Tree encroachement onto peatlands

- studying factors triggering natural regeneration of conifers plantations –

The case of Lodgepole pine (*Pinus contorta*) and Sitka spruce (*Picea Sitchensis*)

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Tree encroachement onto peatlands - studying factors triggering natural regeneration of conifers plantations – The case of Lodgepole pine and Sitka spruce
(*Etude de l'avancée des plantations de conifères (Pin contourné et Epicéa de Sitka) sur les tourbières d'Ecosse*)

Pour l'obtention du :

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Résumé

En Ecosse, les tourbières doivent faire face à une exploitation importante, en particulier durant les années 1970 et 1980. A cette époque en effet, planter des forêts de conifères sur sols tourbeux (tourbières hautes et tourbières de couverture) était monnaie courante, étant donné que le secteur agricole requérait les meilleurs sols et entrait de ce fait en compétition avec le secteur forestier. De nombreuses tourbières ont également vu leur étendue diminuer pour cause d'intensification agricole et d'exploitation de tourbe. Selon les cas, ce sont quelque 10% (pour les tourbières de couverture) voire même 90% (pour les tourbières hautes) des surfaces tourbeuse d'Ecosse qui ont été perdues.

De nos jours la tendance s'inverse ; il s'agit de protéger et de restaurer les tourbières, en éliminant les arbres et en retournant à un système hydrologique plus « naturel ». Néanmoins l'expansion des plantations de conifères sur les tourbières n'est pas totalement comprise. Rien ne permet de certifier que ce phénomène mettrait en danger le bon fonctionnement de ces écosystèmes et de leur rôle en tant que puit à carbone.
D'où la question : **quels sont les facteurs qui permettent la colonisation des plantations de résineux sur les tourbières adjacentes ?**

Cette étude porte seulement sur le cas de l'épicéa de Sitka (*Picea Sitchensis*) ainsi que le pin contourné (*Pinus contorta*), car ils constituent les essences non-autochtones les plus représentatives et les plus importantes en Ecosse. A la manière d'une expérimentation scientifique, après avoir situé le contexte de ce travail, de la part des tourbières et des plantations de résineux en Ecosse, cette étude se basse sur un important travail sur le terrain, puis d'une phase d'analyse statistique. Des relevés botaniques ainsi que des données environnementales ont été collectées sur divers sites. Malgré des résultats peu significatifs dans l'ensemble, il semblerait que les dynamiques de régénérations répondent plutôt positivement à de forts niveaux de drainage, tandis que certains habitats (selon la classification britannique, NVC) constitueraient un milieu plus favorable à l'installation de résineux.

Cependant des études plus poussées devraient être mises en œuvre, afin d'assurer le suivi de ces dynamiques de régénération, de confirmer ou non ces premières tendances observées.

Abstract

Peatlands in Scotland are subjected to fierce exploitation, especially during the 1970s and the 1980s. At the time planting on blanket bogs and on lowland raised mires was allowed, for agricultural demands prevented planting on more suitable soils. Most peatlands have also faced serious shrinkage through agricultural intensification or commercial peat extraction. Depending on cases, it represents a loss of 10% (for blanket bogs) up to 90% (for lowland raised bogs) of peat surfaces in Scotland.

Nowadays, the trend is to protect and restore peatlands, by removing trees and rebalancing hydrological systems. Yet conifer encroachment onto bogs is not fully studied and there are no real clues as to whether this phenomenon would threaten the functioning of these ecosystems and their role as carbon sinks.
Hence the question: **what are the factors that could trigger or favour conifer plantation encroachment onto adjacent peatlands?**

This works focuses only on Sitka spruce (*Picea Sitchensis)* and Lodgepole pine (*Pinus contorta*), for their importance in Scottish Forestry, these two species being non-native tree species in UK.
This study will follow a research approach, after stating the general background in Scotland, concerning peatlands, conifer plantations and the effect of afforestation on bogs. Methods used to assess which factors could facilitate conifer plantations' regeneration onto peatlands implied going on the field and sampling vegetation and environmental factors. Statistical results were not highly significant, even if high levels of drainage and certain types of NVC habitats were expected to be more likely to embed tree regeneration.

However further studies should be carried on to assess these tendencies and furthermore to monitor the regeneration dynamics observed at the selected sites.

Acknowledgements

First of all, I would like to thank my supervisor, Russell Anderson, who answered positively to my internship apply and made it possible for me to come in Scotland and work on its amazing wildlife for these past six months; I thank him for his time, patience, pieces of advice and Scottish humour;

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Of course, all this wouldn’t have been possible without my family: parents, grandparents, aunts and uncles; and without my friends, scattered all around the world but still present; they were here to support me, reassure me, or simply listen to me;

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Merci, thank you, gracias, grazie, cheers!

Foreword

This research was made by a student, not a professional, so mistakes might have been done, even though Russell Anderson supervised my work. Given the limited amount of time, some results could have been more analysed and interpreted. I also apologise for any English mistakes, misspeaking, cloudy or incorrect sentences. I am far from being bilingual, my mother tongue being French. I hope it won't tarnish the overall meaning of what is said.

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UK BAP: United-Kingdom's Biodiversity Action Plan

NVC: National Vegetation Classification

EUNIS: European Union Nature Information System

FC: Forestry Commission

NBN: National Biodiversity Network

SNH: Scottish Natural Heritage

Dictionary

Peat: tourbe

Peatland: tourbière au sens large

Bog : tourbière

Mire: tourbière, mais aussi bourbier, fange. (Tourbière la plus répandue an Ecosse)

Fen : marais, marécage (ou forme plus « riche » de « bog »)

Blanket bog : tourbière de couverture

Raised bog: tourbière haute

(For more explanations see definitions here: I-1-a)

Ditch: fossé (d'irrigation)

Hummock: tertre, butte, monticule

Ridge : crête

Peat hagg: monticule érdodé entouré de tourbière en contrebas

Afforestation : boisement, reboisement

Spruce: épicea

Birch: bouleau

Rowan: sorbier

Introduction

As a student in environmental management, my naturalist commitment is to ecosystems conservation and protection. My sensitivity goes towards botany and particularly bryology, which is, among other disciplines, quite unknown in France where mosses distributions are still not fully understood. However, as I did not take the opportunity to abide by any "gap year" programs, the idea of spending my end-of-study placement abroad came to me. As I am pretty keen on improving my skills in Shakespeare's' language, my choice was then restricted to English-speaking countries.

In the United Kingdom[1], Scotland, as a matter of fact, meets these two criteria. Peatlands there endorse a wide range of habitats whose biodiversity encompass and rely mostly on *Sphagna*'s life cycles and decomposition, among other habitat specialists (speaking both about plants and animals). Threatened by various factors, namely human activities (not to mention climate change), bogs represent over a tenth of Scotland's land surface, and the Flow Country, up North in Caithness and Sutherland, host what might be the largest extent of blanket bogs in Europe if not the world. The afforestation program in 1919 led to the creation of coniferous plantations, accounting for about 17% of the Scottish land area and currently makes up about 0.5% of the total gross value for the Scottish economy. (National Forest Inventory Report (NFI) "2011 woodland map Scotland") Development of forestry techniques in the 1960s resulted in deep peats drainage and ploughing for afforestation's purposes. Peatlands were subjected to fierce exploitation, especially during the 1970s and the 1980s. At the time planting on blanket bogs and on lowland raised mires was allowed, for agricultural demands prevented planting on more suitable soils. Most peatlands have also faced serious shrinkage through agricultural intensification or commercial peat extraction. Depending on cases, it represents a loss of 10% (for blanket bogs) up to 90% (for lowland raised bogs) of peat surfaces in Scotland. (National Forest Inventory Report (NFI) "2011 woodland map Scotland")

The Scottish Forestry Strategy stated that an increase in woodland cover in Scotland to around 25% in the second half of the century would be needed. This would involve the creation of some 650,000ha of new woodland, which now represent about 1,334,000ha. (National Forest Inventory Report (NFI) "2011 woodland map Scotland") However land use balance is a serious issue in Scotland. Hence, forest creation is likely to occur on lower quality agricultural land which would offer a significant net carbon sequestration potential, as better soils would be dedicated to food production.

The value and international importance of peatland habitats is now acknowledged and new afforestation on deep peats are forbidden. Indeed, the benefit of woodlands as carbon sinks is questionable on deep peat soils. Besides, tree establishment tends to release carbon from soils due to cultivation and aeration, but this phenomenon is counterbalanced during growth periods and deadwood forming. (K.J. Hargreaves, R. Milne and M.G.R. Cannell, 2003)

Nowadays, the trend is to protect and restore peatlands, by removing trees and rebalancing hydrological systems. This only concerns a small part of peat soils on a small scale in UK though, where approximatively over 50 sites are being restored after afforestation or agricultural/industrial exploitation. (Anderson, 2010) No clear answers as to re-establishing their ecosystem services were assessed (Anderson, 2001), as well as restoring their previous state.

Yet tree encroachment onto bogs is not fully studied and there are no real clues as to whether this phenomenon would threaten the functioning of these ecosystems and their role as carbon sinks. A first step is to understand how and why trees expand onto these open areas. Hence the question: **what are the factors that could trigger or ease tree encroachment onto adjacent peatlands**?

This works focuses only on Sitka spruce (*Picea Sitchensis)* and Lodgepole pine (*Pinus contorta*), for their importance in Scottish Forestry, these two species being non-native tree species in UK.

First of all, this work will state the general background in Scotland, concerning peatlands, conifer plantations and the effect of afforestation on bogs. Then methods used to assess which factors could favour tree encroachment onto adjacent peatlands will be presented. Eventually the results from field surveys and statistical analysis will be prsented in a third part.

[1] This report was written before the Scottish referendum, Thursday 18th, September 2014: apologies for references to Scotland as part of the United Kingdom; hence when speaking about "National" Inventories or Institutions it does not refers to the Scottish Nation, but to the UK's Nation and Institutions. I really don't want to offend Scottish's political claims or sensitivities.

I. Context

The word “tourbière” in french embraces in English over 6 words to describe the various types of peatlands found in UK and particularly in Scotland.[2] Hence the need to define what the word “peatland” encompasses and how these habitats are classified.

a. *Different classifications for many types of peatlands*

i. Definitions of peatlands

Peatland: any wetland with peaty soils. Whether or not the natural vegetation remains and the ecosystem are still peat-forming, it is a peatland. More than 10% of peat soil no longer support blanket bog vegetation.

Mire: wetland which supports at least some vegetation which is normally peat forming, in their natural state. Mires support very distinctive wildlife communities including many specialist species. This category of peatland is divided into fens and bogs on the basis of their source of water. In Scotland, “Muir” toponymies are often related to mires, which rather mean “Moorland” in Scots and “Sea” in Scots Gaelic.

Fen: type of mire which receives rainwater and also water flowing from the surrounding land as surface run-off or flows through soil or rocks. Fens are distinguished from bogs, which are acidic, low in minerals, and usually dominated by sedges and shrubs, along with abundant mosses in the genus *Sphagnum*. A distinction between topogenous and soligenous fen is broadly accepted. Topogenous fens support vertical water movements, whereas soligenous fens are characterized by predominant lateral water movements. Fens can also be described as `poor-fens` or `rich-fens`. Poor-fens, where the water is derived from base-poor rock occur mainly in the uplands, or are associated with lowland heaths. On the other hand rich-fens are fed by mineral-enriched calcareous waters (pH > 5) and are mainly confined to the lowlands.

Bog: peat-forming mires which are provided with water and nutrients only from rain, snow, mist and dust: bogs are ombrotrophic system and include blanket bogs, lowland raised bogs and intermediate bogs. These first two types are mostly distinctive, but yet they rather represent two extremes of what can be considered as an ecological continuum where intermediate or mixed types can occur.
The vegetation of bogs has been modified by surface drying and aeration or heavy grazing. It is nonetheless broadly dominated by acidophilous species such as bog-mosses *Sphagnum* spp., cotton-grass *Eriophorum* spp. and cross-leaved heath *Erica tetralix*. The purple moor-grass *Molinia caerulea* would rather belong to the impoverished forms of bogs. Other modified vegetation resembles wet or dry dwarf shrub heath, occurring on shallow peat and once supporting peat-forming vegetation.

Active bogs: bogs that are actively peat forming i.e. still functioning as bog ecosystem. Active bogs still support significant areas of vegetation which is normally peat forming. *Sphagnum* mosses are the principal peat forming species on natural UK lowland raised peat bogs. The ability of this layer to store water is thought to be important and keeps the bog surface wet during the dry season.

Blanket bogs: peatland habitat mainly confined to cool, wet, typically oceanic climates, where the water table is usually at the ground level or below. Blanket bogs are defined by climate, not by altitude, and are found in wetter uplands sites, but also at sea level in Scotland. This type of bogs is the result of a combination of paludification and terrestrialisation. Some areas of blanket bog began to form following clearance of the original forest cover by early man, but the importance of this activity and climates changes over the past have yet to be determined.
The cover of blanket peat soil (over 0.5 m deep) represents approximately 1,060,000 ha in Scotland where it accounts for some 13% of the land area.

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[2] Adapted mainly from the Joint Nature Conservation Committee for priority habitats (available at the JNCC’s website), “Bogs: the ecology, classification and conservation of ombrotrophic mires” (Lindsay et al., 1988), , “An illustrated guide to British Upland Vegetation”, (A.Averis, et al.2004), “british plant communities: mires and heath”, vol 2. (J.S. Rodwell, 1991) and “National Vegetation Classification: Field guide to mires and heaths”, (Elkington et al., 2001).

Upland heathland: characterised by the presence of dwarf shrubs at a cover of at least 25%, heathland vegetation occurs widely on mineral soils and thin peats (<0.5 m deep). Blanket bog vegetation may also contain substantial amounts of dwarf shrubs, but is distinguished from heathland by its presence on deep peat solely (>0.5 m).
This habitat type is present on 1,700,000ha to 2,500,000 ha in Scotland. There is likely to be further significant loss of heather moorland to acid grassland if grazing levels and pressures continue.

(Lowland) Raised bog: occurs in shallow basins or on flat, low-lying areas where poor drainage waterlogs the ground and slows down plant decay. Layers of *Sphagnum* moss have developed into huge peat domes. Around 94% of this habitat has been destroyed or damaged in the UK. The raised bog surface may support a mosaic pattern of pools, hummocks and lawns, a microtopography partly created by plants themselves.

This work focused on bogs, but in the following pages "peatland" or "mire" will also be used to refer to this type of wetland.

ii. Classifications of peatlands

There is no unique classification for peatlands, but a wide range of classifications to describe peatlands' communities, from a European-based system to a UK national classification of its own.

UK Biodiversity Action Plan for Broad habitats: (UK BAP)

The Convention on Biological Diversity arising from the Earth Summit held in Rio de Janeiro in 1992, aimed at developing national strategies for the conservation and sustainable use of biological diversity, hence the UK Action Plan's publication in January 1994.

Consequently, a UK Biodiversity Group was given the task of delivering a program, which was meant to identify 'priority' habitats and species along with developing a classification of broad habitat types: class 11 referred to fen, marsh and swamp, and class 12 referred to bogs. In addition, a Biodiversity Action Plan for priority habitats was created between 1995 and 1999 and revised in 2007: section 11 and 12 are now divided into more classes: bogs into lowland raised bogs and blanket bogs, fens into fens, reedbeds, wet woods, upland and lowland heath and purple-moor grass rush pasture, other types of peatlands into either heathland or wet woodlands.

The European Union classification:

The EU 'Habitats' Directive in 1992 established a common framework for the conservation of natural habitats of importance to the European Community. The interpretation manual that follows the Annex I is primarily focused on 'priority habitats'. The remaining habitat types are described by CORINE Biotopes. Although this classification is more precise than the UK Biodiversity Action Plan, it still omits subtypes and regional varieties. (See annex 1).

The EUNIS classification

Habitat types from the European nature information system (EUNIS) are based on habitat types listed in Annex I of the EU 'Habitats' Directive and of the habitat types in Resolution 4 of the Bern Convention. The EUNIS habitat classification covers all types of habitats (natural, artificial, terrestrial as well as freshwater and marine habitats). The EUNIS classification is more precise than the UK Biodiversity Plan for Priority Habitats but is still based on a European point of view and thus does not focus on regional particularities. (See annex 2).

The National Vegetation Classification (NVC)

Given the diversity of communities described as fen or bog ecosystems according to the previous classifications, a national approach to describe habitats has been adopted, according to a specific system of its own, namely the National Vegetation Classification (NVC). Developed in the 80s, the NVC has become the standard classification used. The NVC aims to describe all the vegetation in Great Britain. The NVC is a phytosociological classification, and solely works on the basis of plant species forming communities. They can usually be correlated to other factors, such as geology and soils, climate, water chemistry and management; but plant species alone are used to assign a set of species to a community.

Each broad vegetation type – heath, mire and woodland- is divided into communities designated by a letter and a number. (M is then for "Mires", H for "heath", W for "Woodland").The second volume of "British Plant Communities" (Rodwell, 1991) provides a detailed account of 38 mire communities, among which 31 fen communities. (See annex 3 and 4).

