritage Council Classification - Fossit (2000)	Vegetation type (Farrell 2001)	Bord na Móna Habitat Scheme - Habitat Type 2011	% of site in 2011
PF2 Poor fen and flush	*Juncus effusus* pioneer community	BP/pJeff	**10.50**
		pJeff	**7.36**
		pJeffM	**4.54**
		pJeff/oPine	3.36
		BP/pJeff/pEang	2.60
		pJeff/pEang	1.54
		pJeffG	1.25
		pJeffM/oPine	1.00
		gravel/BP/pJeff	0.87
		BP/pCamp	0.85
		gravel/pJeffM/pJeff	0.85
		gravel/pJeff	0.77
		BP/pJeffM	0.60
		pJeff/ePine	0.46
		gravel/pJeff/dHeath	0.45
		gravel/BP/pJeff/pEang	0.39
		gravel/pJeffM	0.35
		Gravel/pJeff/oPine	0.34
		oPine	0.32
		BP/pJeff/oPine	0.27
		pJeff/pEang/pRos	0.26

		pJeffM/pEang	0.24
		pJeff/dHeath	0.24
		pJeffM/ePine	0.23
		pJeff/pJeffM	0.20
		pJeffG/dHeath/oPine	0.20
		BP/pCamp/pJeff	0.19
		Gravel/dHeath/BP/pJeff	0.16
		pJeffM/eWill	0.14
		pJeffG/oPine	0.13
		pJeffM/oWill	0.13
		pJeffM/pEq	0.10
		pRos	0.08
		oWill	0.07
		Gravel/fossiltimber/pJeff/pEang/BP	0.06
		pJeffG/ePine	0.05
		pJeff/pCamp	0.03
		pJeff/pEang/eWill	0.02
		ePine	0.02
		eWill	0.00
		pJeff/pTyph	0.00
Total			41.23

The most common types of the Bord na Móna *J. effusus* dominant pioneer community are (a) BP/pJeff (a high cover of bare peat with *J. effusus* colonising) followed by (b) more established tussocks of *J. effusus* and (c) *J. effusus* stands with a developing bryophyte layer (pJeff/M).

Those Bord na Móna Habitats (9 in total) that are not yet dominated by *J. effusus* comprise patches within pioneer *J. effusus* areas where *J. effusus* is only beginning to colonise. For example the Bord na Móna habitat, gravel/BP/pJeff/pEang describes a habitat where gravel and bare peat are dominant with *J. effusus* (pJeff) and *Eriophorum angustifolium* (pEang) beginning to colonise.

In total the habitats of this community cover 41% of the site. It is a significant component of the site and can be considered as the most widespread habitat in 2011. This plant community did not occupy more than 7% of the site in 2001.

4.3.2 *Juncus bulbosus* pioneer community

Farrell (2001) classified this pioneer vegetation type – '*Juncus bulbosus* pioneer community' and reported that it was found in cutaway bog areas where the peat is permanently water logged.

The Bord na Móna Habitat Scheme outlines 3 habitat types that correspond to this community which is essentially a pioneer stage of poor fen habitat. The habitat is largely characterised by the presence of *J. bulbosus*, which forms the main vegetation component. This habitat is never dominated by a pure sward of *J. bulbosus*, instead it forms an open habitat in water logged areas. Both the Farrell (2001) description and the Bord na Móna Habitat Scheme aligns with Fossit (2000) – PF2 – Poor fen and flush habitat essentially being a rudimentary form of poor fen vegetation.

Figure 4.6* Juncus bulbosus *pioneer community

This vegetation community is located within depressions in the cutaway that are permanently water logged. The plants are generally low growing (20cm) and *J. bulbosus* is often the only species present but may be accompanied by patchy, emerging growth of *J. effusus* and *E. angustifolium*. Bryophytes such as *Campylopus introflexus* and *Polytrichum commune* may be present along the drier edges of these areas while *Sphagnum* species may also be present in small amounts in the open water.

Table 4.3 lists all of the Bord na Móna habitats that are included in this vegetation community and illustrates the relationship with the habitats described by Farrell (2001) as part of this study and how they relate to the poor fen and flush (PF2) habitat (Heritage Council classification system). The most common habitat type is shown in bold.

Table 4.3 *Juncus bulbosus* pioneer community

Heritage Council Classification - Fossit (2000)	Vegetation type (Farrell 2001)	Bord na Móna Habitat Scheme - Habitat Type 2011	% of site in 2011
PF2 Poor fen and flush	*Juncus bulbosus* pioneer community	BP/pJbulb	**0.06**
		pJbulb	0.01
		BP/Equ	0.00
	Total		0.07

The most common Bord na Móna habitat recorded in 2011 that aligns with this community is BP/pJbulb. In this habitat *J. bulbosus* forms a patchy cover in water filled depressions. The habitat pJbulb has higher cover of *J. bulbosus* than the latter habitat BP/Equ which describes vegetation where the main component was bare peat (BP) along with *Equisetum* spp. (Equ), with less cover of *J. bulbosus*. Both the BP/pJbulb and BP/Equ habitat types are rudimentary types of the pJbulb pioneer community.

This community is encountered throughout the Bellacorick site but is of low overall cover. It covered less than 1% of the site in 2011 and is encountered where shallow, permanently waterlogged depressions occur between established *J. effusus* dominant areas. It is likely that this community never represented a significant component of Bellacorick as it is confined to small pools within larger swards of pioneer poor fen habitat.

4.3.3 *Eriophorum angustifolium* pioneer community

Farrell (2001) classified this pioneer community – '*Eriophorum angustifolium* pioneer community' and reported that it was found in cutaway areas of water-logged peat, typically in locations where the peat remains wet for much of the year. The emergent plants establish on bare peat, spreading out from a central core of parent plants in a clonal fashion, developing larger patches over time (see Figure 4.3).

The Bord na Móna Habitat Scheme outlines 10 habitat types that correspond to this community which is essentially a pioneer stage of poor fen habitat. The habitat is largely characterised by the presence of *E. angustifolium*, which forms the main vegetation component. Those 10 habitat types where *E. angustifolium* is dominant align with the Farrell (2001) description due to the fact that the main vegetation component is comprised of patchy to open cover of *E. angustifolium.* Both the Farrell (2001) and the Bord na Móna Habitat Scheme fit in with Fossit (2000) – PF2 – Poor fen and flush where the dominant vegetation type comprises *E. angustifolium.*

Figure 4.7 **Eriophorum angustifolium** ***pioneer community***

Figure 4.7 illustrates a typical area of pEang/BP (pioneer *Eriophorum angustifolium* with patches of bare peat) at the Bellacorick site. This area typically consists of *E. angustifolium* plants at a height of 30cm with areas of bare peat between areas of open water. A bryophyte layer may be present, comprised of *C. introflexus* and *P. commune* along with low cover of *Sphagnum* spp. The rush *J. effusus* is commonly present (in patchy form) but never dominant. Shallow water is also present commonly amongst this habitat type and deep peat (>40cm) is a feature of areas where this vegetation community occurs.

Table 4.4 lists all of the Bord na Móna habitats that are included in this vegetation community and illustrates the relationship with the habitats described by Farrell (2001) as part of this study and how they relate to the PB bogs (PB) habitat (Heritage Council classification system). The most common habitat types are shown in bold.

Table 4.4 *Eriophorum angustifolium* pioneer community

Heritage Council Classification - Fossit (2000	Vegetation type (Farrell 2001)	Bord na Móna Habitat Scheme - Habitat Type 2011	% of site in 2011
PB Bogs	*Eriophorum angustifolium* pioneer community	BP/pEang	**1.34**
		pEang/pJeff/oPine	**0.51**
		pEang	**0.41**
		BP/pCamp/pEang	0.20
		pEangS	0.13
		pEang/pJeff/pRos	0.10
		pEang/pRos	0.09
		Gravel/BP/pEang	0.03
		BP/pEang/pTrig	0.02
		BP/gMol/pEangM	0.02
	Total		2.85

The most common of the Bord na Móna habitats of this vegetation community is the BP/pEang (bare peat with emerging *E. angustifolium*). The group of Bord na Móna habitats, where pEang is the first word, belong to pioneer habitats where *E. angustifolium* is dominant. For example the Bord na Móna habitat-type pEang/pJeff/pRos, is dominated by *E. angustifolium* but also includes *Juncus effusus* (pJeff) and *Carex rostrata*. For pEang/pJeff/oPine, *E. angustifolium* is the dominant plant species but there is also a cover of *Juncus effusus* (<50%) and *Pinus contorta* saplings are occasional.

The Bord na Móna habitats that do not begin with pEang belong to habitats where *E. angustifolium* is a variant within the species composition and is establishing within it. For example the Bord na Móna habitat, BP/pEang/pTrig describes a habitat variation where bare peat is dominant along with *E. angustifolium* with the grass *Triglochin palustre* (pTrig) emerging.

This is not a common habitat across the Bellacorick site and overall it occupied approximately 3% of the site in 2011. This habitat represents a pioneer phase similar to the *J. effusus* and *J. bulbosus* pioneer communities and it would be expected at this stage that the *E. angustifolium* pioneer community will occupy less and less of the site into the future as it gives way to more diverse vegetation communities. Where *E. angustifolium* is established, depending on levels of wetness it may develop a ground layer of bryophytes, dominated by *Sphagnum* spp. That in turn, creates peat forming (embryonic bog) conditions.

4.3.4 Sphagneto-Juncetum effusi community

Farrell (2001) described this habitat – 'Sphagneto-Juncetum effusi vegetation community' and stated that it was the most extensive vegetation community establishing on the cutaway bog at the Bellacorick site in 2001. Character species of this habitat are *J. effusus* and *Sphagnum cuspidatum*. O'Críodáin (1988) describes the conditions that favour Sphagneto-Juncetum effusi development as an area with a shallow peat layer with a fluctuating water table.

The Bord na Móna Habitat Scheme outlines 14 habitat types that correspond to this community which is essentially a pioneer stage of poor fen habitat. The habitat is largely characterised by the presence of *J. effusus* and *S. cuspidatum*, which forms the main vegetation component. Those 14 types where *J. effusus and S. cuspidatum* are dominant align with the Farrell (2001) description due to the fact that the main vegetation component is comprised of patchy to open cover of *J. effusus* and *S. cuspidatum* usually in ares where permanent water logging occurs.

Both the Farrell (2001) and Bord na Móna Habitat Scheme aligns with Fossit (2000) – PF2 – poor fen and flush where the dominant vegetation type comprises *J. effusus* and *Sphagnum*.

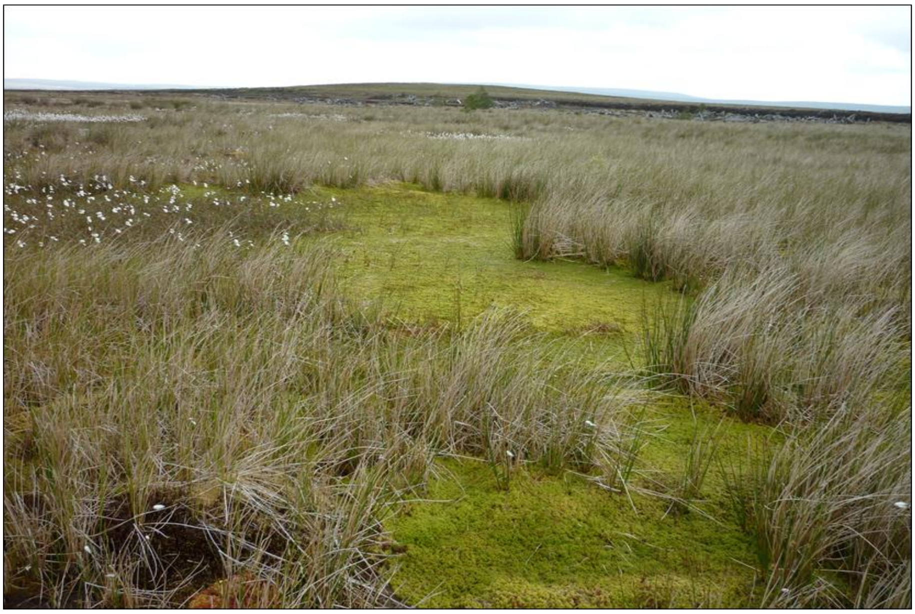


Figure 4.8 Sphagneto-Juncetum effusi community at Bellacorick

Figure 4.8 shows an example of this vegetation community. The bright green vegetation at the centre of the site is dominated by *Sphagnum cuspidatum* and the *J. effusus* is also clearly visible in tussock form.