The following table[3] summarizes classifications and definitions:

CATEGORY OF PEATLAND	UKBAP priority habitats	EU habitat directive of interest	NVC classification
Bogs	Lowland raised bog (UK Biodiversity Group, 1999) [Transitions to blanket bog, upland and lowland heath, fens and wet woodland]	Active raised bogs habitat code: 7110	M1,2,18,19
		Degraded raised bog still capable of natural regeneration habitat code: 7120	M3,M15,16,18,20,25
		Bog woodland Habitat code: 91D0 Transition mires and quaking bogs habitat code: 7140	W4c,W18 M5,M8,M9, S27
	Blanket bog (UK Biodiversity Group, 1999) [Includes intermediate bogs, transitions to and complexes with raised bogs, fens, upland heath, wet woods]	Blanket bog habitat code: code 7130	M1,M15,M17,M18, M19,M20,M25,
		Bog woodland habitat code: 7120	W4c,W18
		Transition mires and quaking bogs habitat code: 7140	M5,M8,M9, S27
Fens	Fens (Anon., 1995) [Transitions to blanket and raised bogs, reedbeds, wet woods, upland and lowland heath, purple moor grass rush pasture]	Transition mires and quaking bogs habitat code: 7140	M5,M8,M9, S27
		Calcium-rich fen dominated by great fen sedge (saw sedge), Calcium-rich springwater-fed fens Habitat 7210,7230	M9, M13, 14, 24, 10, S2, S24, S25
		Petrifying springs with tufa formation, alkaline fens, *Molinia* meadows Habitat 7240, 7220,6410	S2, M13,14,24,9,S24,S2 5, M10,, 12, M37,38,26
Other habitats including peatland [Mostly shallow peat <0.5 m, or very local deeper peat habitats]	Upland heathland (UK Biodiversity Group, 1999) - wet heath areas	Northern Atlantic wet heaths with *Erica tetralix* habitat code: 4110	M5,14, M15,16
	Lowland heathland (Anon., 1995) - wet heath areas	Depressions on peat substrates of the *Rhynchosporion* habitat code: 7150	M1,2,4,M15,16,17,1 8,21,29
		Southern Atlantic wet heaths with *Erica ciliaris* and *E. tetralix* habitat code: 4120	M3,4,16,21,
	Wet woodlands (UK Biodiversity Group, 1998) on fen and bog sites	Bog woodland habitat code: 91D0	W4c,W18

Figure 1: summary table of habitat correspondences between classifications

[3] Adapted from G. Patterson et.al, "Forests and Peatlands Habitats, Guideline Note", 2000 and from the National Biodiversity Network (NBN) dictionary for habitats correspondences, 2008.

iii. Distribution of microhabitats

The NVC classification relies on vegetation communities but microtope's patterns and above all microforms also plays an important role in vegetation distribution and communities. In "Bogs: the ecology, classification and conservation of ombrotrophic mires" (Lindsay et al., 1988) Richard Lindsay calls for a hierarchy of microtope and vegetation stands (divided into terrestrial and aquatic microtope) to describe mires. These "micro-habitats" provide another way of classifying peatlands, on a thinner scale. Bog types (from blanket bog to raised bog, through every intermediate forms) are thus associated with mesotope types (watershed, spur, valleyside, eccentric, ridge-raised, plateau) and each mesotope is linked to microtope types on the small-scale. (See annex 5 to 8 for figures and tables explaining microtopes' distribution)

Terrestrial (T) zones	T5: peat mounds (occurs only in Shetland, Caithness, Sutherland, and the Outer Hebrides; 1-3m above the mean water table)
	T4: erosion hags (associated with erosion, 1-2m above the mean water table)
	T3: tall hummocks (normally the highest element in the pattern, bryophyte formed; 20cm – 1m above water table)
	T2: high ridge (general level of mire surfaces; 10-20 cm above water table)
	T1: low ridge (generally the richest zone for the characteristic mire species, 1-10cm above water table)
	T1/A1: water's edge
Aquatic (A) zones	A1: Sphagnum hollows (aquatic phase of dense *Sphagnum cuspidatum*; 0-10 cm below the mean water table)
	A2: mud-bottom hollows (hollow dominated by a relatively solid bare peat base, with some aquatic *Sphagna* (5-20 cm below water table)
	TA2: erosion gullies (resembling A2 but with flowing water)
	A3: droughts-sensitive pools (open water with unconsolidated peat base remaining flooded for much of the time but which will dry up during droughts; 20-50cm below the water table)
	A4: permanent pools

Figure 2: description of mires' microtopes[4]

Figure 3: an example of mires' microhabitats, from overhanging hummocks to ridges, Sphagnum pools and gullies (Rannoch Forest, Tayside, July 2014 - V.Azambourg)

[4] Adapted from Richards Lindsay's classification described in "Bogs: the ecology, classification and conservation of ombrotrophic mires", 1988.

b. *The afforestation of mires: a threat?*

Woodlands in Scotland are somehow strikingly different from France's forests: usually there are strong discrepancies between recreational woods and productive forests. This stems from plantations' policies back in the previous century. The following paragraphs focus on woodland and conifer plantations' definitions, along with their distribution and importance in Scotland.

i. Definitions for woodland and conifer plantations

Forest (and woodland): according to the National Forest Inventory (NFI) woodland is defined as a land with a minimum area of 0.5 hectare with a minimum tree crown cover of 20%, or with the potential to achieve it. A forest must be at least 20 meters wide. (Definition from the"National Forest Inventory Woodland Area Statistics: Scotland", 2011)

Coniferous woodland: often a large plantation with trees in regular rows with possibly broadleaved trees. However the major part of the plantation (over 80%) consists in conifer trees. The only conifers which are generally recognised as native species in Great-Britain are Scots Pine, Juniper and Yew: coniferous woodlands here are mostly plantations made up of introduced species. (Definition from the National Forest Inventory Report (NFI) "2011 woodland map Scotland")

ii. Conifer plantations on peat: species and practices

Much of conifer plantation occurred during the 70s and the 80s in the UK. Due to technical advances and tax incentives, lands previously considered as "unsuitable" were then planted. However obvious environmental conditions prevent tree species from growing on peat. Some trials in the 20s and 30s showed that seven species of conifers would reliably grow on unflushed peat. (Zehetmayr, 1954)

The total area of mapped woodland of 0.5 hectare and over reaches 1,383,410 hectares which represents 18% of the land area in Scotland. (National Forest Inventory "2011 woodland map Scotland")

The largest forest type across Scotland is conifer, representing 59% of all woodland. In comparison, broadleaved forest represents 14%. Sitka spruce is the most planted species (523.3000 ha), then comes Scots pines and Lodgepole Pines (accounting for 94.1000 ha). (See figure 4 on the left)

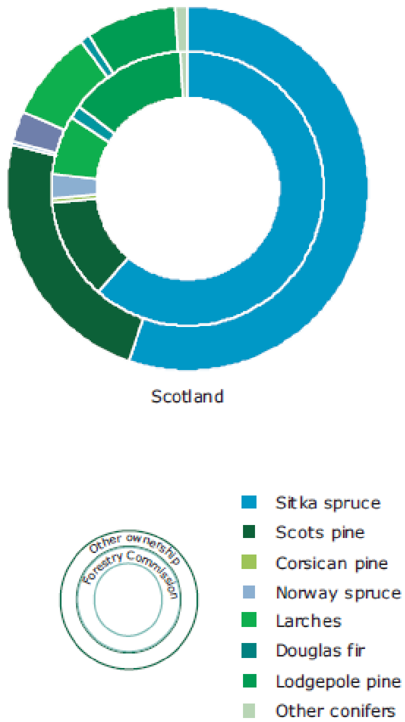

Figure 4: summary of stocked area by principal conifer species in Scotland (Source: National Forest Inventory 2011 woodland map Scotland)

There are approximatively 2.1 million ha of blanket bogs over 50 cm in depths in GB, of which 190 000 ha have been afforested. (K.J. Hargreaves, R. Milne and M.G.R. Cannell, 2003) A reduction of 21% in the extent of blanket mire has been recorded between the 1940s and the 1980s. The greatest single cause of this reduction is afforestation, for 51%. Further losses can be attributed to drainage and heavy grazing, peat cutting and atmospheric pollution. There have been considerable losses of heather moorland in recent times. As for Scotland, over 23% was lost in Scotland, mainly between the 1940s and. Much of it is attributed to agricultural exploitation, heavy grazing by sheep (and, in certain areas, red deer and cattle), and afforestation. The area of lowland raised bog in the UK retaining a largely undisturbed surface is estimated to have diminished by around 94% (in Scotland from 28,000 ha down to 2,500 ha). Historically, the greatest decline has occurred through agricultural intensification, afforestation, and commercial peat extraction. Future decline is most likely to be the result of the gradual desiccation of bogs damaged by a range of drainage activities and/or a general lowering of groundwater tables.

Sitka spruce and Lodgepole pine being the two most planted species over peatland; this study will focus on their encroachment onto peatlands. Spruces have a more valuable timber on peat than Lodgepole pines; which explains its wide expansion in Scotland. While *Pinus contorta* grows the most vigorously on unflushed peat and was planted extensively, *Picea Sitchensis* is more productive on flushed peats. Usually conifers plantations are mixed, pines drying the peat and making more nitrogen available, which benefits spruces. (A.R. Anderson et al., 2000) Besides, Lodgepole pines can bear water table close to the ground surface.

iii. Effect of conifer plantation on peatlands:

Now UK discourages planting on land with peat over 0.5 m deep. Peatlands are recognised as habitats of great value, both for its biodiversity and its role as a carbon sink, and restored. The likelihood of further afforestation has now receded. However conifer plantation on peats' influence on the surrounding peatland is still not fully understood.

By and large, plantations reduce water content of the underlying peat, mainly because of drainage, of water extraction by roots and of rainwater interception by the tree canopy. Bulk densities are also higher whereas depths of water table lower, (P.J. O'Hare, 1968; L. Shotbolt et al., 1998; E.P.Farrell, 1985; R.L Rothwell, 1989) these effects tending to depend on the distance between ditches and the presence of ditches at the forest edge. (In Alberta, Canada R.L Rothwell et al., 1996) Forests on blanket peat dry the surrounding peatland although this effect only extends about 40 m in first rotation forests (Pyatt et al., 1992; Shotbolt et al., 1998). Up to 40 meters away from the forest, water table and dry bulk density are significantly related to distance from the forest edge. (Shotbolt et al., 1998; A.R.Anderson et al., 1995.) Subsidence is a term explaining the lowering of the ground surface under forest plantations because of shrinkage, wastage or oxidation, and compression. Mostly subsidence occurs under the forest, but also in the adjoining peatland. (Pyatt et al, 1992): subsidence occurs only within 50m outside the forest.

Furthermore the underlying peat is usually fertilized when planting, which would enhance mineralization processes. However at high N deposition rates (> 2 g N m−2 year−1) sphagnum reaches its maximum N content and thus N can be used by vascular plants roots (Lee and Woodin 1988; Aerts, Wallén and Malmer 1992; Lamers, Bobbink and Roelofs, 2000). Acidification of the peat (as a result of oxidation processes), ammonium uptakes by plants and proton exchange processes can inhibit mineralization: hence desiccation of the peat would not necessarily trigger higher mineralization rates.

iv. Natural regeneration or colonization:

As conifer plantations are mainly clear-felled when mature, natural regeneration within woodland practically never occurs. However advanced regeneration (AR) would still constitute a "woodland in waiting", responding rapidly to the cessation of grazing. Indeed deer and sheep pressure on peatland are believed to curb tree establishment. (D. Scott et al., 2000; C. Edwards and W.L. Mason, 2006) AR mainly dates back to disturbances (fire, removal of grazing etc.). This would represent the first steps to tree encroachment onto adjacent peatlands.

The extent of natural regeneration onto peatland was studied in the nineties in the Strathmore forest (Caithness): an amount of 2300 stems/ha at 10m from the edge was observed, falling to a density of 100 stems/ha at 30m. Although the Lodgepole pine distribution was less varied and less numerous than Sitka spruce, pines represented there greater volumes. (Report from D.Moreno Manzano for the Forestry Commission of Scotland, 2012) In this restored blanket bog in Caithness, over 90% of the seedlings occurred within 10 m of the conifer plantation edge (Lodgepole pine and Sitka spruce), and a few more even reached distances over 30 m. However many were browsed by deer.

Measures provide clearance within 100m, or 50m, or only in zones with prevailing winds direction, for peatlands are overwhelmingly believed to remain bereft of any tree. Clearance of regeneration is subsidized in order to pull the "weeds", under the Scotland Rural Development Program (SRDP).

However one might question the role of trees in sequestering carbon and thus in mitigating climate change. In some circumstances forestry operations (on deep peats) may release carbon, hence FC guidance to avoid a net carbon loss on peatlands, advising for letting trees on edge woodland for sites that are neither suitable for conventional restocking, nor a priority for peatland restoration. (Forestry on peatland habitats: Supplementary guidance to support the FC Forests and Peatland Habitats Guideline Note (2000)).

v. Deer browsing and sheep grazing

When not in tiny patches surrounded by forests, mires are usually grazed by sheep in Scotland. (Except some protected areas). As seen previously, sheep grazing has an impact on vegetation communities and conifer regeneration on peatlands. (H. Kuechler, et al., 2009) On the other hand, deer browsing has usually a negative impact on tree regeneration in woodland and adjacent bogs. (D. Scott et al., 2000)

There are two types of native deer in Scotland: red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*). Fallow and sika deer have also been introduced to Scotland but remain marginal. Roe deer are found throughout mainland Scotland wherever there is a shelter to hide. They are selective browsers and will prefer herbs, dwarf-shrubs and tree shoots. Roe deer are associated with limiting native woodland regeneration and establishment, particularly in the lowlands and upland fringes of central Scotland. Due to their smaller group sizes and smaller body sizes than red deer, they are not particularly associated with negative grazing and trampling impacts on open ground habitats.
Red deer are selective grazers of grasses, sedges, heathers and woody species. They are found in woodland and on moorland to the tops of mountains, they are widely distributed in the mainland but absent from much of the central belt and the south-east.

Deer browsing pressure should not exceed 4-7 deer per ha for greater levels of regeneration. (R. Thompson, 2004) Using Ecological Site Classification, colonization success were assessed for wet heaths and mires: regeneration for downy birch (*Betula pubescens*) would be possible on purple-moor grass mires (M25). For birch and rowan (*Sorbus sp.*) and to some extent Scots pines (*Pinus sylvestris*), potential regeneration at low density would occur on wet heath (typically M15); on other mire types prospects of regeneration for these species would be very low. (R. Thompson, 2004)

Furthermore, in a previous experiment on birch and Scots pine (R. Thompson, 2004) successful regeneration was observed:

- On heaths where, in a good seed year, the end of sheep grazing followed heavy grazing pressures;
- Within areas of minimal competition stemming from burnt heather
- Where low levels of deer browsing occurred, for red deer densities are <4–7 per 100 ha (Gill, 2000)

On the contrary regeneration was unsuccessful in heather during the growth and mature phases, often associated with deep layers of pleurocarpus mosses and where competitions are high among vascular plants, particularly on “improved” pastures. (R. Thompson, 2004) Although Sitka spruce and Lodgepole pine haven’t got the same physiology and thus do not respond in the same way to environmental conditions, we might think that these factors play as well a role in their regeneration. (R. Thompson, 2004)

c. *Problematic and hypothesis*

What are the factors that could trigger conifer plantations' encroachment onto peatland?

Figure 5: Corrigrennan Forest (near Ben Lomond, May 2014 – V.Azambourg)

No regeneration was spotted next to this Lodgepole pine woodland planted 1967: is it because of heavy browsing/grazing, is this type of habitat less-likely to embed seeds, is the climate too cold and wet there?

Figure 6: Alyth plantation (Perthshire, April 2014 – V.Azambourg)

Some spruce regeneration could be observed through the mist, even though there was a lot a shrub there, which could have presented a competition factor. Could the distribution of certain microhabitats create shelters for seeds, thus protected from browsing?

Figure 7: Moine Dubh (Tayside, near Loch Tummel, July 2014 – V.Azambourg)

Tree regeneration encompassed Scots pine, Lodgepole pine and Sitka spruce. Is it the enclosed nature of this degraded bog which explains these high levels of encroachment? Has the recent adjacent clear-felling triggered advanced regeneration, disturbing grounds and hydrological functioning? Is drainage a factor that could explain the differences between these three examples?

As vegetation structure is mainly determined by previous management and vegetation (Pellerin, S and Lavoie, C, , 2003), regeneration of pines and spruces are believed to be linked to types of drainage, levels of deer browsing and sheep grazing, peat depths, types of habitats and vegetation communities, along with favourable environmental conditions: topography, rainfalls/moisture, acidity, light etc. Fire events, as well as dry climatic periods would also help determine vegetation structures (Pellerin, S and Lavoie, C, 2003) but were not taken into account in this study.

Therefore from diverse literature reviews, degrees of regeneration are expected to be higher on heavily drained peatlands and on thinner soils than on non-drained mires on deep peats. Besides, regeneration would be expected to be more frequent for Lodgepole pine plantations; knowing that the effect of deer browsing and sheep grazing pressures would probably curb tree encroachment.

Furthermore as water tables are lower and bulk densities are higher near woodland edges, there would be more regeneration there that might in turn trigger the lowering of water tables and increase bulk densities and so on. We can thus wonder to what extent is this mechanism threatening peat habitats and where/when this could be stopped, through human or “natural” interventions.

II. Material and methods

This work focused on:

- conifer plantations with Lodgepole pine and/or Sitka spruce for their representativeness and importance in Scotland;
- conifer plantations over 40 years old, so that they are mature enough to have produced seeds
- mainly blanket bogs, although some peatlands had intermediate features and heath patterns;
- Study areas focused on Scottish mires in Tayside, Dumfries and Galloway, Cowall and Trossachs, the lowlands and around Edinburgh; further samples in the Flow Country up North in Sutherland and Caithness were cancelled due to the limited amount of time left.

The initial sample plan aimed at getting the same number of samples in each types of peatland (Lodgepole pine, Sitka spruce and mixed plantations). A hundred plots were then surveyed for statistical significance, in twenty transects, hence an unbalanced amount of plots per types. Surveys were conducted from May until mid-July, 2014, by me.

a. *Phytosociological samples*

In order to record *Sphagum* species, I attended courses at Kindrogan Field Center with Nick Hodgetts for four days up in Tayside. It provided me with identification keys and tips to determine *Sphagna* on the field. For further determining characters, the “Handbook for European *Sphagna*” (Institute of Terrestrial Ecology, Natural Environment Research Council, 1990) was used. For other mosses, the “Mosses and liverworts of Britain and Ireland – a field guide” (Iain Atherton, Sam Bossainquet, Mark Lowley, 2014) was essential. For vascular plants, the “Grasses, Sedges, Rushes and Ferns of Britain and Northern Europe - Collins Pocket Guide” (R. Fitter, 1984) was the reference. I also thank Alice Broome for helping me identifying some sedge, and my supervisor as well, Russell Anderson. We went in Caithness for three days, in Bad á Cheò, and it was the occasion to refresh botanical memories and consider what is or isn’t feasible on the field as well.

The conduct of vegetation sampling is based on Phytosociological methods, recording species abundance for a 2 by 2 m quadrat (as preconized by some experts), according to the Braun-Blanket approach. Abundance-dominance indexes (Cover =C) followed this code:

i: one individual
+: non abundant species and C <1%
1: 1<C<5%
2: 5<C<25%
3: 25<C<50%
4: 50<C<75%
5: C>75%

Proceeding along transects from the tree canopy up to 50 meters away, 5 plots were sampled perpendicular to the plantation’s edge. Distances were: 1m, 5m, 10m, 20m and 50m from the tree canopy. Farther, there were little chances to find regeneration.

a. *Recording tree regeneration/colonisation*

Within these quadrats is also recorded tree regeneration. Seedlings, saplings and trees are differentiated for a more accurate result, along with their level of browsing, to assess any further chances of growth, from lightly browsed to severely browsed. (See annex 9 for levels of deer browsing on trees) Height, diameter and abundance were recorded for each individual.

b. Recording environmental conditions

On the field, slope and aspect were recorded, both to help locating the sample plot and to take this variable into account to possibly explain tree encroachment. Other information related to forest name, district and conservancy area were also added to the form. Then mire mesotope and microtope's distribution at a quadrat's level, in percentages, were also described. Hydrological features, from non-drained bogs to heavily drained bogs and bogs with only ditches at the edge were mentioned, along with the eventual presence of sheep, fences and paths that could influence vegetation. Plantation type and level of healthiness were also added, as well as dominant wind direction. However this latter factor was later abandoned for its little statistical significance; furthermore, prominent wind direction may not directly influence tree settlement onto adjacent bogs if not very strong at the seed season or if supplanted by other minor winds.

c. Levels of deer browsing pressure

Sheep grazing might seem to be easy to assess but on the field it is rather hard to know whether the land is currently grazed or not permanently grazed. Indeed, the absence of sheep does not mean the mire is never grazed, for rotations sometimes imply fallows. Grazing is usually followed by an increase in regeneration on peatlands adjacent to conifer plantations. (H. Kuechler et al., 2009; D. Scott et al., 2000)
So discriminating grazed from non-grazed peatlands could lead to misinterpretations: "non-grazed" peatlands could host more regeneration, but it would not mean that sheep grazing prevents it. Besides, the purpose of this study does not aim at studying sheep grazing itineraries.

Therefore grazing would not be a reliable factor for this study.

Figure 8: sheep grazing (Cameron Muir, June 2014 - V.Azambourg)

Some regeneration is occurring here: is it reflecting a previous break in grazing itineraries or is it due to milder environmental conditions, low deer browsing, or heavy drainage?

On the other hand, deer browsing is a relevant tool used by foresters through pellets counting.
First of all, deer browsing varies according to habitats, but also according to their usage; thus stratification is necessary. For this study, fences were considered to be the limit between the peatland and the forest edge. In each type, a transect of 8 plots is sampled. This transect must avoid running parallel to edges, roads, ditches etc. A plot measures 7*7 m and each is separated by 25m. Searches must be careful, often on hands and knees, but should not penetrate the litter/humus layer. Dung group are counted and recorded. A dung group is defined as a cluster of more than six pellets and dung groups are usually obvious large accumulations of individual pellets. Very low number of pellets can be associated with strings of pellets caused by an animal defecating while on the move, or the pellets being scattered on hitting the ground. (Protocol explained by P.R. Ratcliffe, B.A. Mayle, "roe deer biology and management", Forestry Commission, Bulletin 105, 1992)

d. Locating sample sites

Land Cover Map 2007 (LCM2007)[5] is a map providing information for the entire UK based on the Biodiversity Action Plan (BAP) for Broad Habitats. The Centre for Ecology & Hydrology, on behalf of the Countryside Survey partnership, provides this parcel-based classification at 25x25m accuracy. As to conifer plantations, the National Forest Inventory (NFI-2010)[6] provides forest blocks and subcompartments for each type of FC woodland, along with the LCM2007 for both private and FC woodlands, yet with no distinction between tree species. (Class 2 refers to coniferous woodland) A spatial framework based on generalised digital cartography (Ordnance Survey Map topographic layer (OSMM) for GB), refined with image segments is used by both systems according to the British National Grid reference.

Extracting the sub-layer accounting for “class 12 – bogs” and then overlapping it within a 100m distance of forest subcompartment then resulted in a map with potential sites to study. (See map below)

[5] Full data descriptors for this GIS layer are available at:
http://www.countrysidesurvey.org.uk/sites/default/files/LCM2007%20Dataset%20Documentation%20-%20Version%201.pdf
http://www.forestry.gov.uk/pdf/NFI-Description-of-attributes.pdf/$FILE/NFI-Description-of-attributes.pdf

[6] full data descriptors for these layers are available at:
http://www.forestry.gov.uk/pdf/NFI_Method_Statement_250511.pdf/$FILE/NFI_Method_Statement_250511.pdf

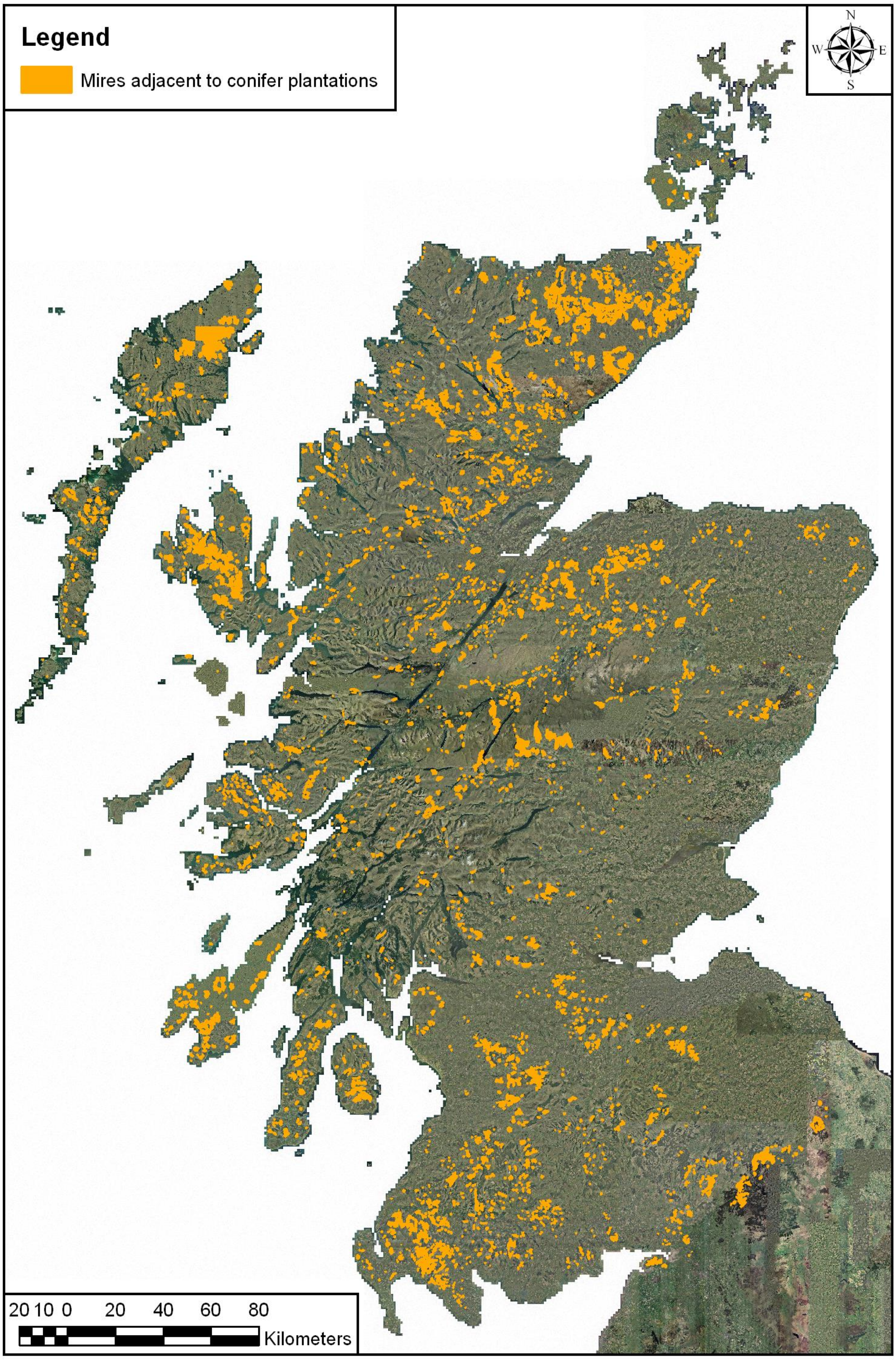

Figure 9: Distribution of mires in Scotland (Source: LCM2007, FC, JHI, OSMM – May, 2014)

However the Land Cover map is not totally reliable to detect mires, so peat depths data helped matching information and checking that adjacent plantations were on peat. This incorporates the 1:250,000 Soils of Scotland data provided by the James Hutton Institute. Peat depth data were examined to ascertain average peat depths for individual bogs from 1985 onwards; some mires were not sampled though. (See annex 10)

Besides the Forestry Commission (FC) browser provided up-to-date data to decipher whether clear-felling had already occurred or whether some areas must be avoided because of forestry works in progress. From then on followed a series of research to find owners and forest managers to ask permission to enter their forests, and moreover to know if there are any constraints (birds nesting, hunting etc.).

Eventually three main areas were retained for this study:

- Cowall and Trossachs and the Scottish lowlands (within and out of the Loch Lomond and the Trossachs National Park) – see annex 11 to 17
- Dumfries & Galloway (Within and out of the Galloway Forest Park) – see annex 18 to 23
- Tayside (around Loch Rannoch and Loch Tummel – within and out of the Tay Forest Park) – see annex 24 to 31

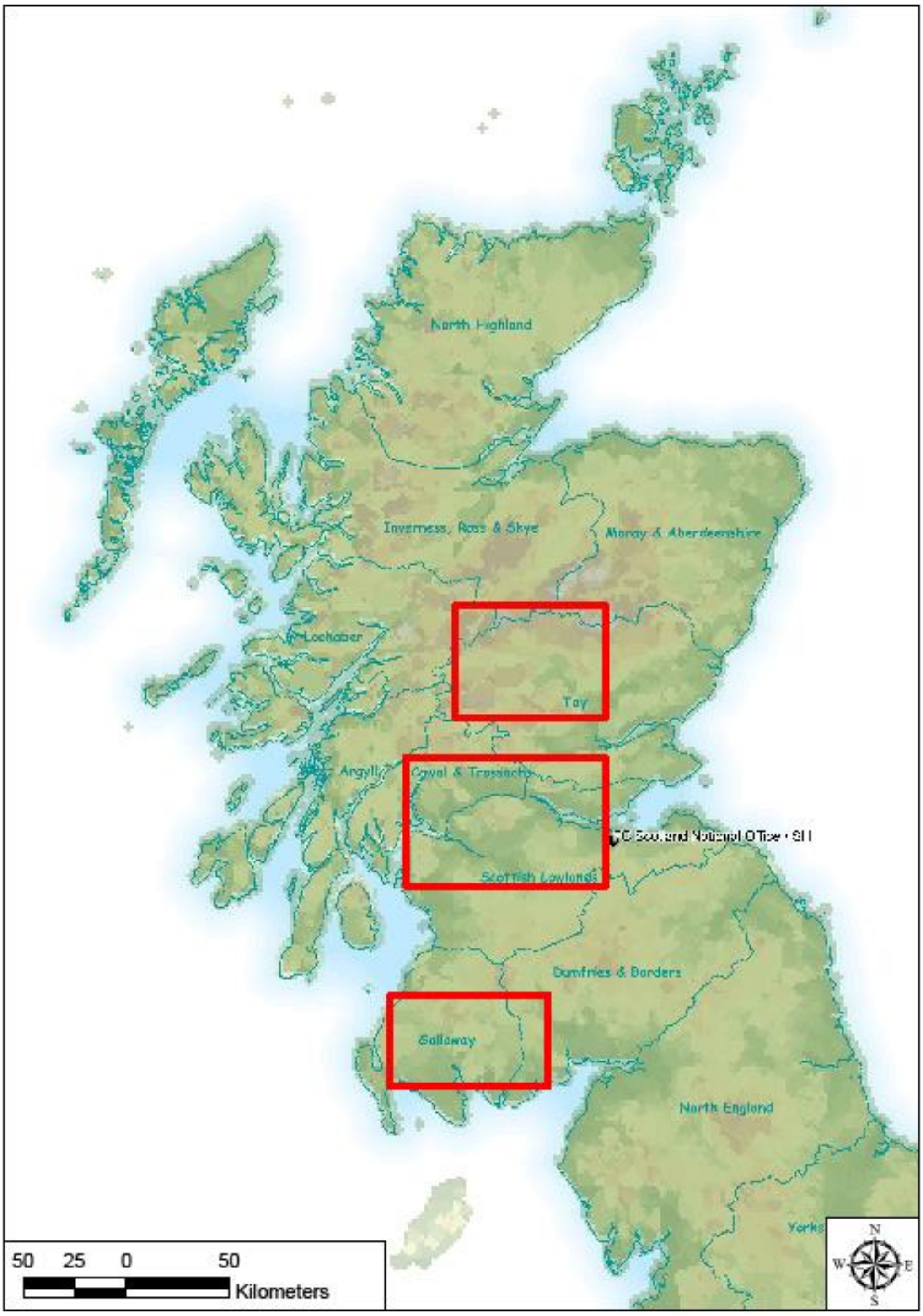

Figure 10: Selected areas for this study (Source: OSMM – May, 2014)

See annex 32 for forms used for field surveys.

III. Results

a. *Presentation of the set of data*

The set of data is divided into two excel sheet: one where, for each quadrat, various environmental measures (aspect, peat depth, topography etc.) were recorded, along with percentage covers previously detailed. The other table only takes into account species in each quadrat, recorded with their abundance.

Among plots, 20 out of 100 had regeneration; mainly for the first ten meters (one plot at 20 meters from the forest edge had regeneration though). In total 14 sites have been surveyed, some presented different type of plantation, hence several transects (20 in total, with 5 plots each). Even though some had tree regeneration, the majority had nearly none. Some scattered trees were sometimes spotted, entangled in fences, which might lead to the conclusion that browsing could explain the lack of regeneration elsewhere. (see picture)

Figure 10: an entangled tree at Corrigrennan Forest; May 2014 - V.Azambourg)

For Moine Dubh (transects 13.1 and 13.2) and Flanders Moss (transect 11.1) there was a lot of regeneration (birch, Scots pine, Sitka spruce and Lodgepole pine) but these transects did not intersect it, for deliberately choosing to sample regeneration would introduce a bias. Assigning a habitat (according to the NVC classification) was not very easy, as they often describe sub-communities and rely on frequency and abundance. By and large, mires were mostly M20, M18, M19, M6 and M25, and accounted for more than a tenth of the cases.

A set of 118 species encountered, over a hundred plots forms a set of data for species. The 10 most encountered species are enlightened in this excerpt.

Scientific names	Count (occurrence)
Eriophorum vaginatum	63
Molinia caerulea	54
Erica tetralix	52
Calluna vulgaris	51
Hypnum jutlandicum	51
Potentilla erecta	44
Pleurozium schreberi	43
Polytrichum commune	39
Trichophorum cespitosum	39
Rhytidiadelphus loreus	36

Table 1: table of occurrence for the ten most frequent species

These species are typical of peatlands. *Molinia caerulea* can also be found elsewhere though. Oddly enough, sphagnum species do not rank first, but still occur in more than 20% of plots for the most frequent of them: *Sphagnum papillosum*, *Sphagnum cuspidatum*, *Sphagnum capillifolium subsp. capillifolium*, and *Sphagnum subnitens*, which all present different microhabitats and environmental conditions.

Hypnum jutlandicum is not particularly labelled as a bog moss; on the contrary, this pleurocarpus moss is mostly associated with acidic heathland, upland grassland, woodland and conifer plantations. It was indeed often spotted under *Calluna* hummocks, in shade.

b. *Statistical analysis:*

i. Correspondence Analysis (CA)

A first attempt was made to analyse species data. A CA (Correspondence Analysis) was thus conducted using Rstudio. Correspondence Analysis is a multivariate statistical analysis applied to categorical data, in this case species presence (noted 1 when found within a plot). CA displays the set of data in a 2 dimensions graph where species and plots are displayed by "minimizing" the distance between plots and species they contain.

However, given the results, another CA has been made on CANOCO, by Andrew Peace, whom I thank for it. Indeed, the previous CA graph was so dense that nothing could be inferred from it. This latter package basically does the same as the CA in Rstudio, but down weights "rare" species' effect in placing plots along CA ordinates. Indeed, as the previous table infers, many species were found less than twice over a hundred plots.

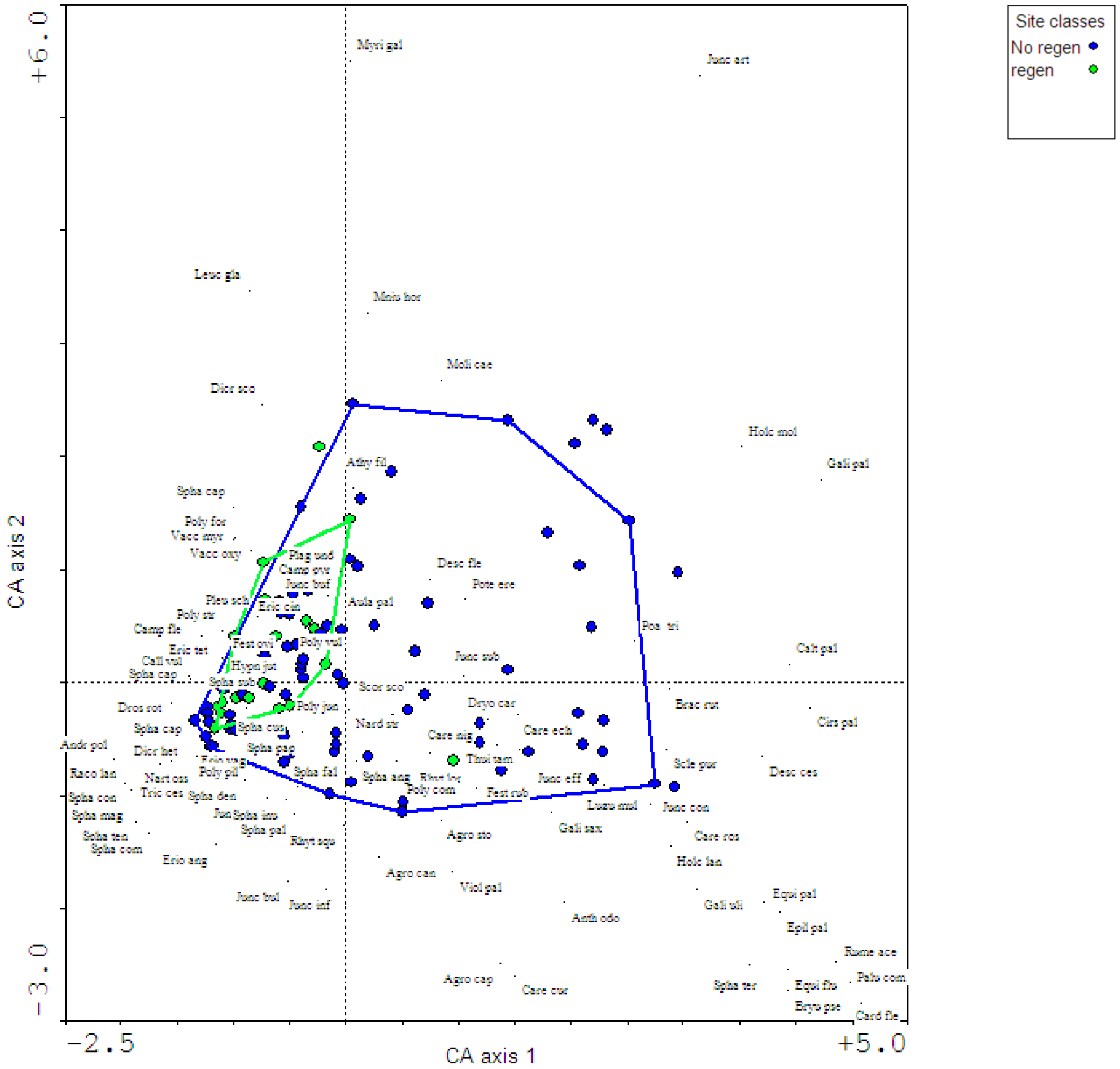

Table 2: Correspondence Analysis graph

Lodgepole pine and Sitka spruce were omitted so that the CA would not, somehow, be biased and would not discriminate plot with regeneration from plots without any on this basis. When adding plots to the CA graph, we can observe a strong discrepancy between these plots. According to the first CA axis, called F1, the majority of the plots with regeneration have coordinates between -1 and 0, whereas plots with no regeneration are widely distributed up to +3 along this axis, whose eigenvalue reaches 56,05 %.

Concerning vegetation, three Sphagnum subspecies are divided into *S. capillifolium*, *S. capillifolium subsp. capillifolium* and *S. capillifolium subsp. rubellum*. On the field, I tried to do my best to decipher which is which but for this graph they should all have been grouped together. This does nonetheless not really affect the overall tendencies. Indeed, we can observe that most of the real bog species are confined to the lower left-hand quarter. This which would then lead to the conclusion that peatlands with the most specific bog vegetation would be more likely to embed regeneration, compared to other types of habitats dominated by grasses or sedges, or swampy mires.

Yet regeneration was not systematically present among these sites.

This other CA graph (see below) presents the same a cloud of points with no tendencies, but where distance is highlighted for each plot (species are there omitted for a better visibility). Each plot has a different colour according to their distance; plots from the same distance are grouped together: those within the lines represent 90% of the total.