Table 4.5 lists the Bord na Móna habitat types that are present within this vegetation community. Table 4.5 lists all of the Bord na Móna habitats that are included in this vegetation community and illustrates the relationship with the habitats described by Farrell (2001) as part of this study and how they relate to the poor fen and flush (PF2) habitat (Heritage Council classification system). The most common habitat types are shown in bold.

Table 4.5 Sphagneto-Juncetum effusi community

Heritage Council Classification - Fossit (2000	Vegetation type (Farrell 2001)	Bord na Móna Habitat Scheme - Habitat Type 2011	% of site in 2011
PF2 Poor fen and flush	Sphagneto-Juncetum effusi	pJeffS	**2.68**
		pJeffS/ePine	**1.80**
		pJeffS/pEangS	**0.51**
		pJeffS/oPine	0.45
		OW/pJeffS	0.20
		pJeffMS	0.19
		pJeffM/pJeffS	0.07
		pJeff/oPine/eWill/S	0.07
		BP/pJeff/pEang/S	0.07
		BP/pJeffS	0.06
		Gravel/pJeff/oPine/M/S	0.05
		Sphagnum (S)	0.03
		OW/pTyph/S	0.01
		pJeffm/OW/pEangS	0.00
	Total		6.21

The most common habitat encountered during the 2011 survey was pJeffS or pioneer *Juncus effusus* (*Sphagnum*-rich). All of the habitat types contain *Sphagnum* while 12 of the habitats contain *J. effusus*. The habitats that do not include *J. effusus* are *Sphagnum* (S) and OW/pTyph/S, these habitats are too wet for *J. effusus* to develop. The *J. effusus* is usually lower growing than it may be in other vegetation communities (< 70cm) and the *Sphagnum* species become more dominant while the *J. effusus* becomes sparser. These areas are generally water logged although they may not appear to be so on first encountering it, as the *Sphagnum* species form a floating raft on the water. Other species encountered within this vegetation community include the sedge *E. angustifolium*, mosses *C. introflexus*, *P. commune* and *Aulacomnium palustre*. Those *Sphagnum* species present include *S. fallax*, *S. cuspidatum*, *S. subnitens* and *S. squarrosum*.

This habitat covered approximately approximately 6% of the site in 2011. In 2001 this habitat covered less than 5% of the site. It is expected that this vegetation community will increase across the site in the future as areas of pioneer *J. effusus* develop into more species rich habitats.

4.3.5 *Sphagnum cuspidatum-Eriophorum angustifolium* community

Farrell (2001) described this community – '*Sphagnum cuspidatum-Eriophorum angustifolium* vegetation community' and reported that it was found on water logged peat where the water table remained close to the surface for most of the year. Character species of this vegetation community include *E. angustifolium* and *S. cuspidatum*. Farrell (2001) described the stands of *E. angustifolium* as being dense (up to 100%) with a well-developed bryophyte layer consisting of mostly *S. cuspidatum*. The rush *J. effusus* was also present and comprised no more than 10% of the vegetation.

Two of the Bord na Móna habitats can be aligned with this community. The habitat is largely characterised by the presence of *S. cuspidatum and E. angustifolium,* which form the main vegetation components (after open water).

The Bord na Móna habitats align with both the vegetation communities described by Farrell (2001) and Fossit (2000) – PB Bogs where the dominant vegetation type comprises *S. cuspidatum* and *E. angustifolium.*

Figure 4.9* Sphagnum cuspidatum-Eriophorum angustifolium *community

Table 4.6 lists all of the Bord na Móna habitats that are included in this vegetation community and illustrates the relationship with the habitats described by Farrell (2001) as part of this study and how they relate to the bogs (PB) habitat (Heritage Council classification system). The most common habitat type is shown in bold.

Table 4.6 Sphagnum cuspidatum-Eriophorum angustifolium community

Heritage Council Classification - Fossit (2000	Vegetation type (Farrell 2001)	Bord na Móna Habitat Scheme - Habitat Type 2011	% of site in 2011
PB Bogs	*Sphagnum cuspidatum-Eriophorum angustifolium* community	OW/pEangS	<0.01
		OW/pEangS/pJeffS	**0.14**
	Total		0.15

The development of this vegetation type favours shallow water-logging on deep peat and these areas may also have a quaking feel to them. This vegetation community may be dominated by *S. cuspidatum* in places, while *E. angustifolium, J. effusus* and *J. bulbosus* may also be present at low cover. Vegetation height is generally low (<30cm) and peat depths recorded within this vegetation type exceeded 50cm indicating that this habitat type favours deeper peat compared to other vegetation types that occur on shallower peat depths. The *Sphagnum* species may not always include *Sphagnum cuspidatum* but would include other *Sphagnum* species, primarily *Sphagnum fallax* and to a lesser extent *S. subnitens*. Other bryophyte species present include *P. commune*. These habitats were found associated with areas of shallow open water during the survey in 2011.

This habitat occupied less than 1% of the site in 2011. In 2001 Farrell (2001) reported that it occupied a small proportion of the Bellacorick site (<0.1%).

4.3.6 *Juncus bulbosus-Sphagnum cuspidatum* pools

Farrell (2001) classified this community – '*Juncus bulbosus-Sphagnum cuspidatum* pools community' and reported that it was found where the cutaway was permanently flooded all year round with the main species comprised *J. bulbosus* and *S. cuspidatum,* Farrell (2001).

The Bord na Móna Habitat Scheme outlines 5 habitat types that correspond to this community which is essentially a pioneer stage of poor fen habitat. The habitat contains open water and is largely characterised by the presence of *J. bulbosus,* which forms the main vegetation component. Those 5 types with *J. bulbosus* dominant align with the Farrell (2001) description due to the fact that the main vegetation component is comprised of *J. bulbosus* in open water. *J. effusus* also features in this habitat as tussocks amongst the open water while other habitats contain exposed gravel and bare peat. This habitat represents the next stage in sucession from the pioneer *J. bulbosus* habitat (Section 4.3.4).

Figure 4.10 **Juncus bulbosus-Sphagnum cuspidatum** ***pools***

The five Bord na Móna habitats contain open water and are characterised by the presence of *J. bulbosus* and *S. cuspidatum*.

Table 4.7 lists the Bord na Móna habitat types that are present within this vegetation community. Table 4.7 lists all of the Bord na Móna habitats that are included in this vegetation community and illustrates the relationship with the habitats described by Farrell (2001) as part of this study and how they relate to the poor fen and flush (PF2) habitat (Heritage Council classification system). The most common habitat type is shown in bold.

Table 4.7 *Juncus bulbosus*-*Sphagnum cuspidatum* pools

Heritage Council Classification - Fossit (2000	Vegetation type (Farrell 2001)	Bord na Móna Habitat Scheme - Habitat Type 2011	% of site in 2011
PF2 Poor fen and flush	*Juncus bulbosus-Sphagnum cuspidatum* pools	OW/S	**0.21**
		OW/BP/pJeff	0.03
		OW/pJeff/pBulb	0.02
		OW/pJeffM	0.02
		OW/Gravel/BP/M	0.02
Total			0.31

The most common Bord na Móna habitat type that occurred during the 2011 survey was the OW/S (open water with *Sphagnum*-rich cover) habitat type where open water is dominated with *S. cuspidatum* and *J. bulbosus* cover is sparse.

This vegetation community is located in shallow depressions where shallow flooding occurs. The *J. bulbosus* is never dense but grows as a floating raft and is scattered throughout the habitat. The cover of *S. cuspidatum* can vary from 100% cover to 50% cover. Vegetation height is relatively low (<30cm) and water depth varies from 5cm to 50cm. This vegetation community favours small, sheltered areas of open water. Other species may also be present such as *J. effusus*, but these other species are generally present at low cover values.

This vegetation community is not extensive across the site and occupied less than 1% of the Bellacorick site in 2011. Farrell (2001) recorded a similar extent at the

Bellacorick site. It may be possible for this vegetation community to expand its range where suitable conditions occur. However it is unlikely to ever become one of the dominant vegetation communities across the Bellacorick site as shallow areas of open water are limited in their range across the site.

4.3.7 Calluno-Ericetum community

Farrell (2001) classified this community – 'Calluno-Ericetum pioneer vegetation community' and reported that it was found in isolated patches throughout the cutaway, typically where the peat was shallow and well drained. This vegetation is also found in well drained peat alongside streams in intact Atlantic blanket bog (Farrell, 2001; Doyle, 1990).

The Bord na Móna Habitat Scheme outlines 10 habitat types that correspond to this community which is essentially a pioneer stage of dry heath habitat. The habitat is largely characterised by the presence of *Calluna vulgaris* which forms the main vegetation component (dHeath and DH). Those 10 habitat types with *C. vulgaris* dominant align with the Farrell (2001) description due to the fact that the main vegetation component is comprised of patchy to open cover of *C. vulgaris.*

Both the Farrell (2001) description and Bord na Móna habitats are aligned with Fossit (2000) – HH1 – Dry siliceous heath.

Figure 4.11 Calluno-Ericetum community

This pioneer habitat was often found with other pioneer species such as *J. effusus* and *Molinia caerulea* with some bare peat often present. This pioneer habitat sometimes, developed in areas where fossil timber had been deposited, the timbers provided shelter for the *C. vulgaris* to develop. *Pinus contorta* saplings are common in these areas as a result of this tree species favouring these drier areas of cutaway. The species *Pinus contorta* readily colonises the cutaway from the adjacent plantations.

Table 4.8 lists all of the Bord na Móna habitats that are included in this vegetation community and illustrates the relationship with the habitats described by Farrell (2001) as part of this study and how they relate to the dry siliceous heath (HH1) habitat (Heritage Council classification system). The most common habitat types are shown in bold.

Table 4.8 Calluno-Ericetum community

Heritage Council Classification - Fossit (2000	Vegetation type (Farrell 2001)	Bord na Móna Habitat Scheme - Habitat Type 2011	% of site in 2011
HH1Dry siliceous heath	Calluno-Ericetum	BP/dHeath/pEang	**0.56**
		dHeath	**0.29**
		dHeath/pJeff/pEang	**0.27**
		BP/dHeath/pJeff	0.23
		dHeath/gMol	0.16
		dHeath/Sphagnum/pEang	0.08
		DH/oPine	0.07
		dHeath/pJeffM	0.06
		BP/dHeath/pJeffM	0.03
		DH/ePine	0.02
Total			1.78

The three most common Bord na Móna habitat types were all dominated by *C. vulgaris* along with *J. effusus* and *E. angustifolium*, as follows (a) the habitat type BP/dheath/pEang is dominated with bare peat that is being colonised by *C. vulgaris* with some *E. angustifolium*; (b) the habitat type dHeath is dominated by *C. vulgaris* alone while (c) the habitat type dheath/pJeff/pEang is dominated by *C. vulgaris* but also contains lesser ammounts of *J. effusus* and *E. angustifolium*.

This habitat accounted for approximately 2% of the site in 2011. It is expected that this habitat will increase its range on the site in the future as it is colonising areas that are exposed such as those on slopes where the spread of vegetation is not as rapid as the wetter sections of the site. Farrell (2001) found that this habitat did not occupy more than 1% of the site in 2001.