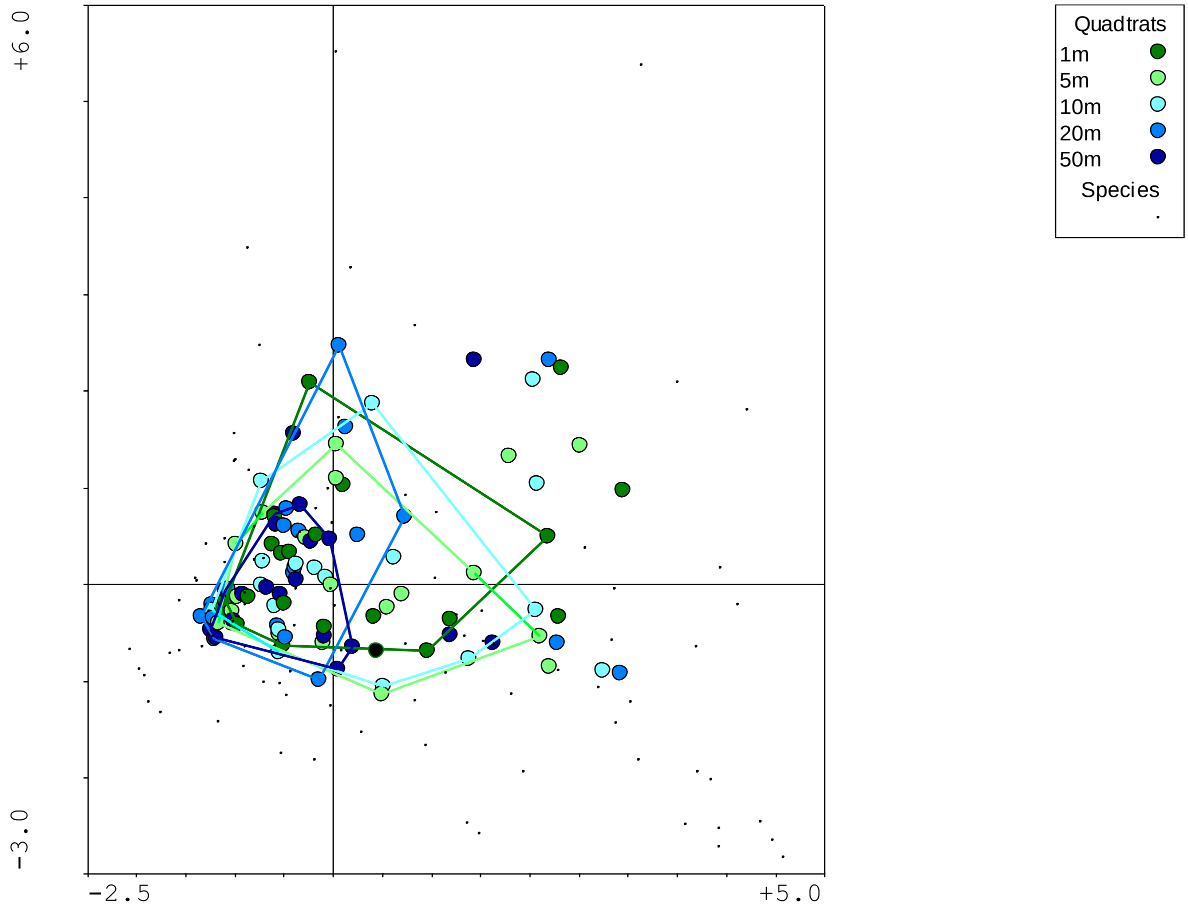

Table 3: Correspondence Analysis graph with distances highlighted

Indeed, contrary to what we might expect, i.e. that distance to the seed source may have a great influence on regeneration (and the way plots are displayed on the CA graph), this CA graph shows that the display of quadrats is not obviously linked to distance. Therefore the first axis does not reflect distance, but other environmental factors which strongly divide plots with regeneration from those without any, with little regard for distance to the seed source.

However this CA graph shows that plots located 20 and 50 m away from the edge are for the majority confined to the same place as plots with regeneration, knowing that these plots are yet often situated near the forest edge (D=1m or 5m or 10m for the great majority). This would suggest that for transects with no regeneration at all, the more we go away from the edge, and the more we tend to be closer to plots where regeneration was spotted. This could lead to the conclusion that far plots with no regeneration display similar features to plots with regeneration. Would it also mean that close stands are more likely to get regeneration if similar features are displayed further out, contrary to other situations where the farther we get from the plantation edge, the more different the vegetation is?

On the one hand this CA graph suggests that transects with regeneration are different from transects with none as they would be placed altogether at low F1 values. Besides, we can wonder if sites with regeneration near the edge would, on the long term, show further regeneration once there is settled regeneration at the edge.

On the other hand we can say that plots with regeneration are strongly affected by the proximity of plantations but this tends to fade away when we look at farther plots. This would then suggest that these ecotones are inherently different from plots with no regeneration. Is it reflecting managements (drainage, browsing etc.) or intrinsic characteristics (type of habitat, peat depths etc. although the planting may have, somehow, affected the ecosystem)?

Another remark is that these differences of distribution according to distance seems to show various stages or steps; there would be transitory distances which might refer to shifts in vegetation and/or ecosystems functioning, which might remind us of mires zonation (successions of habitats from driest fringes to wet centres)

In the end, we can suppose that species close to plots with regeneration could be associated to regeneration and vice-versa. These species are: *Plagiothecium undulatum*, *Campylopus pyriforme*, *Pleurozium schreberii*, *Polytrichum vulgare*, *Hypnum jutlandinicum*, *Polytrichum juniperum*. (The others are either too rare or too "far" from plots to be considered as related to regeneration, as *Sphagnum subnitens* and *Sphagnum cuspidatum*). *Polytrichum sp*. and *Hypnum jutlandicum* in particular are almost always spotted with regeneration; are they indicator species or induced species by the ecotones? Is regeneration triggering a shift in vegetation, or is it a specific vegetation that embeds regeneration? These mosses tolerate dryer habitats than usually found in mires, especially *Polytrichum formosum* and *Polytrichum juniperum* (), which like dry and acidic substrates, often exposed. As *Polytrichum juniperum*, this moss even occurs as a pioneer on recently disturbed or burnt soils. This could mean that seeds, as well as this acrocarp, would take advantage of fire episodes and disturbances.

As a matter of fact, I personally observed that next to recently clear-felled areas there was often much more regeneration than on adjacent stands where trees were still standing.

Figure 11: regeneration on disturbed grounds (Campsie Fells, June 2014 - V.Azambourg)

To boot, some *Sphagna* and other mosses are rather found everywhere: are they competitors, are they less affected by tree encroachment and represent the last remnants of a former bog with no regeneration?

The analysis of variables that could explain the construction of the first axis, called F1, should explain the presence of regeneration.

ii. Study of the first CA axis: F1

First of all, a shift has been made to turn factors into categorical variables concerning such as peat depths, hydrological features and to a certain extent deer browsing pressure. Deer browsing is then divided into two classes: 0 for low browsing pressures, under 4 pellets on average that is to say under 4-5 deer per ha; 1 is for higher values. This division is quite common among foresters: 4-5 deer per ha is the usual threshold. Peat classes discriminates "shallow" peat, fewer than 50 cm deep, from "deep" peat, over 50 cm deep. Indeed experts always make the distinction between these two cases, as there are typical vegetation and habitats associated to shallow peat bogs. Hydrological features are divided in three sections: 0 means "no drainage", 1 refers to bogs with ditches at the edge of the plantations, and 2 means that the peatland is heavily drained, not solely at the edge of the forest.

Using Rstudio, a stepwise method has been applied to the set of site data. This method uses both backward and forward methods to find a model with the "best" Akaike Information Criterion (AIC). This AIC is a goodness of fit measure that favours smaller residual error in models, and also selects the simpler model with the fewer variables possible. In the end the stepwise method selects the maximum likelihood models whose AIC is the smallest. (See annex 33)

In this case, a stepwise linear regression ended up with the following variables:

-Reaction[7] (Ellenberg's index for acidity): its estimate is ~0.53; hence regeneration is rather found on acidic soils (R<3) which is counter-intuitive since pines and spruce need fertilization to grow on peat; however as peat dries out, it becomes more acidic ((Lee and Woodin 1988; Aerts, Wallén and Malmer 1992; Lamers, Bobbink and Roelofs, 2000): so this indices would reflect the dryer stands where regeneration could settle;

- Nitrogen (Ellenberg's index for soil richness): its estimate is ~0.69; looking at graphs, regeneration plots are located on poor soils, which is, again, quite surprising ; however this could be explained by the fact that, the acidification and desiccation of the peat near the forest edge as a result of fertilization does not trigger higher mineralization rates (Lee and Woodin 1988; Aerts, Wallén and Malmer 1992; Lamers, Bobbink and Roelofs, 2000);

- National Vegetation Communities (although some have no significant parameter results, M23, M24 and M25, M9 and S27 seem to be positively correlated to F1): even if the results are not significant, there seems to be more regeneration in M15, M18 and M20 than in other types of habitats, but this will be further analysed;

- Salt tolerance (Ellenberg's index for salinity, which should not appear in the model since most of the species are not found in salt zones);

- Bryophyte percentage cover: its estimate is 0.003; F1 is positively correlated to bryophytes cover so there would be more regeneration for low bryophytes covers, however looking at the graph there seems to be regeneration for a wide range of percentages;

- Precipitation (index for rainfall – mm per hectads): its estimate is -0.004 (standard error is 0.001); regeneration plots are found for rainfalls between 1250 and 1350 mm/hectads, which ranks among the highest rainfalls; we would rather expect to find seedlings on drier lands, but there might nonetheless be other factors to take into account, such as moisture, light etc. which would represent suitable environment conditions for regeneration;

- Mean temperature of January Tjan): its estimate is -1, 05 (with a high standard error though, 0, 47): plots embedding regeneration are located at low temperatures, which is, again, counter-intuitive;

- Distribution of T2 (percentage cover of high ridges): its estimate is 0,0029 (with a "high" standard error : 0,0012): regeneration is rather found at every level of covers;

- Distribution of A1 (percentage cover of *Sphagnum* hollows), whose estimate nearly is the same as for T2; the more there is sphagnum hollows, the less likely there would be regeneration for F1 is negatively correlated to A1;

- Distance to the plantation edge: its estimate is negative, which is logical: the farther we go, the less we find regeneration, which makes sense;

- Distribution of A3 (percentage cover of drought-sensitive pools): its estimate is 0,01: as this type of microhabitat was hardly found on the field, no definite answer can be made.

This model fits well as its p-value is very low (p-value: < 2.2e-16) and its adjusted R-square reaches 0.97. However variables that could have been linked to F1 according to a binomial model were out of the model.

The type II Analysis of Variance Table (Anova test) is a way of considering variables in terms of importance: those with the highest sum of square or the lowest p-value are the ones that bring the most information. Here R, N, habitat and Prec strongly build the first axis F1. To a certain extent bryophyte cover, Tjan, distribution of microhabitats and distance to the edge play a minor role. (See annex 33)

Annex 34 presents graphs of F1 according to these main variables.

Given these results, further statistical analysis have been conducted to find what are the variables that could explain the presence of regeneration, for this model for F1 is not satisfying enough.

iii. Study of regeneration at a transect's level: Rtr

Rtr is another variable related to the presence/absence of regeneration, but this time at a transect's level rather than at a plot's level, contrary to REGENTOT. By doing so, the effect of distance to the edge of the conifer plantation is erased. However it turned out to skew results and this variable was finally abandoned given the very insignificance of the results.

[7] Ellenberg's indices as well as Rainfalls and Mean Temperatures were obtained by the mean of these indices for each species, their abundance being taken into account. For vegetation species, these indices were available in PLANTATT revised in 2008 and for bryophytes, thanks to BRYOATT, 2007.

iv. Study of regeneration at a quadrat's level: REGENTOT

REGENTOT is the variable that merely indicates that a plot contains conifer regeneration or not.
Basically, REGENTOT is nearly the same variable as Rtr, but contrary to Rtr, REGENTOT is at a plot's level, which makes more sense when regarding microhabitats and environmental indices. Moreover, some transects presented no regeneration whereas a hundred feet away some regeneration could be spotted.
This variable nevertheless has downsides: the effect of distance is expected to be very strong and could thus erase other variables' effect over REGENTOT.

The graph presented in annex 35, along with the predictive model, illustrates the correlation between the first axis F1 and REGENTOT. However F1 isn't the only factor that could explain the distribution of REGENTOT, and the model which explains F1 does not fit REGENTOT.

Previous statistical analysis conducted with the whole set of data proved to be little significant. Moreover, to address foresters effective tools to assess any areas "at risks" (I.e. possibly threatened by encroachment), the most useful variables were selected and kept for further statistical analysis. (see annex 36 for the graphs of REGENTOT according to these variables).
These are:

- Tjan, Tjul, Prec, to represent climatic conditions;
- deer browsing put into two classes an taken as a variable and not a factor;
- shrubs and vascular plants covers, in an attempt to consider possible competitions;
- slope, to take into account topography;
- distribution of T3 (high hummocks), this microtope being the most relevant among others and maybe the easiest one to assess on the field;
- peat depths put into two classes but still taken as a variable and not a factor;
- hydrological features, into three classes, arranged from the undrained type to the strongest drained type, taken as a variable and not as a factor.

Model selection via the stepwise method

Both with the forward and backward method, the stepwise analysis of deviance ends up with a final model which encompasses: distance to the seed source, hydrological features, percentage of shrubs cover, slope and percentage of vascular cover, using a binomial model for REGENTOT has only two values: 0 or 1.

Source	d.f.	Deviance	Mean deviance	Deviance ratio	Approx chi pr
Regression	6	47.87	7.9782	7.98	<.001
Residual	93	52.21	0.5614		
Total	99	100.08	1.0109		
Change	-2	-4.22	2.1109	2.11	0.121

Figure 12: summary of analysis

First of all, the residual deviance accounts for more than a half of the total deviance, which suggests that the model does not totally explain the variability of responses.

Furthermore, the residuals do not appear to be random; for example, fitted values in the range 0.00 to 0.08 are consistently larger than observed values and fitted values in the range 0.32 to 0.40 are consistently smaller than observed values. The error variance does not appear to be constant too: intermediate responses are more variable than small or large responses. This model is nonetheless the "best" one found by this stepwise method.

Parameter	estimate	s.e.	t(*)	t pr.	antilog of estimate
Constant	2.95	1.56	1.89	0.059	19.06
distance	-0.1696	0.0665	-2.55	0.011	0.8440
shrubs	0.0758	0.0264	2.87	0.004	1.079
slope	-0.435	0.264	-1.65	0.100	0.6473
vasc	-0.0487	0.0195	-2.49	0.013	0.9525
hydro 1	-1.14	1.12	-1.02	0.309	0.3200
hydro 2	1.135	0.841	1.35	0.177	3.112

Figure 13: estimates of parameters

The reference level endorse both the intercept and the first level of drainage, i.e the level “0 – no ditches at the plantation edge”. Hence the difficulty to analyse the effect of this hydrological level. However while comparing it to other levels of drainage; we can infer the following things.

Whether there is a ditch at the edge or not, this type of hydrology is positively correlated to the presence of regeneration; indeed, even though the estimate for “hydro 1” is negative (estimate=-1.14), its standard deviation is 1.12, which means that the estimate might as well be 0. This can be explained by the fact that this category encompasses several cases: ditches were either very deep and wide, or rather shallow and sometimes even filled with litter and/or recolonized by *Sphagnum*.

Figure 14: a deep ditch (Bad á Cheò, Caithness, April 2014 - V.Azambourg)

Figure 15 (left): a ditch progressively filled with Sphagna (Bad á Cheò, Caithness, April 2014 - V.Azambourg)

Compared to the constant, the fact that the peatland is heavily drained would result in higher probabilities of regeneration, as its estimate is positive (1, 14 – for a standard deviation of 0, 8).
Therefore we can conclude that a high level of drainage would trigger more regeneration than an undrained peatland.

As expected, distance has a negative estimate, as well as slope and vascular plant cover. Therefore we can conclude that the steeper slopes are, the less likely there would be regeneration, which, in a way makes sense, but if slopes were combined with heavy levels of drainage, the results might be different. For higher levels of vascular plants covers, there would be a lesser probability of regeneration, with would then epitomize the effect of competition. But when looking at the graph of REGENTOT according to vascular plants covers (See annex 37), such a link doesn’t seem pretty obvious. On the contrary, the estimate for shrubs cover is positive, which may mean that *Calluna vulgaris*, *Erica tetralix* or *Vaccinium myrtillus* would be associated with higher probabilities of regeneration. This could also be explained by the fact that these shrubs can be associated to high hummocks, which are dryer than the surrounding microhabitats and would thus provide seeds with shelters. However distribution of T3 was not selected in this statistical model with five variables.

The following plots have high leverage:

Unit	Response	Leverage
2	0.00	0.301
33	0.00	0.199
42	1.00	0.226
44	0.00	0.297
61	0.00	0.179
64	0.00	0.209
66	1.00	0.185
73	1.00	0.285
76	0.00	0.194

The second plot (unit 2) was next to fences and possible trampling might have occurred there, elsewhere, for example in plot 42, a profound ditch was at the forest edge, somewhere else the plantation had suffered wind damage (plot 66), which might explain why these observations did not fit the model closely. For unit 76, which is located in Rannoch Forest (Tayside), the slope might have been too high for seeds to settle in, partly because there was stretches of bare peat possibly subjected to water run-off. By and large, some peatlands had a high deer browsing value, but yet embedded regeneration (transect 12.1 especially, plots 71 to 75): this might be due to the assessment of it, for pellets counting is at a wider scale than the quadrat level, so locally, depending on microhabitats and vegetation, deer might turn their back on other stands and let regeneration grow.

Change	d.f.	deviance	mean deviance	deviance ratio	Approx chi pr
+ distance	1	16.7781	16.7781	16.78	<.001
+ shrubs	1	16.9955	16.9955	17.00	<.001
+ slope	1	5.1802	5.1802	5.18	0.023
+ vasc	1	4.6936	4.6936	4.69	0.030
+ hydro	2	4.2218	2.1109	2.11	0,121
Residual	93	52.2112	0.5614		
Total	99	100.0805	1.0109		

Figure 16: regression analysis

For this model, the variance analysis shows that hydrological features hasn't got a "good" p-value and might not be kept in the model, as it apparently brings little information about REGENTOT compared to other variables (shrubs cover for example, which account for nearly 17 out of 100, 1 in terms of deviance). Drainage is nonetheless a good tool for foresters on the field and should be taken into account anyway.

The following analysis considers different subsets of models with AIC: this gives thus alternative models for the same fitness and the same number of variables.

All possible subset selection

Free terms are:
(1) Prec
(2) T3
(3) Tjan
(4) Tjul
(5) deer
(6) distance
(7) hydro
(8) peat
(9) shrubs
(10) slope
(11) vasc

Best subsets with 1 term

Adjusted	Aic	Df	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
15.92	87.30	2	-	-	-	-	-	.000	-	-	-	-	-
7.38	95.76	2	-	-	-	-	-	-	-	-	.004	-	-
3.87	99.23	2	-	-	-	-	-	-	-	-	-	-	.028
3.54	99.56	2	-	-	-	-	-	-	-	-	-	.034	-

Best subsets with 2 terms

Adjusted	Aic	Df	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
32.38	72.31	3	-	-	-	-	-	.000	-	-	.000	-	-
21.57	82.91	3	.011	-	-	-	-	.000	-	-	-	-	-
19.85	84.59	3	-	-	-	-	-	.000	-	-	-	.030	-
19.72	84.72	3	-	-	.032	-	-	.000	-	-	-	-	-

Best subsets with 3 terms

Adjusted	Aic	Df	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
37.01	69.13	4	-	-	-	-	-	.000	-	-	.000	.023	-
34.51	71.56	4	-	-	.097	-	-	.000	-	-	.000	-	-
33.74	72.31	4	-	-	-	-	-	.000	-	-	.000	-	.157
33.38	72.65	4	-	-	-	.198	-	.000	-	-	.000	-	-

Best subsets with 4 terms

Adjusted	Aic	Df	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
41.24	66.43	5	-	-	-	-	-	.000	-	-	.000	.005	.030
39.02	68.56	5	-	-	.109	-	-	.000	-	-	.000	.025	-
38.65	68.92	5	.138	-	-	-	-	.000	-	-	.001	.015	-
38.27	69.29	5	-	-	-	.175	-	.000	-	-	.000	.021	-

Best subsets with 5 terms

Adjusted	Aic	Df	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
44.46	66.21	7	-	-	-	-	-	.000	.121	-	.000	.003	.006
41.96	67.16	6	-	-	-	-	-	.000	-	.259	.000	.005	.037
41.75	67.35	6	.298	-	-	-	-	.000	-	-	.001	.005	.059
41.41	67.67	6	-	-	-	.384	-	.000	-	-	.000	.006	.057

Best subsets with 6 terms

Adjusted	Aic	Df	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
45.22	66.95	8	-	-	-	-	-	.000	.122	.261	.000	.003	.009
44.54	67.58	8	.427	-	-	-	-	.000	.152	-	.002	.006	.013
44.28	67.82	8	-	-	-	-	.532	.000	.118	-	.000	.005	.012
44.26	67.84	8	-	-	-	.540	-	.000	.147	-	.000	.006	.020

Best subsets with 7 terms

Adjusted	Aic	Df	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
46.26	67.44	9	.219	-	-	-	-	.000	.143	.143	.003	.008	.023
45.36	68.26	9	-	-	.408	-	-	.000	.152	.197	.000	.016	.035
45.34	68.28	9	-	-	-	.413	-	.000	.135	.212	.000	.007	.029
44.72	68.85	9	-	.752	-	-	-	.000	.123	.279	.000	.005	.014

The first subset shows that distance is the best variable to put into a model with one variable; if we want to rely on another variable, shrubs cover, vascular plants cover or slope are also possible choice, but their AIC is higher and does not totally explain REGENTOT distribution. The second subset confirms that distance must be taken into account as this variable appears in every model with only two variables. Compared to subsets with 6 and 7 variables injected in the model, the AIC does not lowers much; this suggest that a model with only 5 variables to explain the presence of regeneration over a hundred plots is enough. Then distance, shrubs and vascular plants cover and slope are in each model; the best one (AIC=66.21) also takes into account the level of drainage. (See highlighted lines). Adding peat depths to it does not really improve the model since its AIC reaches 66.95 (see the highlighted line for subsets with 6 terms). Hence keeping those five variables is an easy way of assessing on the field whether the probability to have regeneration is high or not.

As drainage, peat depths and habitats are variables that could be taken as factors, the following analysis aimed at considering any differences of regeneration between types. (I.e. between poorly drained and heavily drained bogs, between deep and shallow peats, and between types of habitats.)

REGENTOT according to factors

REGENTOT and drainage

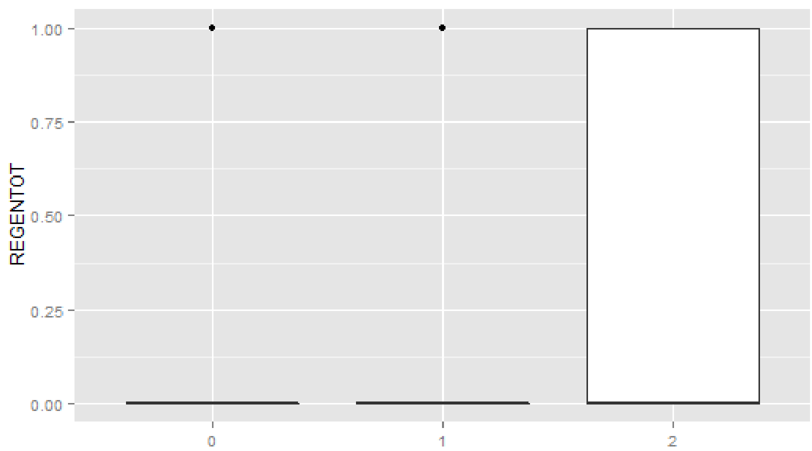

Figure 17: REGENTOT according to levels of drainage

Even though there seems to be a link between REGENTOT and the level of drainage, neither a linear model nor a binomial model could be clearly fitted. Hence the classification of drainage into three classes, compared to each other. The following table summarizes the presence of regeneration for each type of drainage. The difference of means would suggest that heavily drained bogs are more likely to have regeneration.

	Non-drained bog: level "0"	Bog with a ditch at the edge: level "1"	Heavily-drained bog: level "2"
Count of regeneration	40	27	33
Mean	0.1500000	0.1481481	0.3030303
Standard deviation	0.3616203	0.3620140	0.4666937

Table 4: summary of regeneration spotted for each level of drainage

The Tukey test compares each type of drainage from one another; the null hypothesis is that each has the same mean, and the adjusted p-value gives a statistical answer to it. In any case, this value is higher than 0.05, which means that none of the hydrological feature is significantly different from the other. The adjusted p-value is even nearly equal to 1 for the comparison between non-drained peatland and peatland with ridges at the forest edge, which means that both are quite similar in terms of regeneration's response. Another explanation is that each treatment has not the same amount of observation, so if there had been the same amount of observation per type of drainage, there might have been more differentiated features appearing. Furthermore, we can argue on the ordination of drainage, as "0" is supposed to host less regeneration as "1", which is supposed to have less regeneration than "2". Yet on the field, peatlands classified as "lightly drained" encompass a variety of ditches, whose depth and width may affect the hydrology and thus regeneration potentialities. In some cases ridges were quite filled with litter and Sphagnum had begun to colonize it.

Comparison between levels	Difference	Lower value	Upper value	p adjusted
1-0	-0.001851852	-0.23866282	0.2349591	0.9998090
2-0	0.153030303	-0.07055887	0.3766195	0.2383729
2-1	0.154882155	-0.09184280	0.4016071	0.2981795

Table 5: Tukey multiple comparisons of means with a 95% family-wise confidence level

Attempts to fit models with interaction between drainage and other variables did not prove to be significant.

REGENTOT and peat classes

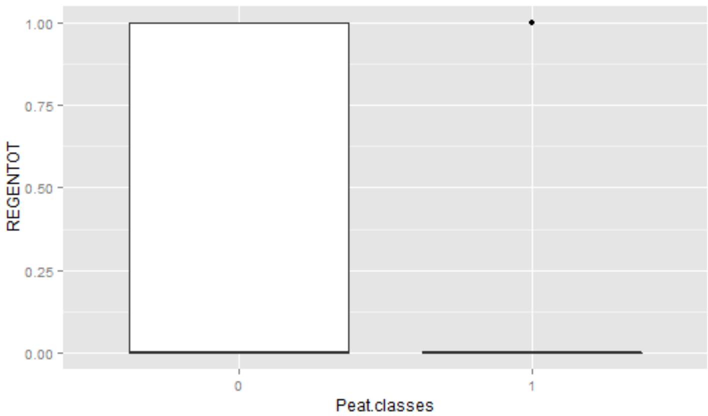

Figure 18: regeneration at a plot's level according to peat depths

From this graph and the following table which summarizes the presence of regeneration for each classes of peat depth, there would be a huge difference of means, which would suggest that shallow peat bogs would be more likely to embed tree regeneration.

	Shallow peat depths: level "0"	Deep peat depths: level "1"
Count of regeneration	10	90
Mean	0.4000000	0.1777778
Standard deviation	0.5163978	0.3844675

Table 6: summary of regeneration spotted for each peat depths classes

The Tukey comparison test based on means lead to the conclusion that there is a difference between shallow peat and deep peat at p < 0, 1, which is not highly significant. However, there might be not enough data for shallow peat, as there are only 10 observations out of 100 for this section. Sometimes conifer forests were planted on shallow peat, which would explain why near the edge there would be more regeneration. Besides, now plantations on shallow peat are forbidden by the British law.

Comparison between classes	Difference	Lower value	Upper value	p adjusted
1-0	-0.2222222	-0.4857658	0.04132136	0.0974536

Table 7: Tukey multiple comparisons of means with a 95% family-wise confidence level

REGENTOT and habitats

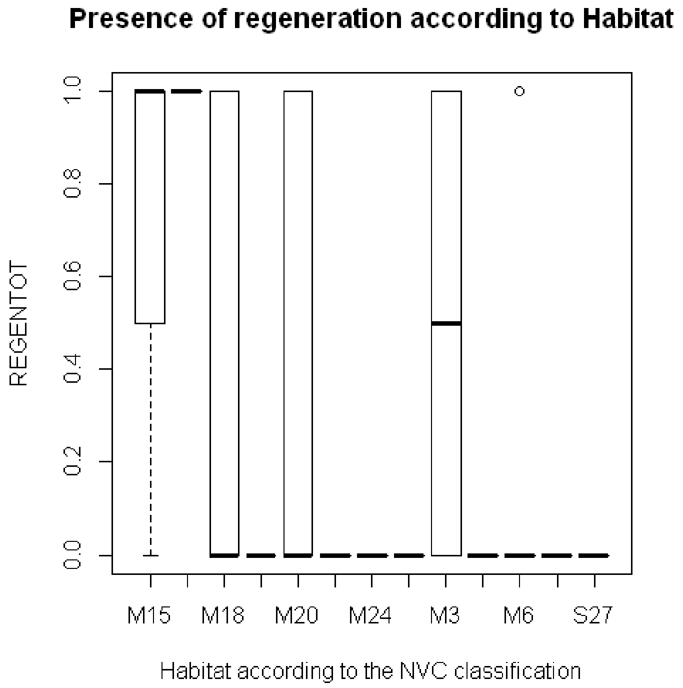

Figure 19: boxplot of regeneration's presence per habitats

	M15	M17	M18	M19	M20	M23	M24	M25	M3	M5	M6	M9	S27
Count of regeneration	4	1	20	13	21	2	4	10	2	1	10	7	5
Mean	0.75	0.3	0	0.38	0	0	0	0.5	0	0	0.1	0	0
Standard deviation	0.5	NA	0.47	0	0.50	0	0	0	0.71	NA	0.32	0	0

Table 8: summary of regeneration spotted for each habitat (NVC classification)

See annex 36 for the detailed account of statistical tables.

As F1 seems to be linked to habitats, REGENTOT would be expected to occur on certain type of habitats. A multiple comparison of means was conducted using the Tukey method, and showed that there were no significant differences between them. However, comparing M15 from M9, M25 or M19 lead to the conclusion that there would be more regeneration found on M15 mires. This NVC habitat is the *Scirpus cespitosus – Erica tetralix* wet heath, and can displays a wide range of variations in vegetation but is mostly composed of *Molinia caerulea*, *Scirpus cespitosus* (or *Trichophorum cespitosum*), *Erica tetralix* and *Calluna Vulgaris*; *Shagna* do sometimes occur, with a low abundancy though: *Sphagnum capillifolium, S. subnitens, S.palustre* and *S. auriculatum* in wetter stands; other mosses found at moderate frequency are: *Hypnum jutlandicum*, *Hylocomium splendens*, *Aulocomnium palustre* and *Dicranum scoparium*. Some of these species were indeed close to regeneration plots in the CA graphs. *Eriophorum vaginatum*, on the contrary, is hardly ever found there. This habitat is characteristic of moist and generally acid and oligotrophic peats, and especially associated with thin or drained areas of ombrogeneous peatlands (i.e. raised and blanket bogs). This community is almost wholly confined to areas with an annual rainfall of 1200 mm/hectads and even more. Overall, the M15 occurs on a wide range of slopes.

This habitat pretty well summarizes the range of conditions for which regeneration was spotted and is actually predicted by models. Without burning or grazing, M15 would be able to revert to blanket mire or progress to woodland. Some stands of M15 may derive from blanket bogs as a result of a combination of burning and grazing, and possibly climatic changes.

On the contrary, the *Carex rostrata – Calliergon cuspidatum/giganteum* mire (M9) is characteristic of spongy peats kept moist, which is not a favourable condition for tree settlement. The *Molinia caerulea-Potentilla erecta* mire (M25) encompasses a wide range of floristics and physiognomy, but is overwhelmingly populated by *Molinia*. This vascular species might be a competitor to seedlings, since high vascular plants covers may receive less regeneration. In the upland situations, this habitat has nonetheless often been drained for coniferous forestry purposes, so we can conclude that its hydrology must be carefully preserved next to plantations if tree encroachment is not wanted.

At last, *Calluna vulgaris-Eriophorum vaginatum* blanket mire (M19), which is characterized by the abundance of *Eriophorum vaginatum*, is often characterized by relatively dry tussocks and sometimes has the appearance of a heathy moorland (with high frequencies in *Calluna vulgaris*). However this habitat would not embed much regeneration compared to the M15 previously described. This community is typical of high-altitude blanket bogs where peats have accumulated in a wet and cold climate, which might explain why regeneration does not much appear in these stands. Moreover moderate levels of grazing maintain a stable diversity in vegetation thus minimizing tree settlement.

Comparisons between a given distance

For a given distance, one would hope to erase the effect of distance without the bias introduced by the variable Rtr. Unhopefully; there are only 20 observations for over 16 variables that could explain the presence of regeneration, which is far too many. As a result, any statistical analysis can't be accurate.

v. REGENTOTAB

Another variable called REGENTOTAB corresponding to regeneration for both Sitka spruce and Lodgepole pine in terms of abundance seemed to be relevant to analyse. No significant results in terms of treatments have been proved though, i.e. comparisons between types of drainage, peat depths and type of plantation (mixed, pine woods or Sitka spruce plantations).

IV. Discussion

First of all, given the inequality of distribution between plots embedding regeneration and plots with none, statistical analysis may have been biased. This would also explain the rather insignificance of many results, and maybe would have helped getting liable answers as to differences between types of plantations, levels of drainage, classes of peat depths and habitats. However it was quite difficult to know in advance whether a peatland hosted scattered trees or not: the only solution would have been to survey more plots, possibly in the Flow Country.

Moreover some sites had indeed regeneration but transects did not intercept it; doing larger quadrats would have taken into account more data on regeneration and would have mitigated this previous issue. However this would have been more time-consuming, knowing that vegetation sampling and assessing microhabitats distribution come along with it.

Relying on Ellenberg's indices and species indicator values for annual rainfalls, mean temperatures of January and July could be either too acute or too inappropriate with the goal of addressing recommendations to foresters, since these data are not directly assessed on the field. These were nonetheless the most acute account of environmental conditions at a quadrat's level and are directly linked with microtope's conditions and constraints. This is why other sources to assess ph., rainfalls and temperatures were not taken into account, but again, this could be criticized.

Some other environmental conditions may have been useful to explain conifer colonization over peatlands: despite its interest, water table could be hardly assessed for over a hundred plots in just three months, for it needs a reasonable amount of time to reach a balance. Indeed the water table fluctuates through seasons, years and weather and there would have been too many parameters influencing the results from one site to another. In addition, bulks densities may bring important information about tree encroachment, as well as subsidence data.

Another approach would have been to focus on one site only or a very few, to study regeneration more closely. But this would have meant abandoning the comparative analysis of treatments. (Drainage and types of plantation above all)

Assessing habitats according to the National Vegetation Classification wasn't an easy task, especially since samples started in early May and ended in mid-July, encompassing a wide range of vegetation communities which were mostly not at its peak. There might have been some mistakes leading to the wrong habitat assignment. Besides this study focused on ecotones which have never been fully studied and described, so we can wonder to what extent communities encountered were forming new types of habitats on their own, or merely consist in "degraded" forms of peatland habitats.

When looking at the statistical results, models proposed do not tally with each other and some variables can't fully be explained. For regeneration at a plot's level, the model with five pre-selected variables is quite satisfying but solely explains half of the observations on the field, which decreases its reliability. Nonetheless the combination of Correspondence Analysis, the explanation of the presence of regeneration along its first axis (F1) and the construction of a model for REGENTOT lead to some interesting conclusions and answers some hypothesis.

Conclusions

In Scotland, peatlands are seriously threatened by human activities and climate change. Afforestation trends in the past decades are mainly responsible for the creation of coniferous plantations over peats. This accounts for nearly 17% of the land area and represents less than one quarter of the woodland area that once covered Scotland's land surface. The Scottish Forestry Strategy aims at an increase in woodland cover to around 25% in the second half of the century, which would involve the expanding of forests, in competition with agricultural demands on suitable soils.

On the other hand, peatland restoration projects are enhanced and broadly supported by the Scottish Natural Heritage (SNH) on behalf of the current Scotland's National Peatland Action Plan.[8]
Its purposes are:

- restoring and managing peatlands to maintain and encourage carbon sequestration (with the restoration of 6500 ha peatland by March 2015);
- restoring peatland ecosystem functions;
- enhancing ecosystem resilience to climate change;
- Spreading a better understanding amongst land managers and the public.

Yet plantations on peat will not fully cease, and tree encroachment onto bogs will probably continue. This study, replaced in this context, aims at studying factors and environmental conditions which would trigger or ease tree regeneration/colonization onto peatlands. Owing to the results, no definite answers could be given. Wet heaths proved to host more regeneration as any other vegetation communities (namely M15), but this does not mean that other habitats should be neglected or not monitored. Significant differences could be spotted between levels of drainage, but that would not mean that bogs bereft of ditches would not face regeneration, for other variables might play a role as well. Besides, restoring hydrological functioning would maybe not prevent any future regeneration.

In addition, the exact status of this phenomenon is not fully settled: is tree encroachment a threat to peatlands' functioning, would these ecosystems be less efficient as carbon sinks? What are the pros and cons of it? Should trees be systematically removed, should this colonization be let alone? Should foresters wait for a while before cutting down conifer regeneration, and then select types of regeneration to erase?

In the light of climate change (and drought events associated with it), according to future scenarii, some research suggests that pines and spruce would turn out to be more adapted to the Scottish climate, for example Sitka spruce (D.Ray et al., 2002) Can we imagine that some bog woodlands would support non-native species and thus represent new types of "habitats" to deal with? Will it be preferable to keep trees on peats? Will trees be more likely to expand on open bogs and endanger this whole ecosystem? Would these trees be persistent or transient, which would then imply that bogs' resilience potentials should be carefully analysed? (Heijmans, et al., 2013)

[8] This Action Plan is currently under consultation with various stakeholders.