4.3.8 Caricetum paniculatae community

Farrell (2001) classified this community – 'Caricetum paniculatae vegetation community' and reported that it was sporadically located at Bellacorick where it had established on areas of flushed cutaway peat.

The Bord na Móna Habitat Scheme outlines 1 habitat type that corresponds to this community which is essentially a pioneer stage of reed and large sedge swamps. The habitat is characterised by the presence of *Carex rostrata* which forms the main vegetation component. This habitat type with *C. rostrata* dominant aligns with the Farrell (2001) description due to the fact that the main vegetation component is comprised of *C. rostrata* with patches of *Carex paniculata.*

Both the Farrell (2001) description and Bord na Móna habitat types align with Fossit (2000) – FS1 – reed and large sedge swamps. In 2011 the community was found only in drainage ditches and its presence was confined to very patchy distribution.

Figure 4.12 Small area of* Carex rostrata *that has developed in an old drainage channel

Table 4.9 lists all of the Bord na Móna habitats that are included in this vegetation community and illustrates the relationship with the habitats described by Farrell (2001) as part of this study and how they relate to reed and large sedge swamps (FS1) habitat (Heritage Council classification system).

Table 4.9 Caricetum paniculatae community

Heritage Council Classification - Fossit (2000)	Vegetation type (Farrell 2001)	Bord na Móna Habitat Scheme - Habitat Type 2011	% of site in 2011
FS1 Reed and large sedge swamps	Caricetum paniculatae	pRosPan	<0.01
Total			<0.01

This habitat type was confined to drainage ditches on the site in 2011. *C. rostrata* was the most dominant with patches of *E. angustifolium* and some prominent patches of *C. paniculata*

Within the Bord na Móna Habitat Scheme, one habitat type was recorded, pRosPan. This vegetation community occupied less than 0.01% of the Bellacorick site in 2011 and is not a significant feature of the vegetation, nor is it likely to be in the future.

4.3.9 Typhetum paniculatae community

Farrell (2001) classified this vegetation – 'Typhetum paniculatae pioneer vegetation community' and reported that it was found on parts of the cutaway where fen peat had been exposed and was flooded throughout the year. Stands of *Typha latifolia* occurred in depressions across the cutaway although Farrell (2001) stated that these stands were infrequent.

The Bord na Móna Habitat Scheme outlines 5 habitat types that correspond to this community which is essentially a pioneer form of a combination of (FS1) reed and large sedge swamps (PF2), poor fen and flush and (FW4) drainage ditches. The habitat is largely characterised by the presence of *Typha latifolia* which forms the main vegetation component (pTyph). Open water features in 3 of these habitat types and 1 habitat type is dominated solely by *Phragmites australis* (pPhrag).

Both the Farrell (2001) description and the Bord na Móna habitat scheme align with a number of Fossit (2000) habitats including – reed and large sedge swamps (FS1), poor fen and flush (PF2) and drainage ditches (FW4).

Figure 4.13 Stand of* Typha latifolia *that developed in an old drainage ditch

Table 4.10 lists all of the Bord na Móna habitats that are included in this vegetation community and illustrates the relationship with the habitats described by Farrell (2001) as part of this study and how they relate to the reed and large sedge swamps (FS1), poor fen and flush (PF2) and drainage ditches (FW4) habitats (Heritage Council classification system). The most common habitat types are shown in bold.

Table 4.10 Typhetum paniculatae community

Heritage Council Classification - Fossit (2000)	Vegetation type (Farrell 2001)	Bord na Móna Habitat Scheme - Habitat Type 2011	% of site in 2011
FS1 Reed and large sedge swamps PF2 Poor fen and flush, FW4 Drainage ditches	Typhetum paniculatae	OW	**1.23**
		pTyph	0.06
		OW/pTyp/pRos	0.04
		OW/pTyph	0.01
		pPhrag	0.00
Total			1.35

Within the Bord na Móna Habitat Scheme, five habitat types were recorded, all of which are characterised by the presence of open water and *Typha latifolia*. Open water and temporary open water are included in this vegetation type due to the fact that these pioneer habitats generally were bordered by pioneer *Typha latifolia* (pTyp). This habitat was often found with other pioneer species such as *Juncus effusus* and *Carex rostrata* while open water was always present even if only in small amounts.

This habitat occupied less than 2% of the site in 2011 and occupied less than 1% of the site in 2001. It will never be widespread and it is confined to pockets of fen peat in depressions. It is interesting to note that this habitat is very common on midlands cutaway bogs.

4.3.10 Tussilaginetum community

Farrell (2001) classified this vegetation – 'Tussilaginetum pioneer vegetation community' and reported that it was establishing on drain-edges where the underlying glacial till has been turned up to deepen drains. The Tussilaginetum vegetation community was diverse and consisted of perennial herbs that are characteristic of disturbed habitats and wet grassland communities. Farrell (2001) reported that the substrate in these areas was made up of glacial till which had been compacted by machinery and typically had a pH of 5.0.

The Bord na Móna Habitat Scheme outlines 2 habitat types that correspond to this community. The habitat is largely characterised by the presence of *Tussilago farfara* which forms the main vegetation component (DisTuss) along with some other herbs and grass species. Both the Farrell (2001) description and the Bord na Móna Habitat Scheme aligns with a number of Fossit (2000) habitats including – BL3 – Buildings and artificial surfaces, ED2 – Spoil and bare ground, ED3 – Re-colonizing bare ground and ED1 – Exposed sand, gravel or till.

Figure 4.14 Patch of* Tussilago farfara *growing along an old access road

Table 4.11 lists all of the Bord na Móna habitats that are included in this vegetation community and illustrates the relationship with the habitats described by Farrell (2001) as part of this study and how they relate to the BL3 – Buildings and artificial surfaces, ED2 – Spoil and bare ground, ED3 – Re-colonizing bare ground and ED1 – Exposed sand, gravel or till habitats (Heritage Council classification system).

Table 4.11 Tussilaginetum community

Heritage Council Classification - Fossit (2000)	Vegetation type (Farrell 2001)	Bord na Móna Habitat Scheme - Habitat Type 2011	% of site in 2011
ED1 Exposed sand, gravel or till	Tussilaginetum	gravel/gMol	0.01
ED2 Spoil and bare ground		DisTuss	0.01
BL3 Buildings and artifical surfaces			
ED3 Recolonising bare ground			
Total			<0.01

Within the Bord na Móna Habitat Scheme, two habitats were recorded, both of which are characterised by *Tussilago farfara* and other species that readily colonise disturbed ground. This habitat type is located on disturbed areas where machinery use was frequent, such as along roadsides, works areas and drainage channels where excavations had been deep enough to expose the underlying sub soil. The dominant species in general is the herb, *Tussilago farfara*. Other plant species included in this vegetation type include *Agrostis stolonifera* and *Molinia caerulea*. A bryophyte layer is generally absent.

This habitat type occupied <0.01% of the site in 2011. It is likely that this habitat type will decline in the future as other plant species colonise these areas.

4.3.11 Centaureo-Cynosuretum community

Farrell (2001) classified this vegetation– 'Centaureo-Cynosuretum pioneer vegetation community' and reported that it was establishing within areas that have been modified in the past in conjunction with peat extraction in Bellacorick, such as railway embankments and roads. Farrell (2001) reported that the vegetation included *Cynosurus cristatus, Bellis perennis, Trifolium repens* and *Senecio jacobaea*.

The Bord na Móna Habitat Scheme outlines 6 habitat types that correspond to this community. Both the Farrell (2001) and Bord na Móna Habitat Scheme align with a number of Fossit (2000) habitats including – GS4 – wet grassland and GS3 – dry humid acid grassland.

Figure 4.15 Centaureo-Cynosuretum community growing along an old railway embankment

Table 4.12 lists all of the Bord na Móna habitats that are included in this vegetation community and illustrates the relationship with the habitats described by Farrell

(2001) as part of this study and how they relate to the (GS4) wet grassland and (GS3) dry humid acid grassland habitat (Heritage Council classification system).

Table 4.12 Centaureo-Cynosuretum community

Heritage Council Classification - Fossit (2000)	Vegetation type (Farrell 2001)	Bord na Móna Habitat Scheme - Habitat Type 2011	% of site in 2011
GS4 Wet grassland	Centaureo-Cynosuretum	gMol	**0.21**
GS3 Dry humid acid grassland		GS4/oPine	0.19
		gMol/oPine/pEqu	0.02
		gMol-Arr	0.01
		gMol/oWill	0.01
		BP/gMol	<0.01
Total			0.44

Within the Bord na Móna Habitat Scheme, two habitat types were recorded located, both of which are characterised by the presence of grass species. The Bord na Móna Habitat Scheme aligns with the Farrell (2001) description due to the fact that the main vegetation component is comprised of *Cynosurus cristatus*, *Bellis perennis*, *Molinia coerulea*, *Senecio jacobaea*, *Cirsium arvense* and *Holcus lanatus*, the bryophyte *Campylopus introflexus* may also be present. This vegetation community is located along roads and areas where the remaining peat is dry for the majority of the year. Grazing animals were often present in these areas. Seedlings of *Pinus contorta* were often present as this species readily colonises these drier areas from the adjacent plantations. This habitat is dry and dominated by grass species.

This habitat occupied less than 1% of the site in 2011, and similarly occupied less than 1% of the Bellacorick site in 2001. It is not a significant feature but it is a relatively diverse habitat. It may become dominated by *Pinus contorta* and *Salix* spp. if grazing ceases.

4.4 Vegetation monitoring –permanent quadrats

As outlined in Chapter 2, a number of permanent quadrats were set up to provide a representative sample of the different habitats across the Bellacorick site. Figure 4.16

shows the location of each of the permanent quadrats in the relative habitat types, GPS points for each quadrat are included in Appendix III.

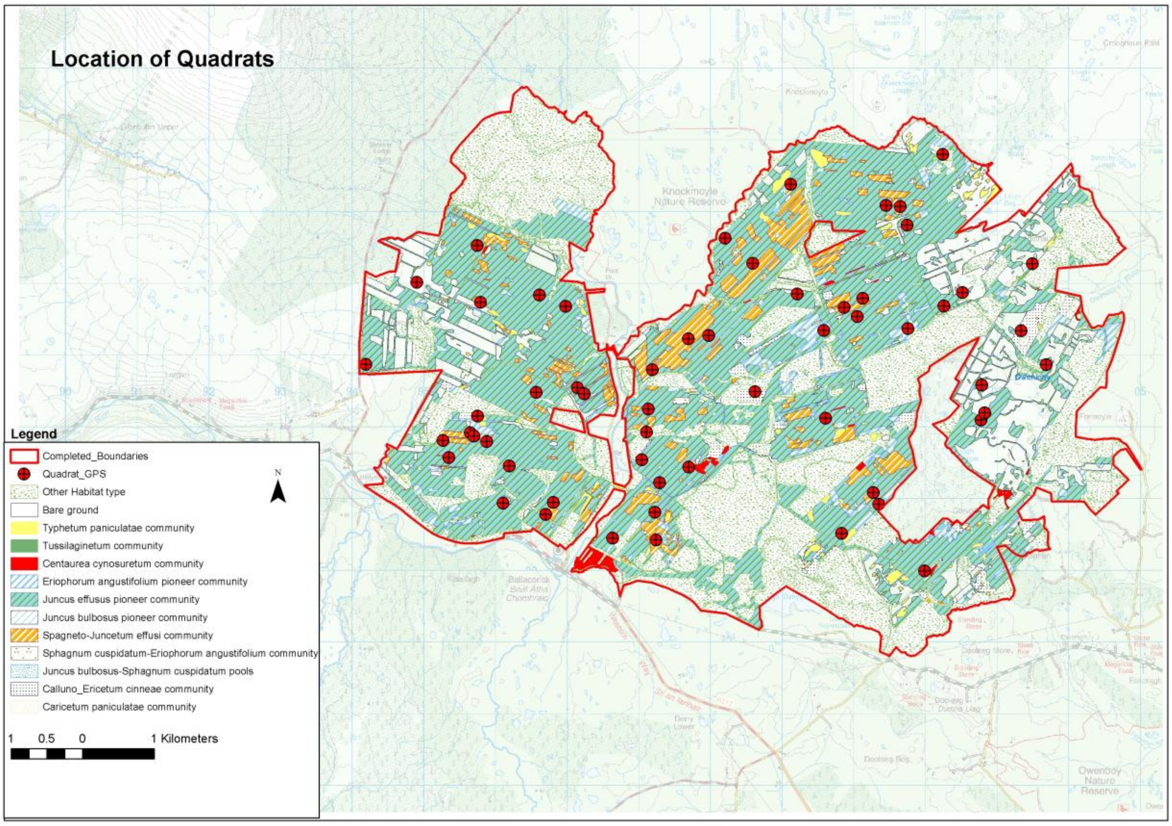


Figure 4.16 Habitat map with location of all 57 permanent quadrats

A total of 59 species were recorded from 57 quadrats across the site (Table 4.13). Of the species recorded, 36 were vascular plants, 1 species of algae, 18 species of moss, 1 lichen species and 1 species of liverwort. This list of species represents the vegetation within the permanent quadrats and is not the entire list of vegetation for the Bellacorick site.