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Contacts list

Contacts and grid reference for Cowall and Trossachs and the Lowlands

Corrigrennan 1.1

Forest District Boundary

District: Cowal & Trossachs
Cost Centre: 701
Address: Aberfoyle
: Stirling
Postcode: FK8 3UX
Phone: 01877 382383
Email: cowal&trossachs@forestry.gsi.gov.uk

Flander'sMoss 9.1

Woodland Creation Target Areas

Name: Central Scotland Green Network

CSGN Mixed Woodland Target Areas

Name: Central Scotland Mixed Woodland Option - Capped

Woodland Officer Areas

Woodland Officer: David Anderson

Council Boundaries

Council: Stirling

RPAC Areas

RPAC Area: Forth

Conservancy Boundaries

Conservancy: Perth and Argyll
Address: Algo Business Centre
: Glenearn Road
: Perth
Postcode: PH2 0NJ
Phone: 01738 442830
Email: panda.cons@forestry.gsi.gov.uk

Forest District Boundary

District: Cowal & Trossachs
Cost Centre: 701
Address: Aberfoyle
: Stirling
Postcode: FK8 3UX
Phone: 01877 382383
Email: cowal&trossachs@forestry.gsi.gov.uk

T11 Balgair Muir 10.1

Natural Heritage Zones

Feature Name: West Central Belt

National Inventory of Woodland and Trees

Feature Code: 0083
Reference Date: 310395
IFT: Ground prepared for planting
Hectares: 168.055
Sub Class: Temp

T15 Campsie Muir 2.1

Natural Heritage Zones

Feature Name: West Central Belt

Woodland Officer Areas

Woodland Officer: Jennifer Flavell

Council Boundaries

Council: North Lanarkshire

RPAC Areas

RPAC Area: Clyde Valley

Conservancy Boundaries

Conservancy: Central Scotland
Address: Bothwell House
: Hamilton Business Park
: Caird Park
: Hamilton
Postcode: ML3 0QA
Phone: 01698 368530
Email: centralscotland.cons@forestry.gsi.gov.uk

Forest District Boundary

District: Scottish Lowlands
Cost Centre: 704
Address: Five Sisters House
: Five Sisters Business Park
: West Calder
Postcode: EH55 8PN
Phone: 01555 660190
Email: scottishlowlands@forestry.gsi.gov.uk

T19 Cameron Muir 3.1

Natural Heritage Zones

Feature Name: West Central Belt

Woodland Officer Areas

Woodland Officer: David Anderson

Council Boundaries

Council: Stirling

RPAC Areas

RPAC Area: Forth

Conservancy Boundaries

Conservancy: Perth and Argyll
Address: Algo Business Centre
: Glenearn Road
: Perth
Postcode: PH2 0NJ
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Forest District Boundary

District: Scottish Lowlands
Cost Centre: 704
Address: Five Sisters House
: Five Sisters Business Park
: West Calder
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Contacts and grid reference for Tayside

Woodland Officer Areas

Woodland Officer: Jared Stewart

Council Boundaries

Council: Perth and Kinross

RPAC Areas

RPAC Area: Tayside

Conservancy Boundaries

Conservancy: Perth and Argyll

Address: Algo Business Centre
: Glenearn Road
: Perth
Postcode: PH2 0NJ
Phone: 01738 442830
Email: panda.cons@forestry.gsi.gov.uk

Forest District Boundary

District: Tay
Cost Centre: 504
Address: Inverpark
: Dunkeld
Postcode: PH8 0JR
Phone: 01350 727284
Email: tay@forestry.gsi.gov.uk

Contacts for Dumfries and Galloway

Woodland Officer Areas

Woodland Officer: John MacBeth

Council Boundaries

Council: Dumfries and Galloway

RPAC Areas

RPAC Area: Dumfries and Galloway

Conservancy Boundaries

Conservancy: South Scotland

Address: 55/57 Moffat Road
: Dumfries
Postcode: DG1 1NP
Phone: 01387 272440
Email: southscotland.cons@forestry.gsi.gov.uk

Forest District Boundary

District: Galloway
Cost Centre: 710
Address: Creebridge
: Newton Stewart
Postcode: DG8 6AJ
Phone: 01671 402420
Email: galloway@forestry.gsi.gov.uk

T3: loch Riecawr 5.1

Natural Heritage Zones

Feature Name: Western Southern Uplands and Inner Solway

Important Bird Areas

Name:	GALLOWAY FOREST PARK
Description:	First identified in 2000; no significant boundary changes since. 2000 area of 76000ha was an overestimate. Digitised onto 1:50,000 scale OS maps.
Comment:	A very large area of forest, including lochs, rivers and moorland, that stretches from Newton Stewart in Dumfries and Galloway into the Strathclyde region.First identified in 2000; no significant boundary changes since. 2000 area of 76,000ha

Ornithology Reason: The IBA supports a range of breeding waders and waterbirds, in addition to species of forest and moorland.
Start Year: 2000

Woodland Officer Areas

Woodland Officer: John MacBeth

Council Boundaries

Council: East Ayrshire

RPAC Areas

RPAC Area: Ayrshire

Conservancy Boundaries

Conservancy: South Scotland
Address: 55/57 Moffat Road
: Dumfries
Postcode: DG1 1NP
Phone: 01387 272440
Email: southscotland.cons@forestry.gsi.gov.uk

Forest District Boundary

District: Galloway
Cost Centre: 710
Address: Creebridge
: Newton Stewart
Postcode: DG8 6AJ
Phone: 01671 402420
Email: galloway@forestry.gsi.gov.uk

Contacts for Mossdale 14.1 and 14.2:

Woodland Officer Areas

Woodland Officer: Louise Payne

Council Boundaries

Council: Dumfries and Galloway

RPAC Areas

RPAC Area: Dumfries and Galloway

Conservancy Boundaries

Conservancy: South Scotland
Address: 55/57 Moffat Road
: Dumfries
Postcode: DG1 1NP
Phone: 01387 272440
Email: southscotland.cons@forestry.gsi.gov.uk

Forest District Boundary

District: Galloway
Cost Centre: 710
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: Newton Stewart
Postcode: DG8 6AJ
Phone: 01671 402420
Email: galloway@forestry.gsi.gov.uk

Contacts for Longbridge Muir 9.1

Woodland Officer Areas

Woodland Officer: Lenka Zaoralova

Council Boundaries
Council: Dumfries and Galloway
RPAC Areas
RPAC Area: Dumfries and Galloway
Conservancy Boundaries
Conservancy: South Scotland
Address: 55/57 Moffat Road
: Dumfries
Postcode: DG1 1NP
Phone: 01387 272440
Email: southscotland.cons@forestry.gsi.gov.uk
Forest District Boundary
District: Dumfries & Borders
Cost Centre: 714
Address: Ae Village
: Parkgate
: Dumfries
Postcode: DG1 1QB
Phone: 01387 860247
Email: dumfries&borders@forestry.gsi.gov.uk

Contacts for Harlaw Muir 7.1

Council Boundaries
Council: Scottish Borders
Conservancy Boundaries
Conservancy: South Scotland
Address: 55/57 Moffat Road
: Dumfries
Postcode: DG1 1NP
Phone: 01387 272440
Email: southscotland.cons@forestry.gsi.gov.uk

Woodland Creation Target Areas
Name: Central Scotland Green Network
CSGN Mixed Woodland Target Areas
Name: Central Scotland Mixed Woodland Option - Capped
Woodland Officer Areas
Woodland Officer: Liz Poulsom
Council Boundaries
Council: Midlothian
RPAC Areas
RPAC Area: Forth
Conservancy Boundaries
Conservancy: Central Scotland
Address: Bothwell House
: Hamilton Business Park
: Caird Park
: Hamilton
Postcode: ML3 0QA
Phone: 01698 368530
Email: centralscotland.cons@forestry.gsi.gov.uk
Forest District Boundary
District: Scottish Lowlands
Cost Centre: 704
Address: Five Sisters House
: Five Sisters Business Park
: West Calder

Postcode: EH55 8PN
Phone: 01555 660190
Email: scottishlowlands@forestry.gsi.gov.uk

Table of annexes

Annex 1: classification for mires and wet heaths (which are considered as bogs in other classification) according to the Directive I ‘Habitat’ and Corinne Biotope.

Blanket bog	is probably equal to	H7130	Blanket bog
	overlaps with	H3160	Acid peat-stained lakes and ponds
		H7140	Very wet mires often identified by an unstable 'quaking' sur
		H7150	Depressions on peat substrates
Fens	overlaps with	H7230	Calcium-rich springwater-fed fens
		H7140	Very wet mires often identified by an unstable 'quaking' sur
		H7220	Hard-water springs depositing lime
		H7150	Depressions on peat substrates
	probably contains	H7210	Calcium-rich fen dominated by great fen sedge (saw sedge)
Lowland heathland	contains	H4020	Wet heathland with Dorset heath and cross-leaved heath
		H4040	Dry coastal heaths with Cornish heath
	overlaps with	H7150	Depressions on peat substrates
		H4010	Wet heathland with cross-leaved heath
		H4030	Dry heaths
Lowland raised bog	contains	H7110	Active raised bogs
		H7120	Degraded raised bog
	overlaps with	H3160	Acid peat-stained lakes and ponds
		H7150	Depressions on peat substrates
Lowland heathland	contains	H4020	Wet heathland with Dorset heath and cross-leaved heath
		H4040	Dry coastal heaths with Cornish heath
	overlaps with	H7150	Depressions on peat substrates
		H4010	Wet heathland with cross-leaved heath
		H4030	Dry heaths
Upland heathland	overlaps with	H4010	Wet heathland with cross-leaved heath
		H4030	Dry heaths
	probably overlaps with	H4060	Alpine and subalpine heaths

Annex 2: classification of mires (UK BAP) according to the EUNIS.

Blanket bog	is probably equal to	H7130	Blanket bog
	overlaps with	H3160	Acid peat-stained lakes and ponds
		H7140	Very wet mires often identified by an unstable 'quaking' sur
		H7150	Depressions on peat substrates
Fens	overlaps with	H7230	Calcium-rich springwater-fed fens
		H7140	Very wet mires often identified by an unstable 'quaking' sur
		H7220	Hard-water springs depositing lime
		H7150	Depressions on peat substrates
	probably contains	H7210	Calcium-rich fen dominated by great fen sedge (saw sedge)
Lowland heathland	contains	H4020	Wet heathland with Dorset heath and cross-leaved heath
		H4040	Dry coastal heaths with Cornish heath
	overlaps with	H7150	Depressions on peat substrates
		H4010	Wet heathland with cross-leaved heath
		H4030	Dry heaths

Lowland raised bog	contains	H7110	Active raised bogs
		H7120	Degraded raised bog
	overlaps with	H3160	Acid peat-stained lakes and ponds
		H7150	Depressions on peat substrates
Purple moor grass and rush pasture	contains	H6410	Purple moor-grass meadows
Wet woodland	contains	H91E0	Alder woodland on floodplains
		H91D0	Bog woodland

Annex 3: correspondance between the European classifications and the NVC:

H91D0	Bog woodland	overlaps with	W18	Pinus sylvestris-Hylocomium splendens woodland
			W4c	Sphagnum spp. sub-community
H4010	Wet heathland with cross-leaved heath	contains	H5	Erica vagans - Schoenus nigricans heath
			M15	Scirpus cespitosus-Erica tetralix wet heath
			M16	Erica tetralix-Sphagnum compactum wet heath
		overlaps with	M14	Schoenus nigricans-Narthecium ossifragum mire
H4020	Wet heathland with Dorset heath and cross-leaved heath	overlaps with	H3	Ulex minor - Agrostis curtisii heath
			H4	Ulex gallii - Agrostis curtisii heath
			M16	Erica tetralix-Sphagnum compactum wet heath
			M21	Narthecium ossifragum-Sphagnum papillosum valley mire
H6410	Purple moor-grass meadows	contains	M26	Molinia caerulea-Crepis paludosa mire
		overlaps with	M24	Molinia caerulea-Cirsium dissectum fen-meadow
H7110	Active raised bogs	overlaps with	M1	Sphagnum auriculatum bog pool community
			M18	Erica tetralix-Sphagnum papillosum raised and blanket mire
			M19	Calluna vulgaris-Eriophorum vaginatum blanket mire
			M2	Sphagnum cuspidatum/recurvum bog pool community
H7120	Degraded raised bog	overlaps with	M15	Scirpus cespitosus-Erica tetralix wet heath
			M16	Erica tetralix-Sphagnum compactum wet heath
			M18	Erica tetralix-Sphagnum papillosum raised and blanket mire
			M20	Eriophorum vaginatum blanket and raised mire
			M25	Molinia caerulea-Potentilla erecta mire
			M3	Eriophorum angustifolium bog pool community
H7130	Blanket bog	overlaps with	M1	Sphagnum auriculatum bog pool community
			M15	Scirpus cespitosus-Erica tetralix wet heath
			M17	Scirpus cespitosus-Eriophorum vaginatum blanket mire
			M18	Erica tetralix-Sphagnum papillosum raised and blanket mire
			M19	Calluna vulgaris-Eriophorum vaginatum blanket mire
			M20	Eriophorum vaginatum blanket and raised mire
			M25	Molinia caerulea-Potentilla erecta mire
H7140	Very wet mires often identified by an unstable 'quaking' sur	contains	M5	Carex rostrata-Sphagnum squarrosum mire

			M8	Carex rostrata-Sphagnum warnstorfii mire
			S27	Carex rostrata-Potentilla palustris tall-herb fen
		overlaps with	M9	Carex rostrata-Calliergon cuspidatum/giganteum mire
H7150	Depressions on peat substrates	overlaps with	M1	Sphagnum auriculatum bog pool community
			M14	Schoenus nigricans-Narthecium ossifragum mire
			M15	Scirpus cespitosus-Erica tetralix wet heath
			M16	Erica tetralix-Sphagnum compactum wet heath
			M17	Scirpus cespitosus-Eriophorum vaginatum blanket mire
			M18	Erica tetralix-Sphagnum papillosum raised and blanket mire
			M2	Sphagnum cuspidatum/recurvum bog pool community
			M21	Narthecium ossifragum-Sphagnum papillosum valley mire
			M29	Hypericum elodes-Potamogeton polygonifolius soakway
H7210	Calcium-rich fen dominated by great fen sedge (saw sedge)	contains	S2	Cladium mariscus swamp and sedge-beds
		overlaps with	M13	Schoenus nigricans-Juncus subnodulosus mire
			M14	Schoenus nigricans-Narthecium ossifragum mire
			M24	Molinia caerulea-Cirsium dissectum fen-meadow
			M9	Carex rostrata-Calliergon cuspidatum/giganteum mire
			S24	Phragmites australis-Peucedanum palustris tall-herb fen
			S25	Phragmites australis-Eupatorium cannabinum tall-herb fen
			SD14	Salix repens-Campylium stellatum dune-slack community
			SD15	Salix repens-Calliergon cuspidatum dune-slack community
H7220	Hard-water springs depositing lime	contains	M37	Cratoneuron commutatum-Festuca rubra spring
			M38	Cratoneuron commutatum-Carex nigra spring
H7230	Calcium-rich springwater-fed fens	overlaps with	M10	Carex dioica-Pinguicula vulgaris mire
			M13	Schoenus nigricans-Juncus subnodulosus mire
			M9	Carex rostrata-Calliergon cuspidatum/giganteum mire
H7240	High-altitude plant communities associated with areas of wat	contains	M11	Carex demissa-Saxifraga aizoides mire
			M12	Carex saxatilis mire
		overlaps with	M10	Carex dioica-Pinguicula vulgaris mire

Annex 4: correspondences between the NVC and the EUNIS classifications:

M1	Sphagnum auriculatum bog pool community	relationship uncertain	D1.112	Raised bog hollows (schlenken)
M10	Carex dioica-Pinguicula vulgaris mire	contains	D4.15	Carex dioica, Carex pulicaris and Carex flava fens
M11	Carex demissa-Saxifraga aizoides mire	is equal to	D4.19	British Carex demissa - Saxifraga aizoides flushes
M12	Carex saxatilis mire	is equal to	D4.17	Carex saxatilis fens
M13	Schoenus nigricans-Juncus subnodulosus mire	contains	D4.11	Schoenus nigricans fens
M14	Schoenus nigricans-Narthecium ossifragum mire	contains	F4.11	Northern wet heaths
M15	Scirpus cespitosus-Erica tetralix wet heath	contains	F4.11	Northern wet heaths
M16	Erica tetralix-Sphagnum compactum wet heath	contains	F4.11	Northern wet heaths
M17	Scirpus cespitosus-Eriophorum vaginatum blanket mire	contains	D1.21	Hyperoceanic low-altitude blanket bogs, typically with domin
M18	Erica tetralix-Sphagnum papillosum raised and blanket mire	overlaps with	D1.111	Raised bog hummocks, ridges and lawns
M19	Calluna vulgaris-Eriophorum vaginatum blanket mire	contains	D1.221	Hiberno-Britannic Eriophorum-Calluna blanket bogs
M2	Sphagnum cuspidatum/recurvum bog pool community	contains	D1.112	Raised bog hollows (schlenken)
M20	Eriophorum vaginatum blanket and raised mire	is equal to	D1.222	Britannic Eriophorum vaginatum blanket bogs
M21	Narthecium ossifragum-Sphagnum papillosum valley mire	contains	D1.113	Raised bog seeps and soaks
M22	Juncus subnodulosus-Cirsium palustre fen-meadow	contains	E3.41	Atlantic and sub-Atlantic humid meadows
M23	Juncus effusus/acutiflorus-Galium palustre rush-pasture	overlaps with	E3.42	Juncus acutiflorus meadows
M24	Molinia caerulea-Cirsium dissectum fen-meadow	contains	E3.51	Molinia caerulea meadows and related communities
M25	Molinia caerulea-Potentilla erecta mire	contains	E3.51	Molinia caerulea meadows and related communities
M26	Molinia caerulea-Crepis paludosa mire	contains	E3.51	Molinia caerulea meadows and related communities
M27	Filipendula ulmaria-Angelica sylvestris mire	contains	E3.45	Recently abandoned hay meadows
		overlaps with	E5.42	Tall-herb communities of humid meadows
M28	Iris pseudacorus-Filipendula ulmaria mire	contains	E3.45	Recently abandoned hay meadows
		overlaps with	E5.42	Tall-herb communities of humid meadows
		relationship uncertain	E3.418	Blunt-flowered rush meadows
M29	Hypericum elodes-Potamogeton polygonifolius soakway	contains	C3.41	Euro-Siberian perennial amphibious communities
M3	Eriophorum angustifolium bog pool community	contains	D1.112	Raised bog hollows (schlenken)
M30	Related vegetation of seasonally-inundated habitats	overlaps with	C1.6	Temporary lakes, ponds and pools
			C2.5	Temporary running waters
M31	Anthelia julacea-Sphagnum auriculatum spring	contains	D2.2C	Soft water spring mires
M32	Philonotis fontana-Saxifraga stellaris spring	contains	D2.2C	Soft water spring mires
M33	Pohlia wahlenbergii var. glacialis spring	contains	D2.2C	Soft water spring mires
M34	Carex demissa-Koenigia islandica flush	relationship uncertain	D2.2C	Soft water spring mires
M35	Ranunculus omiophyllus-Montia fontana rill	contains	D2.2C	Soft water spring mires
M37	Cratoneuron commutatum-Festuca rubra spring	contains	D4.1N	Hard water spring mires
M38	Cratoneuron commutatum-Carex nigra	contains	D4.1N	Hard water spring mires

	spring			
M4	Carex rostrata-Sphagnum recurvum mire	contains	D2.33	Carex rostrata quaking mires
M5	Carex rostrata-Sphagnum squarrosum mire	contains	D2.33	Carex rostrata quaking mires
M6	Carex echinata-Sphagnum recurvum/auriculatum mire	overlaps with	D2.223	British black-white-star sedge acidic fens
M8	Carex rostrata-Sphagnum warnstorfii mire	contains	D2.33	Carex rostrata quaking mires
M9	Carex rostrata-Calliergon cuspidatum/giganteum mire	contains	D2.33	Carex rostrata quaking mires

Annex 5: figure of terrestrial microhabitats

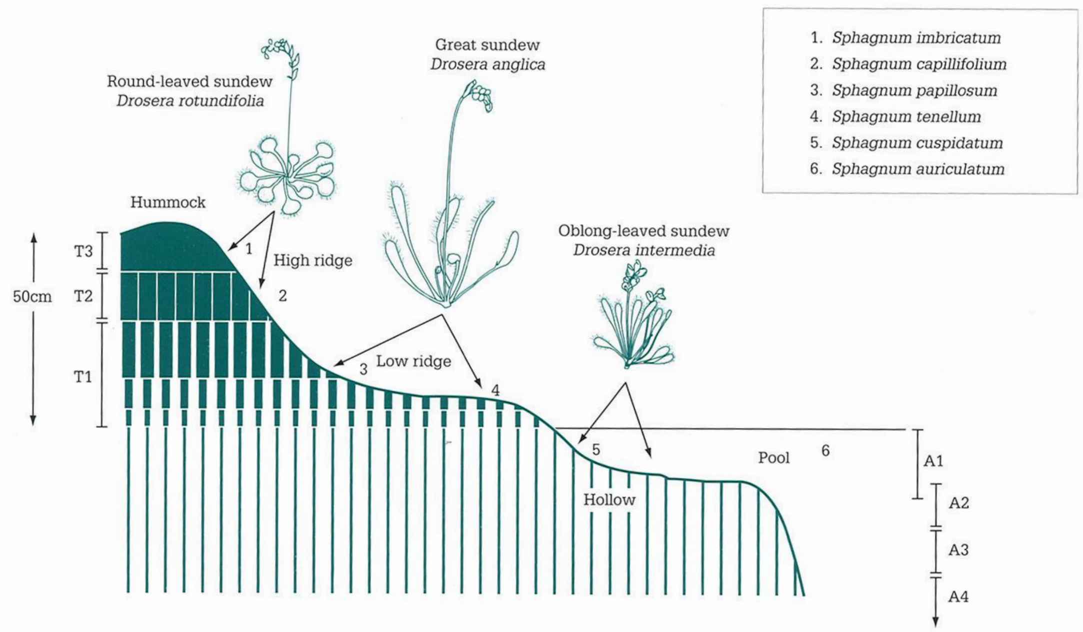


Figure 8.
Generalised distribution of structural features (microforms) and the idealised distribution of species within the pattern (few sites, for example, contain all three *Drosera* species). All natural bogs have some form of pattern, at least across their mire expanse, although in some sites the pattern may consist only of T3 hummocks alternating with T2 high-ridge. Many sites towards the southern and eastern limits of the present bog distribution in Britain have no aquatic (A) zones and consist only of terrestrial (T) zones. (Taken from Lindsay *et al.* 1988. See also Sjörs 1948, Eurola, Hicks & Kaakinen 1984, Moen 1985.)