4.5 Cluster analysis

A dendrogram was produced using the PC Ord (Figure 4.17). Percentage chaining obtained for this test was 2.22. This percentage of chaining is considered to be acceptable as lower percentages of chaining are desirable. McCune and Grace (2002) outline that extreme chaining should be avoided and percentages greater than 25% should not be used.

Indicator species analysis was carried out to determine objectively where to prune the cluster analysis dendrogram. The cluster step giving the smallest average p value and highest number of significant indicator speies (Table 4.13) was taken as the most appropriate level to prune a dendrogram (McCune and Grace 2002).

Table 4.13 Indicator species P-values for cluster analysis groupings

Cluster Analysis Group	Average P value	Number of significant indicators
CA2	0.5267	2
CA3	0.4785	4
CA4	0.4709	2
CA5	0.4671	4
CA6	0.4882	5
CA7	**0.3926**	**5**

Table 4.13 shows the average P values and the number of significant indicators in each cluster analysis grouping. CA7 was selected as the most favourable as it had the lowest P value and the greatest number of significant indicators present.

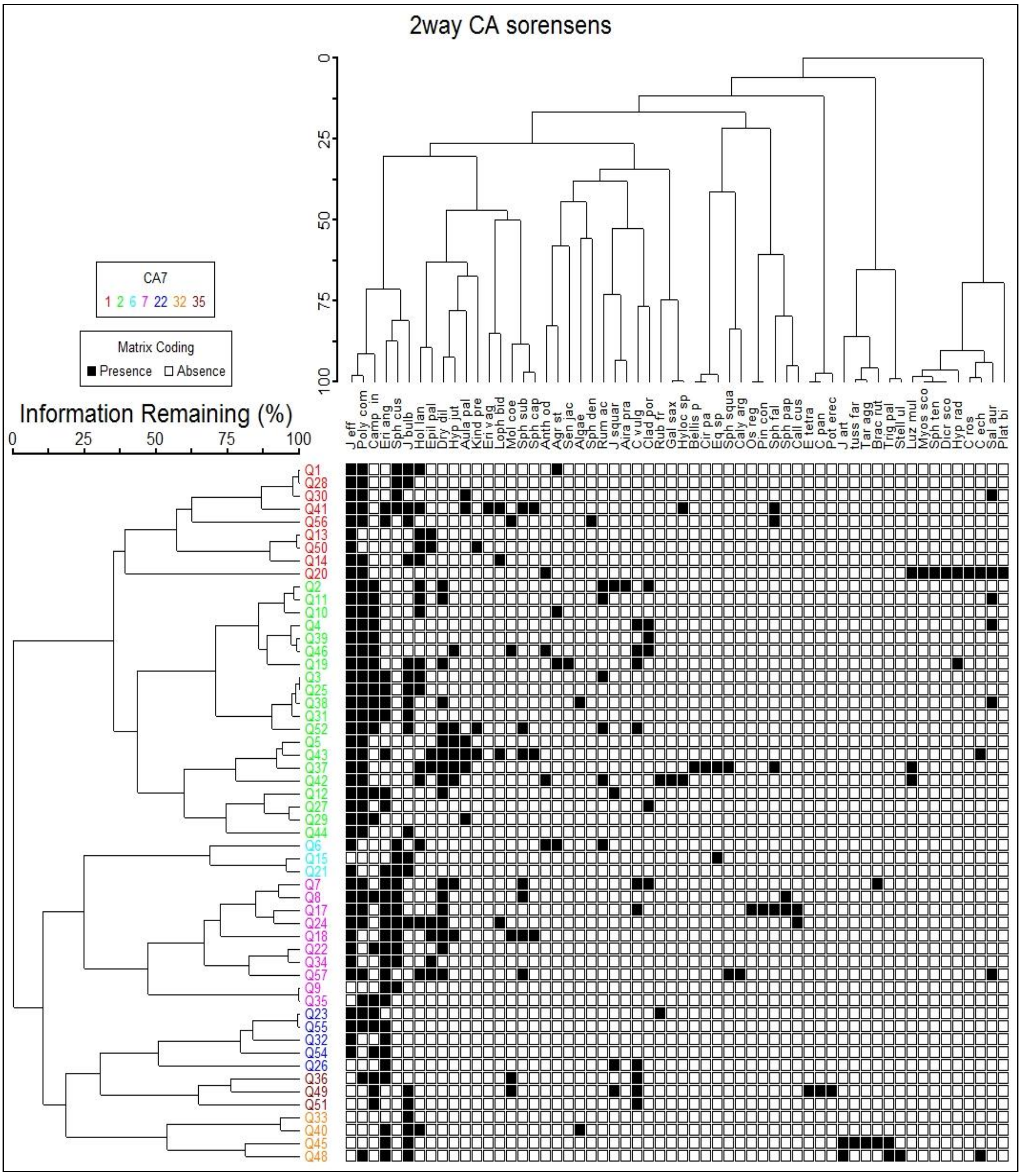


Figure 4.17 2 way cluster analysis Dendrogram

The synoptic table (Table 4.14) provides a summary of the information contained in the cluster analysis dendrogram (Figure 4.17), and shows the vegetation composition of the 7 vegetation communities distinguished using the cluster anlaysis. Cluster analysis catogerised these communities as numbered 1, 2, 6, 7, 22, 32 and 35, however for ease of interpretation these are numbered 1 to 7 respectively for the remainder of the thesis. These can be compared with the vegetation communities described by Farrell, 2001 (Table 4.15).

Table 4.14 Synoptic data for the species which are present in the CA habitats. (Roman numerals I to V were used to express the frequency with I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81=100%, and abundance values using Domin scale are indicated in brackets). Species order follows that of the two way cluster analysis dendrogram (Figure 4.17).

Community number (CA)	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Number of quadrats in each	**9**	**20**	**3**	**10**	**5**	**3**	**4**
Juncus effusus	**IV** (9-10)	**IV** (9-10)	**III** (7-8)	**IV** (9-10)	**IV** (9-10)		
Polytrichum commune	**IV** (9-10)	**IV** (9-10)		**III** (7-8)	**III** (7-8)	**II** (6)	**I** (4)
Campylopus introflexus		**III** (7-8)		**II** (5-6)	**III** (8)	**IV** (9-10)	
Eriophorum angustifolium	**III** (7-8)	**III** (7-8)	**II** (5-6)	**IV** (9-10)	**III** (8)	**II** (5-6)	**I** (4)
Sphagnum cuspidatum	**III** (7-8)		**IV** (9-10)	**IV**(9-10)			
Juncus bulbosus	**III** (7-8)	**III** (7-8)	**III** (7-8)	**I** (4)		**III** (7-8)	**IV** (9-10)
Calluna vulgaris		**II** (5-6)		**II** (5-6)	**II** (5-6)	**IV** (9-10)	
Erica tetralix						**II** (5-6)	
Carex panicea						**II** (5-6)	
Holcus lanatus	**III** (7-8)	**III** (7-8)	**II** (5-6)	**II** (5-6)		**III** (7-8)	**II** (5-6)
Epilobium palustre	**II** (5-6)	**IV** (9-10)		**II** (7-8)			
Dryopteris dilatata		**II** (7-8)		**III** (7-8)			
Hypnum jutlandicum		**II** (5-6)		**II** (5-6)			
Aulacomnium palustre	**I** (4)	**I** (5-6)					
Kindbergia prelonga	**I** (4)	**II** (5-6)					
Eriophorum vaginatum	**II**(5-6)						
Lophocolea bidentata	**I**(4)	**I** (4)		**I** (4)			
Molinia coerulea	**I** (4)	**I** (4)	**II**(5-6)			**III** (7-8)	
Sphagnum subnitens	**II** (5-6)	**II** (5-6)		**III** (7-8)			
Sphagnum capilifolium	**I** (4)	**I** (4)		**I** (4)			
Anthoxanthum oderatum	**II** (5-6)	**I** (4)	**II** (5-6)				
Agrostis stolonifera	**I** (4)	**II** (5-6)		**II** (5-6)			
Senaco jacoba	**I** (4)						
Algae		**I** (4)					**I**(4)

Sphagnum denticulatum	**I** (4)						
Rumex acetosella		**II** (5-6)	**II** (5-6)				
Juncus squarrosus		**I** (4)			**II** (5-6)	**II** (5-6)	
Aira praecox		**I** (4)					
Cladonia portentosa		**II** (5-6)		**I** (4)			
Rubus fruticosus agg.		**I** (4)			**I** (4)		
Galium saxatile		**II** (5-6)					
Hylocomme splendens	**I** (4)	**I** (4)					
Bellis perennis		**I** (4)					
Cirsium paustre		**I** (4)					
Equisetum spp.		**I** (4)					
Sphagnum squarrosum		**I** (4)		**I** (4)			
Calypogenia arguta				**I** (4)			
Osmunda regalis				**I** (4)			
Pinus contorta				**I** (4)			
Sphagnum fallax	**II** (5-6)	**I** (4)		**I** (4)			
Sphagnum papillosum				**II** (5-6)			
Calliergonella cuspidata				**I** (4)			
Potentilla erecta						**II** (5-6)	
Juncus articulatus							**III** (7-8)
Tussilago farfara							**II** (5-6)
Taraxacum agg.							**II** (5-6)
Brachythecium rutabulum				**I** (4)			**II** (5-6)
Triglochin palustre							**III** (7-8)
Stellaria uliginosa							**II** (5-6)
Luzula multiflora		**II** (5-6)					
Myosotis scorpioides	**I** (4)						
Sphagnum tenellum	**I** (4)						
Dicranum scoporium	**I** (4)						
Hypochaeris radicata	**I** (4)	I (4)					
Carex rostrata	**I** (4)						
Carex echinata	**I** (4)	I (4)					
Salix aurita	**II** (5-6)	**II** (5-6)		**II** (5-6)			
Platanthera bifolia	**II** (5-6)						

The plant communities distinguished by the cluster analysis (CA) that are numbered 1 and 4 (Table 4.14) correspond to poor fen dominated by *Juncus effusus* with *Sphagnum cuspidatum* as a major component. These communities align with the Sphagneto-Juncetum effusi and the *Sphagnum cuspidatum-Eriophorum angustifolium* communities respectively as described by Farrell (2001). CA 1 and 4 communities have developed in wetter areas of the site.

CA communities 2 and 5 correspond to dry a *Juncus effusus* pioneer community. These plant communities feature *P. commune and C. introflexus* (ground layer) strongly and are likely to correspond with drier cutaway areas that do not promote a strong *Sphagnum* component. These two plant communities fit in with a drier version of the Farrell (2001) community *Juncus effusus* pioneer community. The CA 2 plant community is one of the most wide spread communities across the Bellacorick site in 2011.

CA community 3 is dominated by *Sphagnum cuspidatum*, *J. effusus* and *J. bulbosus*. This community aligns with the *Juncus bulbosus-Sphagnum cuspidatum* pools as described by Farrell (2001). This vegetation community is not widely dispersed across the Bellacorick site. Open water in this plant community was high – up to 42%.

CA community 6 corresponds to dry heath habitat. In this habitat, *Juncus effusus* does not feature strongly and *C. vulgaris* is dominant. This plant community aligns with the Farrell (2001) Calluno-Ericetum community. This plant community is not widely dispersed across the Bellacorick site in 2011.

The CA community 7 corresponds to open water habitat with *J. bulbosus* as the dominant species and *Juncus articulatus* also present. This plant community corresponds to the *Juncus bulbosus* pioneer community described by Farrell (2001).

Table 4.15 Correlation between Farrell (2001) and the CA plant communities

Farrell 2001 plant communities	**CA plant communities**
Juncus effusus pioneer community	2, 5
Juncus bulbosus pioneer community	7
Eriophorum angustifolium pioneer community	-
Sphagneto-Juncetum effusi community	1
Sphagnum cuspidatum-Eriophorum angustifolium community	4
Juncus bulbosus-Sphagnum cuspidatum pools	3
Calluno-Ericetum	6
Bare peat	0
Exposed gravel	0

4.6 Non-Metric Multidimensional Scaling (NMS) ordination with vector overlays

NMS is used to determine the relationship between plant community composition (Table 4.14) and the measured environmental variables (Table 4.16).

Table 4.16 Mean and standard deviation for environmental variables recorded within each of the 7 communities distinguished using cluster analysis. The number in brackets indicates the standard deviation.

CA Habitat	**% Open Water**	**Peat depth (cm)**	**Vegetation Height (m)**	**ht Bryophytes (cm)**	**% exposed gravel**	**% bare peat**
1	9.4 (12.57)	0.32 (0.42)	0.96 (0.44)	0.14 (0.10)	0 (0)	2.78 (6.67)
2	0 (0)	0.15 (0.17)	0.77 (0.32)	0.18 (0.11)	7 (21.05)	12.5 (23.14)
3	41.6 (42.50)	0.43 (0.05)	0.32 (0.51)	0.05 (0.08)	0 (0)	0 (0)
4	6.25 (0.05)	0.48 (0.46)	0.81 (0.33)	0.21 (0.20)	0 (0)	0.8 (1.75)
5	0 (0)	0.29 (0.31)	0.73 (0.45)	0.05 (0.05)	19 (42.49)	69.0 (38.79)
6	40 (42.43)	0.83 (0.33)	0.3 (0.45)	0 (0)	0 (0)	38.75 (45.16)
7	0 (0)	1.13 (0.64)	0.55 (0.38)	0 (0)	0 (0)	57.67 (41.55)

Table 4.16 highlights the range of environmental factors found at the Bellacorick site and how the environmental conditions within each CA habitat varies. The

environmental variables have a direct influence on the type of pioneer habitat that will develop in every section of the Bellacorick site.

Sorensen distance measures and autopilot were used in PC-ORD in order to obtain the NMS ordination of the plant species data. The final stress of the best solution was 13.91063. Using the Monte Carlo test result, the number of randomized runs and the probability that a similar final stress could have been obtained by chance was 250. In total 52 iterations were used to obtain the final solution.

NMS ordination as shown in Figures 4.18, 4.19 and 4.20 show the plant vegetation quadrats in species space. The measured environmental variables are used as vector overlays illustrating the correlation between the environmental variables and the ordination axes. The environmental variables are used as vectors to explain the variation in vegetation data across the site. The environmental variables r^2 are listed in Table 4.17.

Table 4.17 Pearsons (r) correlation coefficients (Between the measured environmental variables and the NMS ordination axes (Figures 4.18, 4.19 and 4.20). r^2 values >0.2 are shown in bold).

Axis		1			2			3	
	r	r-sq	tau	r	r-sq	tau	r	r-sq	tau
Height of bryophyte	-0.384	0.147	-0.331	-0.061	0.004	-0.019	-0.312	0.098	-0.134
Height of vegetation	-0.52	**0.271**	-0.327	0.079	0.006	0.108	0.022	0	0.034
Peat depth	0.5	**0.25**	0.356	0.212	0.045	0.119	0.101	0.01	-0.084
% bare peat	0.372	0.138	0.24	-0.307	0.094	-0.242	0.33	0.109	0.29
% open water	0.301	0.091	0.114	0.541	**0.292**	0.305	-0.119	0.014	-0.229
% exposed gravel	0.155	0.024	0.022	-0.187	0.035	-0.169	0.206	0.043	0.221
% variance represented		46.9			16.8			19.1	

The cluster analysis groupings are overlayed on the ordination Figures 4.18, 4.19 and 4.20 using different symbols and an outline of the ordination space defined by each group is also shown to further aid interpretation. The main findings were extracted from Figure 4.18 (Axis 1) as its percentage variance was greatest at 46.9%.

The percentage variations represented by Axis 1, 2 and 3 are 46.9%, 16.8% and 19.1% respectively. The correlation coefficients for each environmental variable with the ordination axis after rotation are shown in Table 4.17. Axis 1 is highly correlated with height of vegetation and peat depth while Axis 2 is highly correlated with the percentage of open water only. Axis 3 was not correlated to a sufficient value in any environmental variable.