Annex 6: table of microtopes's distribution according to mire mesotopes

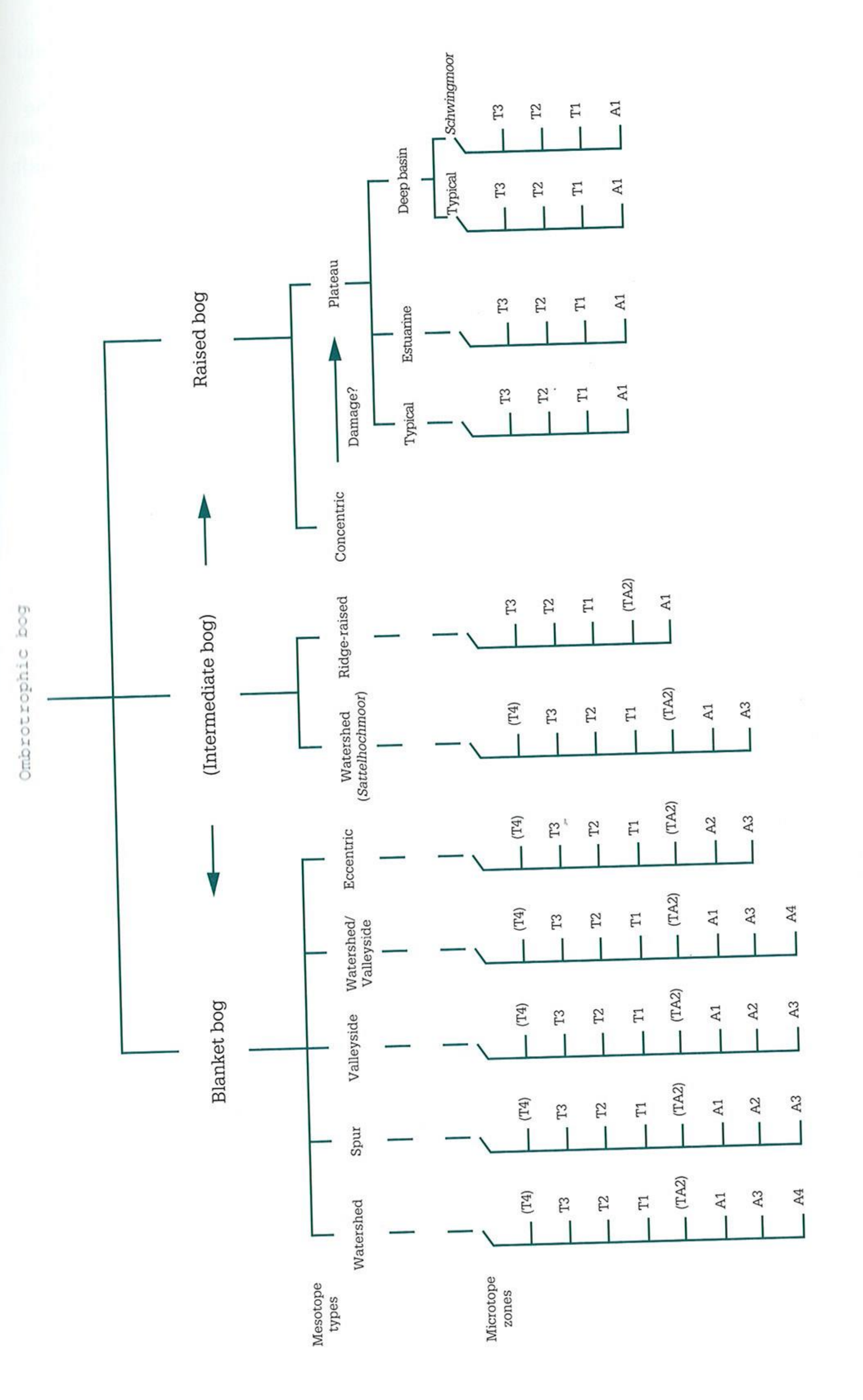


Figure 10.
Hierarchy of bog types, with associated small-scale microtope zones. The various types are described in Sections 4, 5, 6 and 7. Intermediate bog is shown as a type transitional between the two main types, and sites will generally be assigned to one or other of these main types, with a note that intermediate characteristics are present. The distribution of microtope zones between types is indicative rather than absolute.

Annex 7: table of species mostly encountered per type of microhabitats

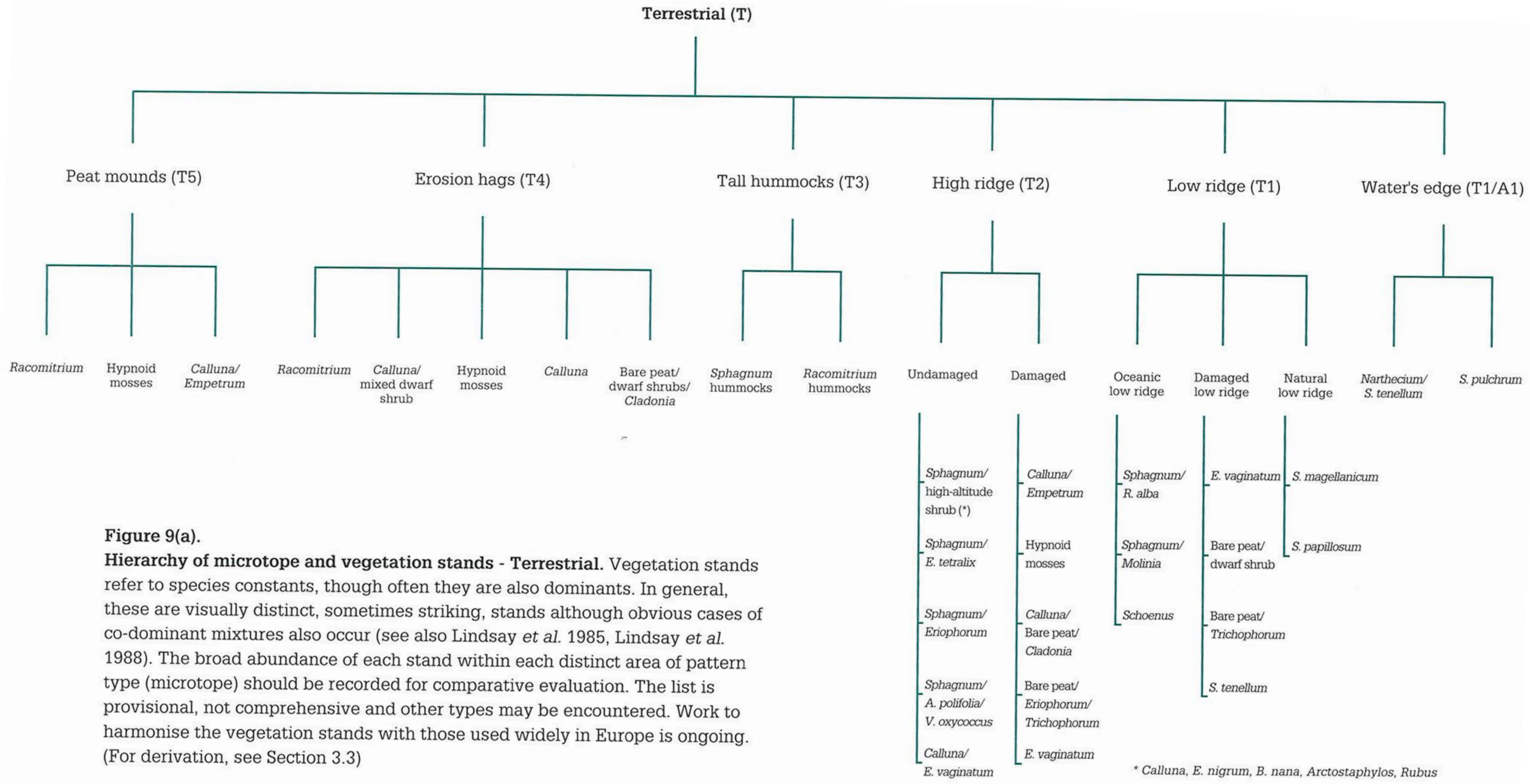


Figure 9(a).
Hierarchy of microtope and vegetation stands - Terrestrial. Vegetation stands refer to species constants, though often they are also dominants. In general, these are visually distinct, sometimes striking, stands although obvious cases of co-dominant mixtures also occur (see also Lindsay *et al.* 1985, Lindsay *et al.* 1988). The broad abundance of each stand within each distinct area of pattern type (microtope) should be recorded for comparative evaluation. The list is provisional, not comprehensive and other types may be encountered. Work to harmonise the vegetation stands with those used widely in Europe is ongoing. (For derivation, see Section 3.3)

Annex 8: table of species encountered pet microhabitats (2)

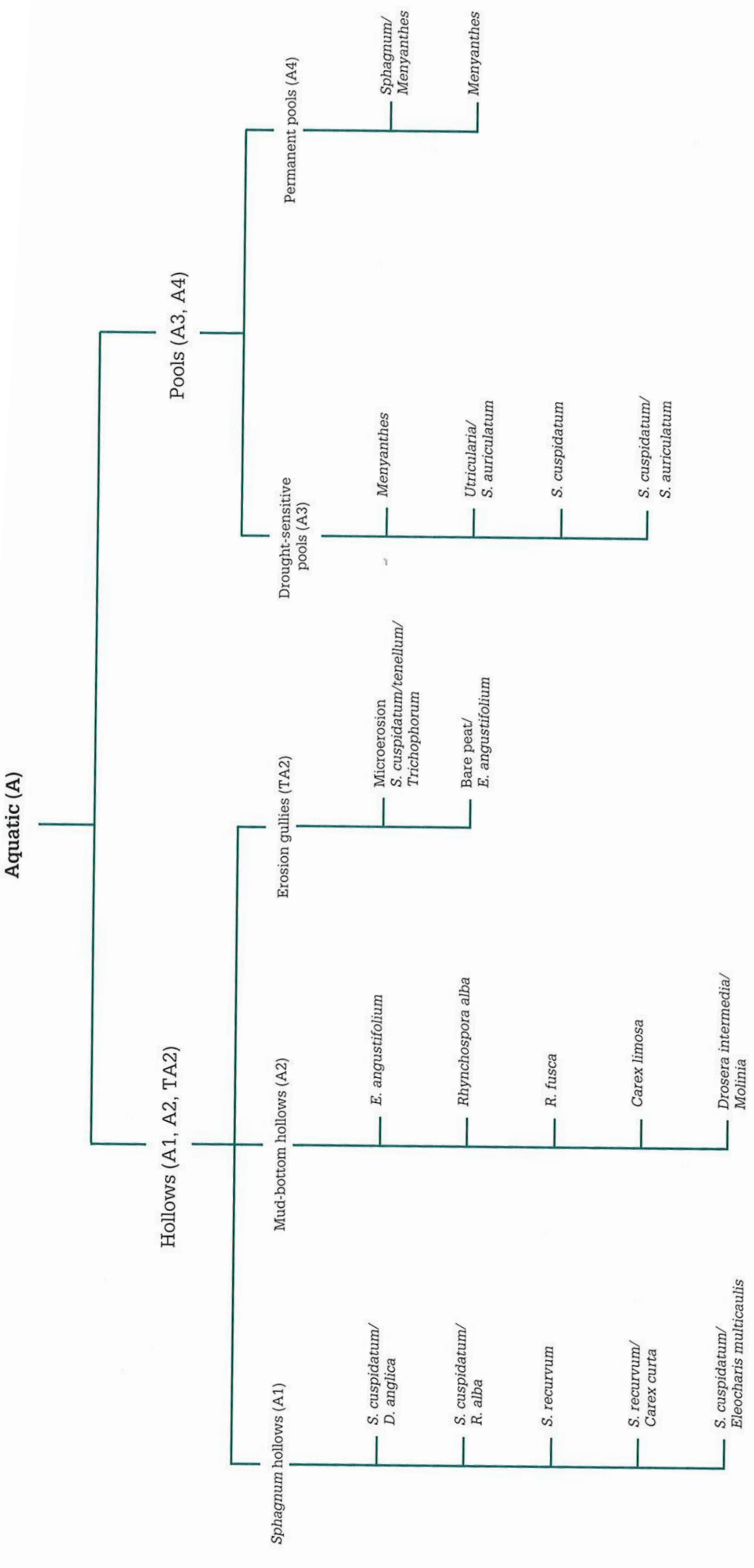
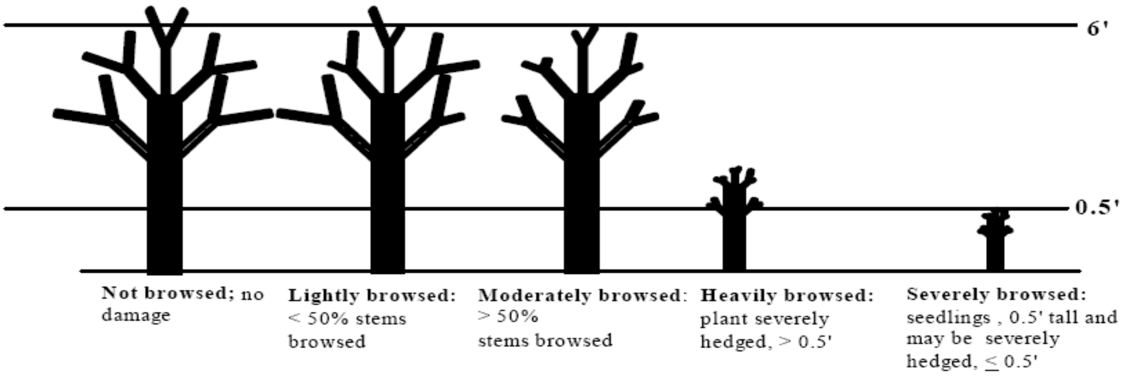


Figure 9(b).
Hierarchy of microtope and vegetation stands - Aquatic. Vegetation stands refer to species constants, though often they are also dominants. In general, these are visually distinct, sometimes striking, stands although obvious cases of co-dominant mixtures also occur (see also Lindsay *et al.* 1985, Lindsay *et al.* 1988). The broad abundance of each stand within each distinct area of pattern type (microtope) should be recorded for comparative evaluation. The list is provisional, not comprehensive and other types may be encountered. Work to harmonise the vegetation stands with those used widely in

Annex 9: levels of deer browsing on tree regeneration

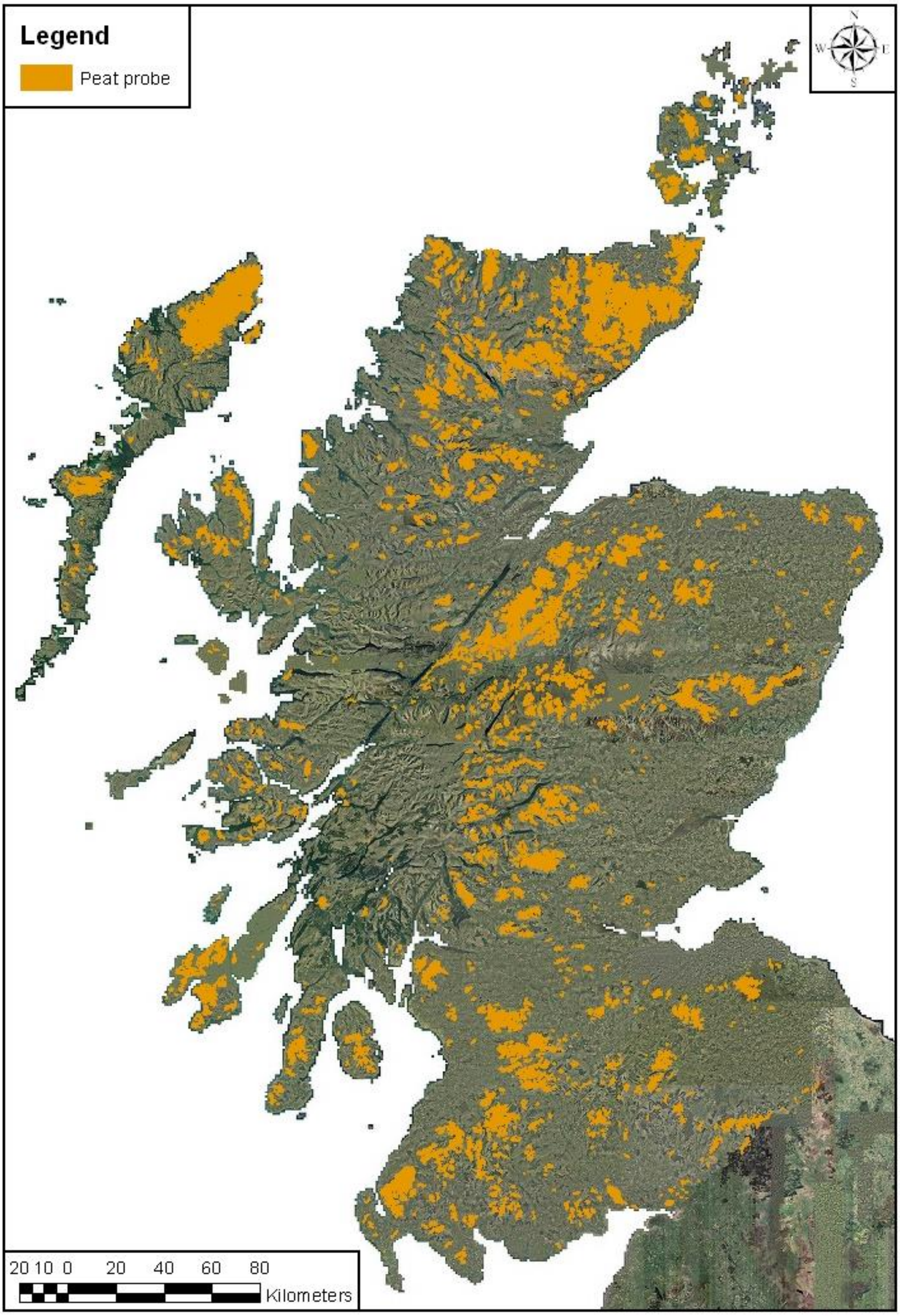


Seedlings > 0.5' provide best evidence of browsing damage. Under severe deer browsing, seedlings may never exceed 0.5' tall and will be severely hedged*: deer browsing keeps them suppressed below 0.5'. Small, current year seedlings may never grow above 0.5' under severe deer browsing.