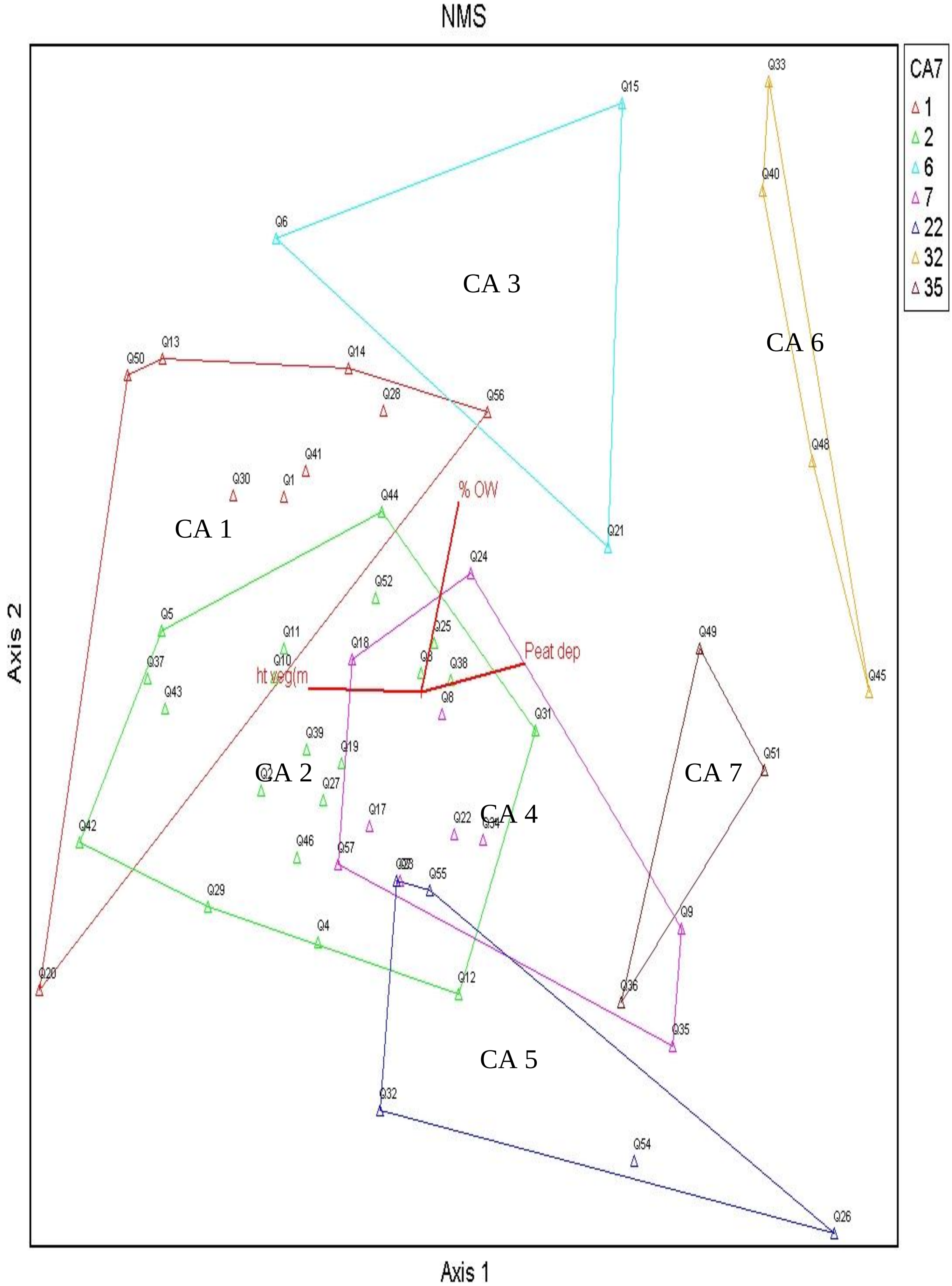


Figure 4.18 NMS Ordination 3D Axis 1 vs 2

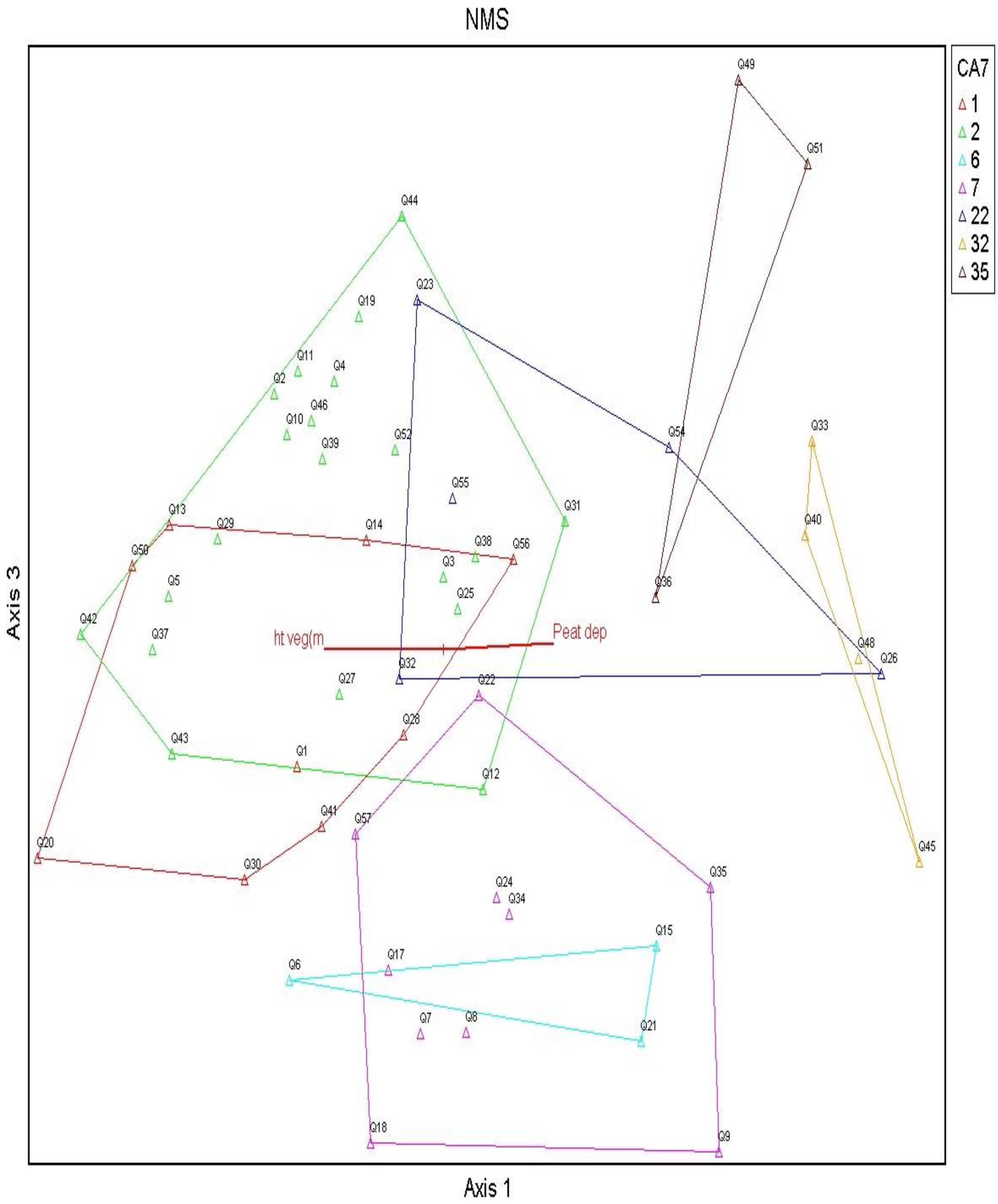


Figure 4.19 NMS Ordination 3D Axis 1 vs 3

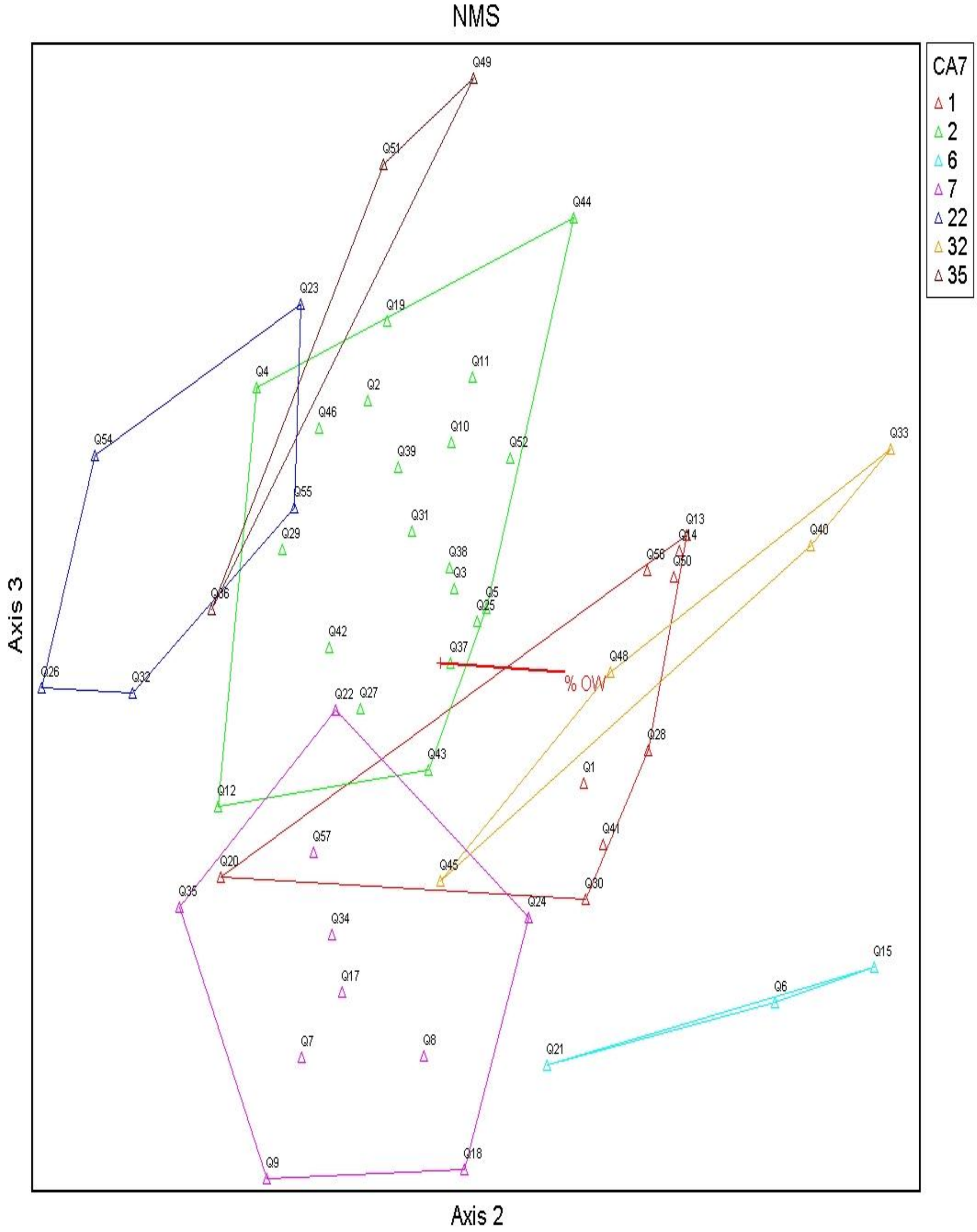


Figure 4.20 NMS Ordination 3D Axis 2 vs 3

Chapter 5 Discussion

5.1 Vegetation development on the Bellacorick cutaway

The previous chapter describes the main vegetation types present at Bellacorick in 2011 and 2012. Many studies have looked at post industrial peat production sites with a view to assessing how these sites revegetate once peat production ceases (Cooper *et al.* 2001; Poulin *et al*. 2005). However, peat production methods can vary within and between countries and there is further variability in local and regional conditions. For example, site specific factors controlling the revegetation of the cutaway bog in Bellacorick include high rainfall and exposure to wind throughout the year as well as physical and chemical characteristics of the peat that are different from the Bord na Móna cutaway raised bogs in the midlands of Ireland. In the midlands, high rainfall and exposure are not strong influencing factors and revegetation occurs relatively quickly across the sites.

Rehabilitation work carried out at the Bellacorick site had a significant role in encouraging the spread of vegetation across areas that had been previously used for industrial peat harvesting. The areas with the most successful rehabilitation were those areas in Bellacorick where it was possible to rewet the remaining peat layer and create saturated conditions. Blocking field drains caused the dry peat fields to rewet, which led to the establishment of pioneer poor fen vegetation types. This poor fen vegetation is characteristic of wet peat soils where there are some fluctuations in water table, but in general wet conditions persist throughout the year. This method of rehabilitation relies solely on rewetting.

Research on cutaway peatlands in Canada and the United States of America has incorporated plant re-introduction methods successfully along with rewetting (Graf and Rochefort, 2008 and Kivimäki *et al.,* 2008). Graf and Rochefort (2008) also found that the use of fertilisers also aided the revegetation of degraded peatlands. In Scandinavia and continental Europe, the focus is often solely on rewetting industrial cutaway and allowing natural colonisation to develop vegetation. Tuittila *et al*.

(2000); Vasander *et al*. (2003) and Trepel (2007) commented on the success of rewetting degraded peatlands in order to aid rehabilitation.

It is clear from the results of the habitat and vegetation mapping at the Bellacorick site that vegetation has increased across the site. There are still some areas of bare peat but even in these areas, scattered patches of vegetation are emerging. This highlights a number of issues, (a) the nutrient poor condition of the cutaway, (b) the impact of climate on bare peat surfaces and (c) the slow growing nature of typical peatland species such as *E. angustifolium*. The establishment however, of even small patches of vegetation is fundamental to the future and complete revegetation of areas of cutaway as these will expand slowly and steadily over time.

Tracking and monitoring the establishment of vegetation on cutaway peatlands can inform future and longterm management options for these areas. Some research in Canada has been based on 56 years of monitoring vegetation of cutaways, Poulin *et al.* (2005). The development of the detailed vegetation maps as part of this study, as well as the establishment of permanent quadrats and fixed point photography will allow for future, and more informed monitoring of the Bellacorick site.

5.2 Vegetation successional trends

Figure 5.1 Bare peat at the Bellacorick site in 2011with fringing pJeff habitat

The 2011 survey indicated that plant community composition largely reflects the communities that were present on the site in 2001. A total of eleven cutaway plant communities were described in 2001, largely comprised pioneer and rudimentary forms of poor fen, dry heath and bog pools. Pioneer poor fen was the dominating plant community (Farrell, 2001).

Since the rehabilitation of the site between 2003 and 2005 in areas where re-wetting occurred, vegetation was quick to establish, particularly by species such as *J. effusus*, *J. bulbosus* and *E. angustifolium.* The dominant pioneer species within these areas is *J. effusus* and this is one of the first plants to colonise areas of bare peat. McCorry and Renou (2003) describe this species as being particularly well adapted to colonising bare peat, acting as a '*nurse species'*. In an area where bare peat can be affected by changes in temperature and levels of exposure, *J. effusus* becomes established, along with bryophyte species such as *P. commune* and *C. introflexus*. The tussocks of soft rush and the presence of these bryophytes allow these areas to further develop wet moss hummocks in the inter tussock areas. When coupled with shallow flooding these rudimentary poor fen stands can favour the spread of *Sphagnum* species including *S.*

subnitens, *S. cuspidatum*, *S. fallax*, *S. auriculatum* and *S. squarrosum*. This vegetation can be considered to be the beginning of peat forming communities (embryonic peatland). Similar situations have occurred on Canadian cutaway peatlands where old ditches that filled with water were readily colonised with *Sphagnum* species (Poulin *et al.*, 2005). Sections of the Bellacorick site where rehabilitation work was not carried out have not developed significant vegetation cover, and drier sections of the site have not had the same level of vegetation establishment as wetter areas. However vegetation is becoming established in these areas albeit at a slower rate than the successfully rewetted and typically lower lying areas.

The creation of microclimatic conditions that favoured *Sphagnum* development by populations of *Polytrichum alpestre* and *Eriophorum vaginatum* has been noted in North American cutaway bog sites (Rochefort *et al.* 2003). A similar situation appears to be the case in Bellacorick where *J. effusus* and the associated *C. introflexus* and *P. commune* moss layer facilitate *Sphagnum* establishment. However, a Canadian study that focused on vacuum mined and trench cut peatlands found that *Sphagnum* development was slow due to unfavourable hydrological circumstances. This study also found that while typical peatland plants including *Eriophorum vaginatum* and *Polytrichum* spp. had developed on some sites, their presence did not necessarly lead to *Sphagnum* development (Poulin *et al.*, 2005). However, given the steady spread and colonisation of *Sphagnum* across the site at Bellacorick, this is not an expected scenario.

Poor fen in its pioneer form, remains the most common plant community at the Bellacorick site and this can be further broken into successional stages/rehabilitation phases. Based on the study in 2001, and the mapping in 2011 it is evident that vegetation is '*changing*' and following a directional path (Figure 5.2). This is clear from the three main pioneer vegetation communities where;

- *Juncus effusus* poor fen has three phases over time -
  - → *Juncus effusus* pioneer poor fen
  - → *J. effusus* dominated poor fen with bryophytes (*Polytrichum commune* and *Campylopus introflexus*)

→ *J. effusus* dominated poor fen with *Sphagnum* sp. (>50%) (in wet areas)

→ *J. effusus* with pine (in dry areas)

- *Juncus bulbosus* poor fen has two phases over time –
  - → *Juncus bulbosus* pioneer community
  - → *Juncus bulbosus- Sphagnum cuspidatum* pools
- *Eriophorum angustifolium* poor fen also has two phases over time
  - → *Eriophorum angustifolium* pioneer community
  - → *Sphagnum cuspidatum – Eriophorum angustifolium* community

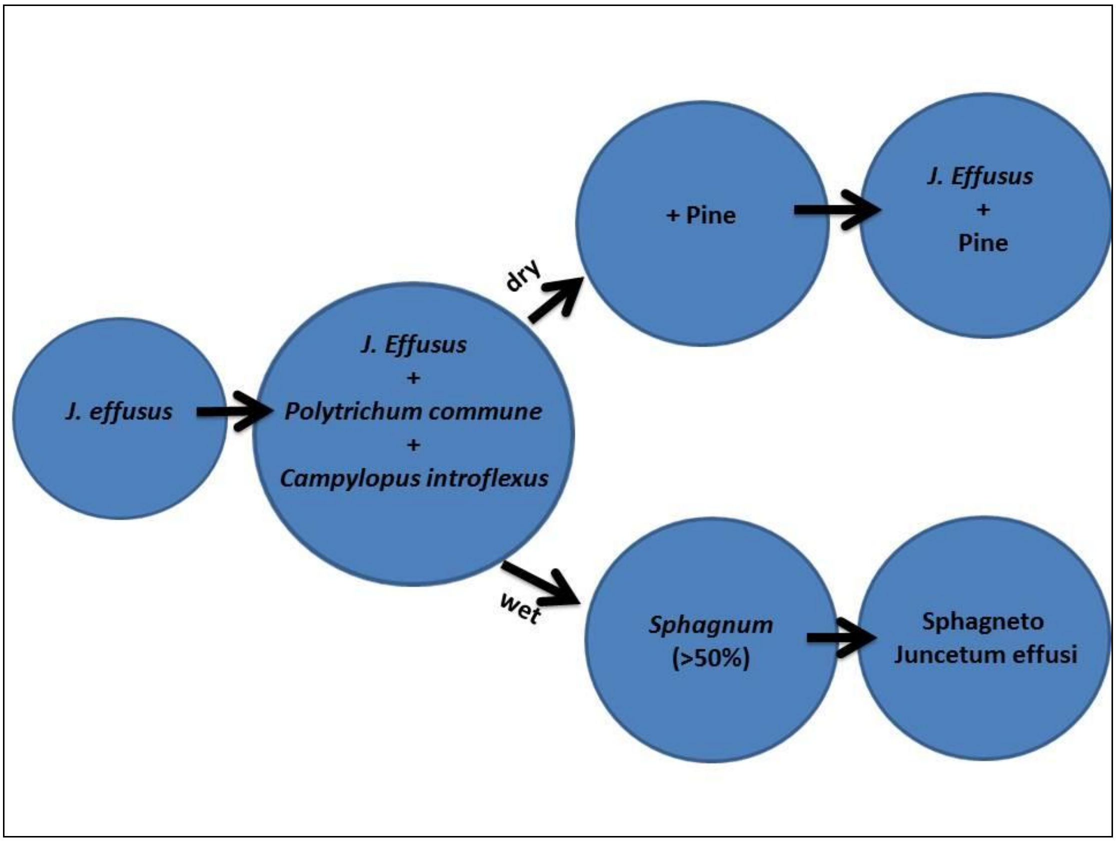


Figure 5.2 Development of poor fen habitats at the Bellacorick site

5.2.1 *Juncus effusus* poor fen communities

Where conditions are favourable at the Bellacorick site, *J. effusus* has proven to be the first species to become established. The *J. effusus* tussocks provided shelter for bryophytes including *C. introflexus* and *P. commune*. Other mosses such as *Sphagnum* spp. also become established with time and in habitats where *Sphagnum* exceeds 50%

cover, it has begun to grow up through the *J. effusus* tussocks. This plant community is expected to spread across the site over time. It is likely that future poor fen will be typically recognisable as the Sphagneto-Juncetum community as described by Farrell (2001) and the variety of Bord na Móna habitat types will be collectively described with this category.

Figure 5.3 Development of Juncus effusus tussocks on an area of former bare peat;* J. effusus *is the dominant species forming large tussocks.

Figure 5.3 demonstrates how, with time, bryophytes (*C. introflexus* in this case) develops below the *J. effusus* tussocks and over time comes to dominate the areas between the *J. effusus* tussocks. This is the pioneer *Juncus effusus* phase.

Figure 5.4 The inter-tussock areas between the rushes are dominated by *Sphagnum cuspidatum*

Figure 5.4 shows the light green coloured vegetation which is dominated by *Sphagnum cuspidatum*. A small amount of water logging is also noticeable as the *Sphagnum* holds water on the surface of the cutaway. In contrast to Fig. 5.3, Fig. 5.4 shows how over time *Sphagnum* species begin to colonise the ground layer. The next phase is illustrated in Fig. 5.5 which shows *Sphagnum* dominating the ground layer with less vigerous rush growth. In areas such as that shown in Fig 5.5, *Sphagnum* growth can reach depths of over 30cm and the vegetation can be considered peat forming (embryonic peatland).

Figure 5.5 Sphagnum dominating the habitat; J. effusus has not retained its tussock form and is less vigorous in growth (shown here as browning stems)

Figure 5.5 shows that *S. cuspidatum* is the dominant species in the ground layer, however other *Sphagnum* species begin to colonise the area. The growth of *Sphagnum* in these areas can exceed 30cm and the habitat is permanently waterlogged (water saturated) due to the presence of the mosses themselves. Overall, it is evident in the areas of Bellacorick where rewetting of peat and/or shallow flooding occurred after the rehabilitation works, these areas developed, or are beginning to develop, embryonic peatland communities.

In 2011 the *Juncus effusus* pioneer community was the most widespread vegetation community across the site (41%) and occupies conditions that are widespread across the Bellacorick site. Cluster analysis of the *Juncus effusus* pioneer community shows that this vegetation community is the most common community as it is found across a wide range of environmental conditions demonstrated by the cluster analysis. However it was not found on the areas of the deepest peat (> 1m peat).

Other pioneer habitat types that have developed in these areas include *Juncus bulbosus* pioneer communities and *Eriophorum angustifolium* pioneer communities. These pioneer communities share similarities with the *Juncus effusus* pioneer community in that they are early successional stages. Over a period of time these pioneer plant communities become more diverse and develop into *Juncus bulbosus – Sphagnum cuspidatum* pools and *Sphagnum cuspidatum – Eriophorum angustifolium* pioneer plant communities and again it is evident that, with time, these plant communities will become more diverse and may become colonised by other typical peatland species such as *Menyanthes trifoliata* and/or *Rhynchospora alba*.

5.2.2 *Juncus bulbosus* poor fen communities

The *Juncus bulbosus* pioneer community forms in small pools of open water and in time it develops into *Juncus bulbosus-Sphagnum cuspidatum* pools. The *Juncus bulbosus* pioneer community requires open water and a peat layer (depths ranging from 0.43m to 1.13m). It would be expected that this habitat will be limited across the site in the future.

Small pools of open water are more likely to become *Sphagnum*-rich than larger areas of open water (*Juncus bulbosus-Sphagnum cuspidatum* plant communities) as wave and water movement had negative implications for *Sphagnum* development on restored peatlands (Poulin *et al.*, 2012). This has been the case at the Bellacorick site where small, shallow pools have developed this habitat type only.

5.2.3 *Eriophorum angustifolium* poor fen community

The *Eriophorum angustifolium* pioneer plant community is the precurser to the *Eriophorum angustifolium-Sphagnum cuspidatum* plant community at the Bellacorick site. This plant community becames established on deeper peat areas (average peat depth 0.5m) that are water logged (average percentage of open water – 5-10%).

Over time *Sphagnum* becomes established in areas dominated by *Eriophorum angustifolium* leading to the development of *Sphagnum cuspidatum-Eriophorum angustifolium* communities. This habitat will be limited to areas of waterlogged, deep peat across the site.

5.2.4 Calluno-Ericetum vegetation community

The Calluno-Ericetum vegetation community has developed on drier areas of the Bellacorick site, particularly where exposed gravel occurs. This vegetation community was identified by cluster analysis as a separate plant community, and the ordination of the Calluno-Ericetum community highlights that it requires areas that are relatively dry with medium to deep peat (average peat depth - 0.83m). This plant community is slower than others to develop at the Bellacorick site, due to the fact that it occupies drier, more exposed sections of the site.

In areas such as where slopes and hills occur, rehabilitation measures focused on contouring sloping ground in order to halt peat erosion from these areas to lower lying areas and the rehabilitation in these areas had varying degrees of success. In many areas *C. vulgaris* has slowly begun to colonise the drier areas with *J. effusus* and even *Sphagnum* sp. establishment where water has been held back by the creation of berms and contours. While these areas are slow to revegetate, this is a feature of exposed bare subsoil and at this time it is not expected that further measures will be required. Monitoring of these areas will inform future management. In other countries, methods such as direct seeding are used in sloping areas of degraded blanket bog in the UK in order to establish similar *Calluna* dominated heathland (Maskill *et al.* 2012).

It is interesting to note that ordination also showed that the Calluno-Ericetum community also favours areas with a medium percentage (40%) of open water. As already described this vegetation community occurs in areas that are generally dry and situated on sloping areas. However, the field season of 2012, when the dry heath permanent quadrats were recorded, was unseasonably wet and water was trapped between the ridges on slopes giving rise to unusually wet conditions for this community.

5.2.5 Other vegetation types

Other habitats that occured at the Bellacorick site in 2011 included: the Caricetum paniculatae community (occasional drainage ditches), the Typhetum latifoliae community (pockets of fen peat), the Tussilaginetum community (disturbed road sides) and the Centaureo-Cynosuretum community (former rail lines). These plant communities are fragmented and together occupied less than 2% of the site in 2011 similarly, Farrell (2001) outlines the patchy occurance of these communities across the cutaway. It is unlikely that these communities will form a significant part of the site into the future and will be confined to small pockets across the site.

5.3 Lodgepole pine spread across the site

Pinus contorta (lodgepole pine) was not described by Farrell (2001) as a significant component of the vegetation of the Bellacorick site. However, since 2001 *P. contorta* has been spreading across the site. This tree species is a native of North America, and has been naturally regenerating from nearby conifer plantations. In 2011 pioneer poor fen with emerging and open pine scrub covered up to 7% of the Bellacorick site compared with 2001 when the species did not feature in the communities described by Farrell (2001) even though occasional pine seedlings/saplings were noted in vegetation samples (Farrell, 2001).

Figure 5.6 Spreading* Pinus contorta *across a section of the Bellacorick site

Work carried out on intact Boreal bogs suggests that pine growth impacted on *Sphagnum* development as the tree growth resulted in a drying out of the site (Ohlson *et al*., 2001). Conifer re-growth on Coillte restored blanket bog sites has not been a problem to date as the seed sources had been removed (Delaney *et al*., 2012). However a number of significant seed sources still remain within and around the Bellacorick site.

Hedberg *et al.* (2012) indicates that peatland plant communities responded very well to tree removal on a fen restoration site and that *Sphagnum* cover had increased on the site by 10 -15 % in the eight years since trees were removed. They also found that tree removal was more effective than drain blocking. Tree removal at the Bellacorick site may be necessary in the future if vegetation dominated by *Sphagnum* growth is to continue to increase across the site.

5.4 Rehabilitation of the Industrial cutaway bog

Time frames for peatland rehabilitation can range from 10 to 56 years depending on the definition of rehabilitation (Rochefort *et al.*, 2003); Poulin *et al.*, 2005); Lucchese *et al.*, 2010; Vasander 2003). In some Canadian cutaway peatlands time is not the issue regarding the revegetation of cutaway sites, instead hydrological conditions are more important in terms of encouraging vegetation, especially *Sphagnum* spp. colonisation (Poulin *et al.*, 2005).

A study was conducted on a Canadian raised bog 10 years post restoration work to determine if the restoration work returned the site to a state that falls within the natural range variation found in intact raised bogs in the area. It was found that restoration led to increased vegetation across the site, however restoration work increased microbial activity leading to a high immobilisation of nitrogen proving that restoration work can give an initial sign of success (revegetation), however, below ground conditions may take longer to recover (Anderson *et al.*, 2013, Pouliot *et al*., 2011). These studies, together with the results of the work at the Bellacorick site highlight that success can be achieved within 10 years in the rehabilitation of cutaway peatlands, particularly when the right hydrological conditions are present.

The first course of action in severely degraded blanket bog in the Pennines, UK is to slow the flow of water over sloping ground (Maskill *et al.,* 2012). This has been achieved in Bellacorick by the sculpting of berms and contours during the rehabilitation work. The second course of work in areas of degraded blanket bog can entail programmes such as heather brashing, geo-textiles and lime, seed and fertiliser applications, Maskill *et al.* (2012). These techniques could also be used to encourage vegetation growth on the sloping areas within Bellacorick that are shown with monitoring to be having difficulty in developing a cover of vegetation in the future.

It is worth noting that numerous indications show that red grouse (*Lagopus lagopus*), a species of conservation interest and a Red-Listed bird species of breeding concern in Ireland (Cummins *et al.*, 2010), are using areas with young heather in Bellacorick. This illustrates that diverse bird communities are also colonising the Bellacorick site in line with the establishment of different vegetation communities.

5.5 Focus on criteria for successful rehabilitation of the Bellacorick site

The main criteria for successful rehabilitation of the Bellacorick site are (described in Section 2.8), (i) stabilisation of bare peat, (ii) mitigation of silt run off and (iii) re-establishment of peat forming plant communities where possible. The 2011 survey allows for an appraisal as to the achievement of the criteria to date.

- *Stabilisation of bare peat*

The stabilisation of the remaining peat at the site has been largely achieved by the rehabilitation measures and natural colonisation. This has been largly achieved through (a) drain blocking which slows the movement of water across the site and makes the site wetter; (b) contouring and creating physical barriers to prevent peat erosion; and (c) drain blocking and contouring combined to accelerate natural colonisation across the site. Where peat has been rewetted the development of poor fen vegetation, *Sphagnum*-rich vegetation and *J. bulbosus* pools is extensive. On drier areas rudimentary poor fen has developed along with dry heath on sloping areas.

- *Mitigation of silt run off*

Former silt ponds at the site have been decommissioned and revegetated. The pools and wet areas that developed as a result of the rehabilitation work have slowed the movement of water across the site and prevented silt from exiting the site rendering the former silt ponds redundant.

Figure 5.7 A decommissioned silt pond, water levels have dropped and vegetation has developed throughout

- *Re-establishment of peat forming plant communities*

The emergence of *Sphagnum*-rich vegetation across the site is illustrated in Figure 4.2. This is a trend that is likely to continue. Peat forming vegetation had a low distribution on the cutaway in 2001 however by 2011 these areas had increased by over 6% and can be expected to increase further in the future. These areas have been shown by Wilson *et al*. 2012, to be acting as carbon sinks (further discussed Section 5.7).

Pioneer vegetation on Canadian cutaway peatlands becomes more diverse with time (Rochefort *et al.*, 2003), with some peatland restoration projects introducing plant species in order to encourage certain plant communities to develop, Hedberg (2012). However, the plant communities at Bellacorick appear, at this stage to be becoming more diverse through natural regeneration.

5.6 Vegetation classification of the plant communities

The maps developed for the site using GIS illustrate the differences in vegetation cover and vegetation types across the Bellacorick site. In order to fully understand how the vegetation is developing on the site it was important to study the different vegetation communities and observe how they are changing over time.

There are various levels of vegetation classification used in this study, with each classification system working on a different level, i.e. more or less detail in some than others. Each classification system and/or scheme is developed on a hierarchical basis. Table 5.1 demonstrates how the different habitat classifications can fit together.

Table 5.1 Comparison of different methods of habitat classification

Vegetation classification system	**level**	**Comments**
Fossit (2000), Heritage Council Classification system	goes to level 3	General habitat descriptions, limited detail for cutaway bog habitats
Farrell (2001) (Braun-Blanquet classification system)	to level 4 with detailed description of variants	Habitat classification of blanket bog cutaway based on the Braun-Blanquet system with reference to Fossit 2000 and the NVC, limited detail for cutaway bog habitats
Bord na Móna Habitats Scheme, developed in 2009 by Bord na Móna Ecologists	5	In depth account of pioneer vegetation on cutaway peatland. Used only by Bord na Móna to date, follows on from studies by Rowlands (2001) and Farrell (2001)

The plant communities that were described by Farrell (2001) were aligned to Fossit (2000) and the British National Vegetation Classification (NVC). The NVC was devised by the Joint Nature Conservation Committee (JNCC) in order to produce a comprehensive classification and description of British plant communities (JNCC, 2012). Perrin *et al*. (2010) comprises an upland vegetation classification system that takes account of poor fen, pools and heaths (amongst others). These are not referred to as part of this study.

Under the Fossit 2000 classification system, all peatlands are classified as P (level 1). Bogs are further classified as PB (level 2). For example cutaway bog is classified as PB4 under Fossit (2000) regardless of different vegetation types such as open water, poor fen or scrub (level 2).

The Bord na Móna Habitats Scheme has been developed to take into account the vegetation types that are present within this very diverse and variable PB4 category, and classifies the habitat accordingly. It is used on a regular basis in the monitoring of the vegetation development on Bord na Móna cutaway peatlands.

The Bord na Móna Habitat Scheme highlights the variability in pioneer communities across cutaway peatland sites and allows for predictions to be made as to how sites will continue to develop over time. For example, *J. effusus* poor fen will in time progress towards *Sphagnum*-rich poor fen. This is a very useful technique to demonstrate how any cutaway site will be stabilised and have a self sustaining habitat over time and into the future (long term stability).

Cluster analysis distinguished 7 plant communities at the Bellacorick site. These plant communities are analogous to existing habitat types identified within the Bord na Móna Habitat Scheme. Thus proving that this habitat classification system is well suited to the further survey and monitoring of cutaway peatlands.

5.7 Carbon sequestration and cutaway peatlands – future work

Work carried out on cutaway sites in Belarus show that carbon dioxide (CO_2) uptake has been reported from rewetted sites, Tanneberger and Wichtmann (2011). On-going work at the Bellacorick site detailed by Wilson *et al*. (2012b) show how sections of the site where *Sphagnum* growth is extensive, are changing from being a CO_2 source to habitats where CO_2 is actively being sequestered. These changes in carbon fluxes have occurred alongside changes in the vegetation of the site.

The widespread emergence of *Sphagnum*-rich plant communities in Bellacorick (Fig. 4.3) indicates that *Sphagnum* would be expected to become even more widespread and extensive within the Bellacorick site in the future, if conditions on the site do not change considerably. The spread of *P. contorta* may pose a threat to the continued spread of *Sphagnum* across the Bellacorick site (Hedberg *et al.*, 2012) and its spread will be monitored.

Habitat mapping projects and carbon monitoring programmes can be combined, especially where vegetation communities can be used as a proxy for carbon sequestration. Numerous studies including Alonso *et al*. (2012), Koehler *et al.* (2000) and Wilson (2001) have monitored carbon sequestration on peatlands; however they do not reflect the full diversity across large sites such as Bellacorick. GHG emissons can even vary at the species level with variations between different *Sphagnum* species namely *Sphagnum palustre* and *S. papillosum* recorded in a *Sphagnum* farming trial in Germany (Albrecht, 2012).

Given the climatic conditions that prevail on the Bellacorick site where little frost occurs and rainfall is evenly spread over the year, climatic conditions for the growth of *Sphagnum* are optimal. Wilson (pers.comm) estimates that *Sphagnum* growth at Bellacorick is constant throughout the year, potentially allowing for the sequestration of carbon year round where it has, and can establish in the future. This is not possible in other countries such as Belarus and Canada where continental climatic conditions mean colder winters where vegetation growth stops according to the seasons.

Wilson *et al*. (2012b) measured the instantaneous net ecosystem exchange (NEE) of CO_2 at the study site from a range of habitats. The results are shown in Table 5.2.

Table 5.2 Annual NEE (g CO2-C m.-2 yr-1) ± SD in parentheses for the microsites at Bellacorick for 2009, 2010 and 2011, positive NEE values indicate a CO2-C sequestration by the peatland (Wilson *et al*. 2012b).

Vegetation community	**2009**	**2010**	**2011**
	NEE	NEE	NEE
Bare peat	**-46.7**	**-81.6**	**-37.3**
Juncus effusus-Sphagnum cuspidatum dominated communities	142.8	43.1	211.2
Sphagnum cuspidatum dominated communities	106.8	47.4	144.7
Eriophorum angustifolium dominated communities	587.9	150.93	305.0

Table 5.2 provides an account of the annual NEE that has been measured on this site over a 3 year period (Wilson *et al*. 2012b). Positive values indicate the vegetation is an active CO_2 sink, negative values (marked in bold) indicate the vegetation is a CO_2 source. The data shows that sections of Bellacorick that have been monitored in terms of GHGs are now strong CO_2 sinks (to varying degrees depending on the vegetation communities present), while areas of bare peat continue to act as CO_2 sources.

Revegetation of the site therefore has the potential to restore the site to a CO_2 sink. However, an accurate estimation of the CO_2 sequestration potential of the site can only be ascertained following monitoring of NEE across the range of habitats and environmental conditions recorded at the site as part of this study. Couwenberg *et al*. (2011) studied the vegetation differences between two Belarusian peatlands and found that vegetation can be used as a proxy to measure carbon emissions from these peatlands. The habitat maps that were produced for Bellacorick revealed the range of pioneer plant communities that developed on the site since peat production ceased. A study combining the data on pioneer plant communities on the Bellacorick cutaway peatlands and their corresponding measured GHG emissions will be required to inform how future management of industrial peatlands will contribute to global carbon pools when peat production ceases.

Chapter 6 Conclusions and recommendations

The change from a bare peat landscape when peat production ceased at the Bellacorick site in 2003, to a largely vegetated landscape (2011-2012) has been aided greatly by the extensive programme of rehabilitation that was carred out post peat production (2003-2005). The rehabilitation work has led to parts of the Bellacorick site reverting to GHG sinks (Wilson *et al*. 2013).

Industrial peat production is set to continue in Ireland for a number of years. Once peat production ceases, rehabilitation will be necessary to ensure these sites revert to environmentally stable habitats. Long term monitoring of previously rehabilitated sites will inform rehabilitation of future cutaway peatlands. The rehabilitation work carried out at the Bellacorick site and the methods used on the site can be applied to other sites where similar conditions are found after peat production ceases.

This study found that former industrial peat production areas at the Bellacorick site had largely moved from areas of bare peat to vegetated habitats. The vegetation types that have developed on the site consist of pioneer forms of poor fen vegetation that are becoming more diverse where conditions are suitable. It is expected that the site will become a mosaic of poor fen (*Sphagnum*-rich) with pools of *Sphagnum* and patches of *Eriophorum angustifolium – Sphagnum cuspidatum* vegetation over time.

The sloping areas within Bellacorick have been slower to re-vegetate than lower lying areas where re-wetting was easier to achieve. However, *Calluna vulgaris* is slowly colonising these areas. Further studies on the use of fertilisers and seeding would be recommended if these areas continue to remain bare after another ten years.

Vegetation monitoring will track the changes on the site (using the quadrats as a baseline) and the rehabilitation success into the future and will also provide an insight as to how the plant communities change further with time. Further habitat maps can be produced in the future (using the Bord na Móna Habitat Scheme) and these can be compared with the 2011 maps in order to further evaluate the changes occurring. As the work highlighted in this thesis has shown that significant changes have occurred within the vegetation communities in a ten year period, it may be advisable to conduct another study in ten years time (2021). The spread of *Pinus contorta* and its effect on the development of peat forming plant communities will be monitored across the Bellacorick site into the future.

It is essential now for all countries to be able to measure the GHG emissions from various land uses for national accounting. Future studies of vegetation communities on cutaway bogs and their carbon fluxes, will present a clearer picture of the GHG emissions from rehabilitated peatlands while also informing future rehabilitation practices. It is expected that the habitat maps developed as part of this study will also inform an overall assessment of the GHG balance for the Bellacorick site, combined with GHG monitoring work that is still ongoing at the site.

Chapter 7 References

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