*** Severely hedged = seedling browsed repeatedly over years; all stems short, thick, with "bonsai" appearance.**

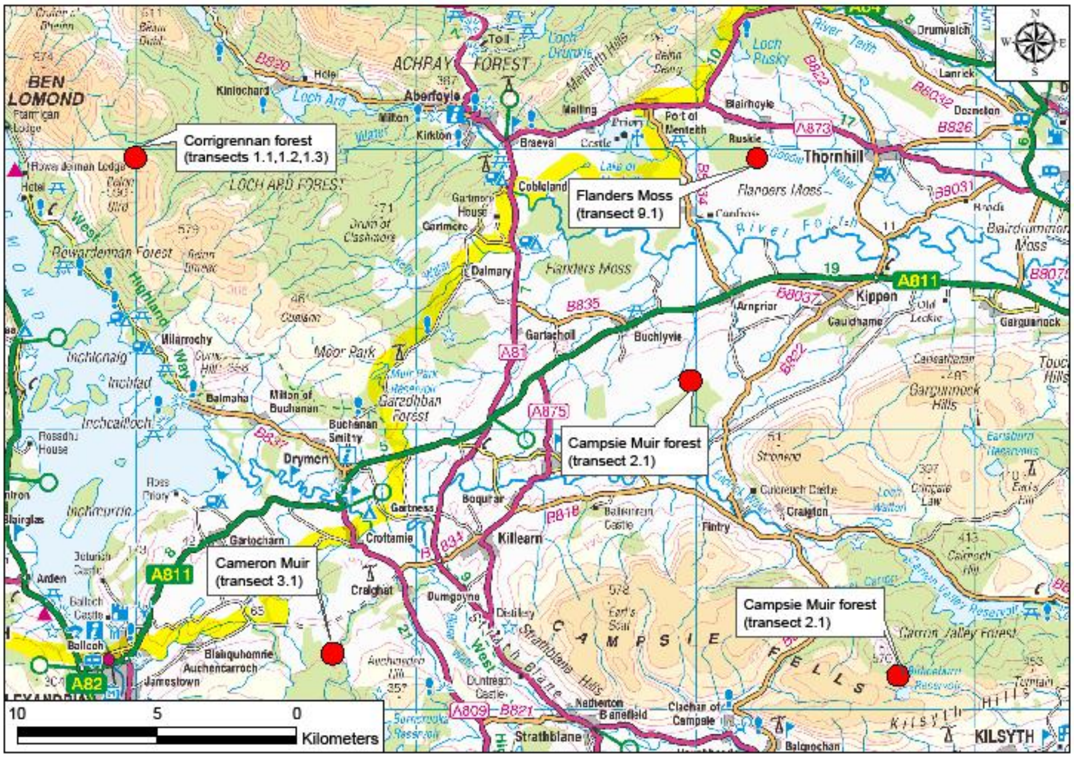
(Source: David deCalesta, Tim Pierson, Dave Jackson, “Deer Density Estimation”)

Annex 10: distribution of peats in Scotland



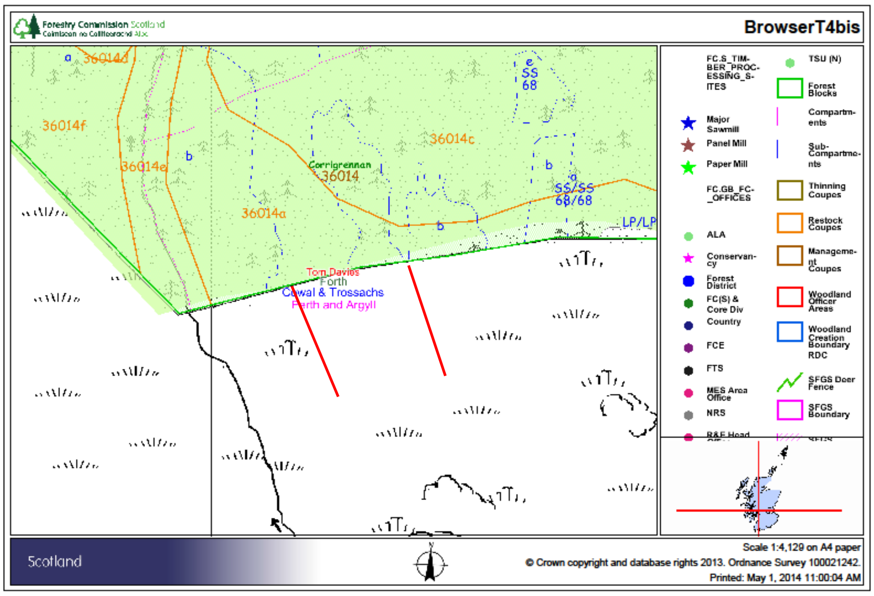
(Source: JHI, OSMM – May, 2014)

Annex 11: location of sites in Cowall and Trossachs and the lowlands



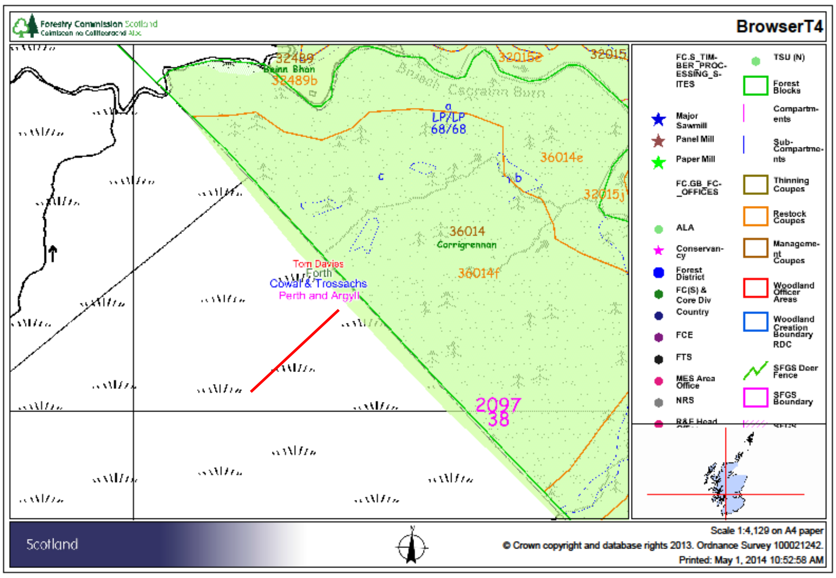
(Source: OSMM – May, 2014)

Annex 12: location of transect at Corrigrennan



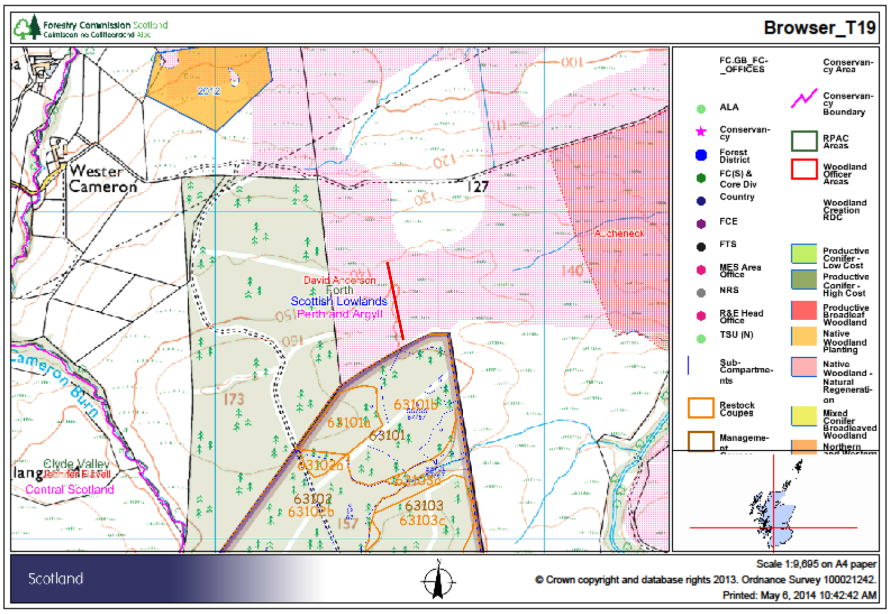
(Source: FC browser, OSMM – May, 2014)

Annex 13: location of transect 1.1 at Corrigrennan



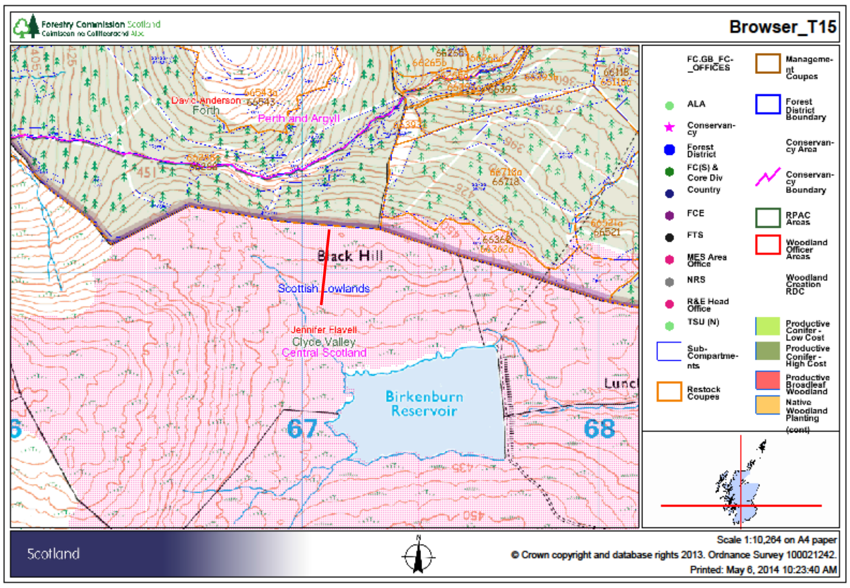
(Source: FC browser, OSMM – May, 2014)

Annex 14: location of transect 2.1 at Cameron Muir



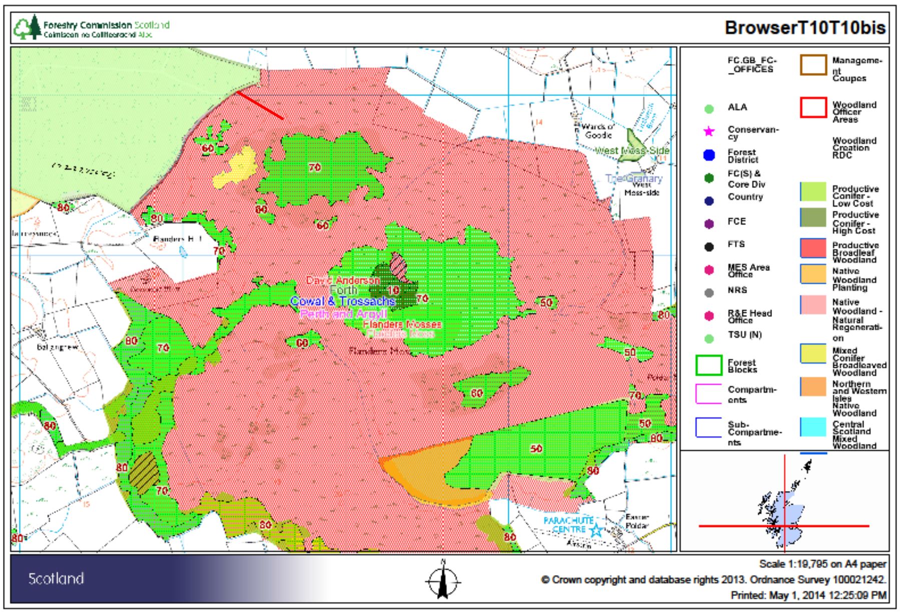
(Source: FC browser, OSMM – May, 2014)

Annex 15: Location of transect 3.1 at Black Hill



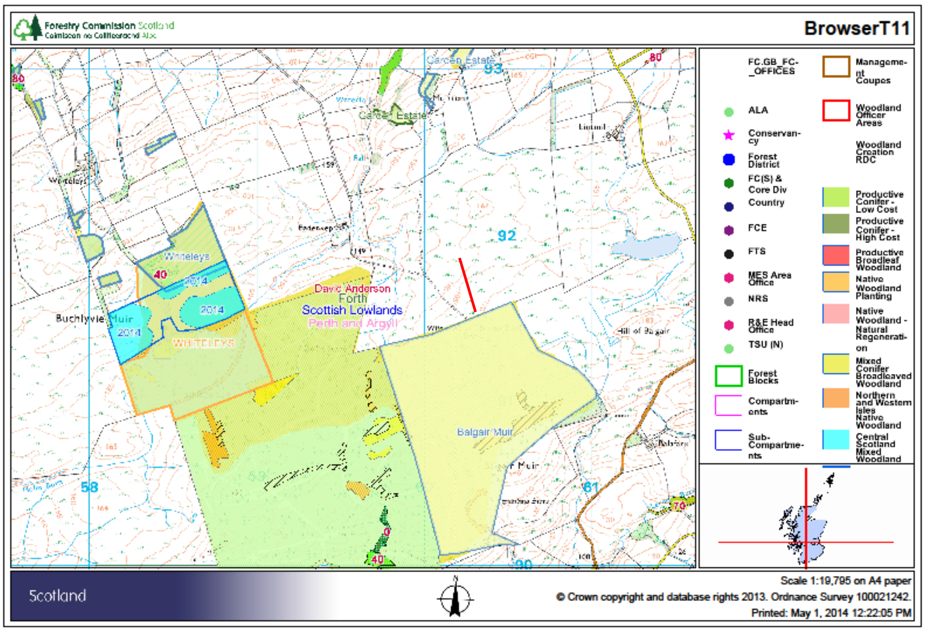
(Source: FC browser, OSMM – May, 2014)

Annex 16: Location of transect 10.1 at Flanders Moss



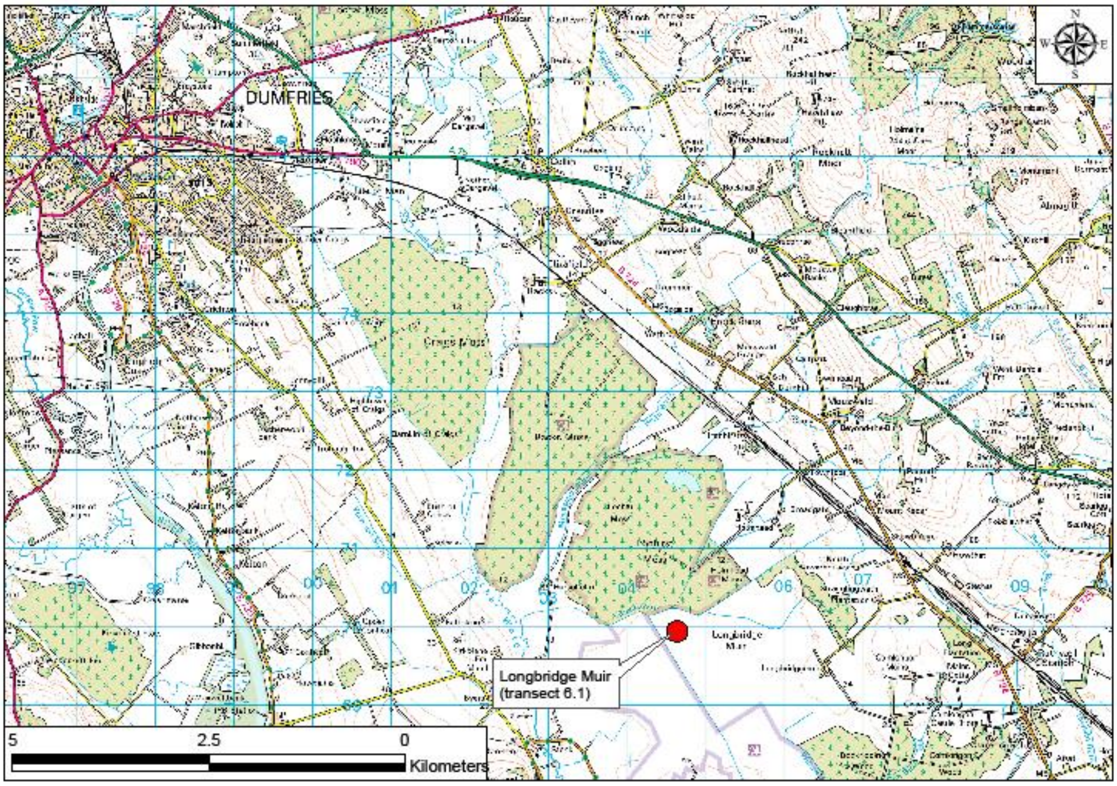
(Source: FC browser, OSMM – May, 2014)

Annex 17: Location of transect 8.1 at Balgair Muir



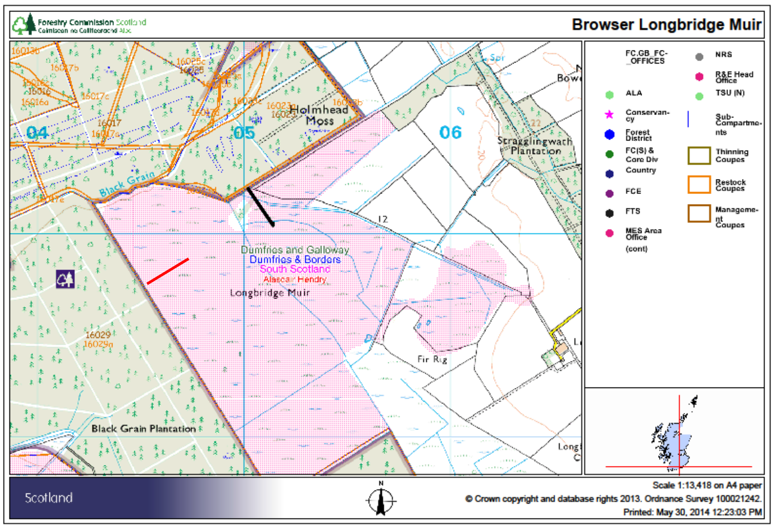
(Source: FC browser, OSMM – May, 2014)

Annex 18: Location of transect 6.1 at Londbridge Muir



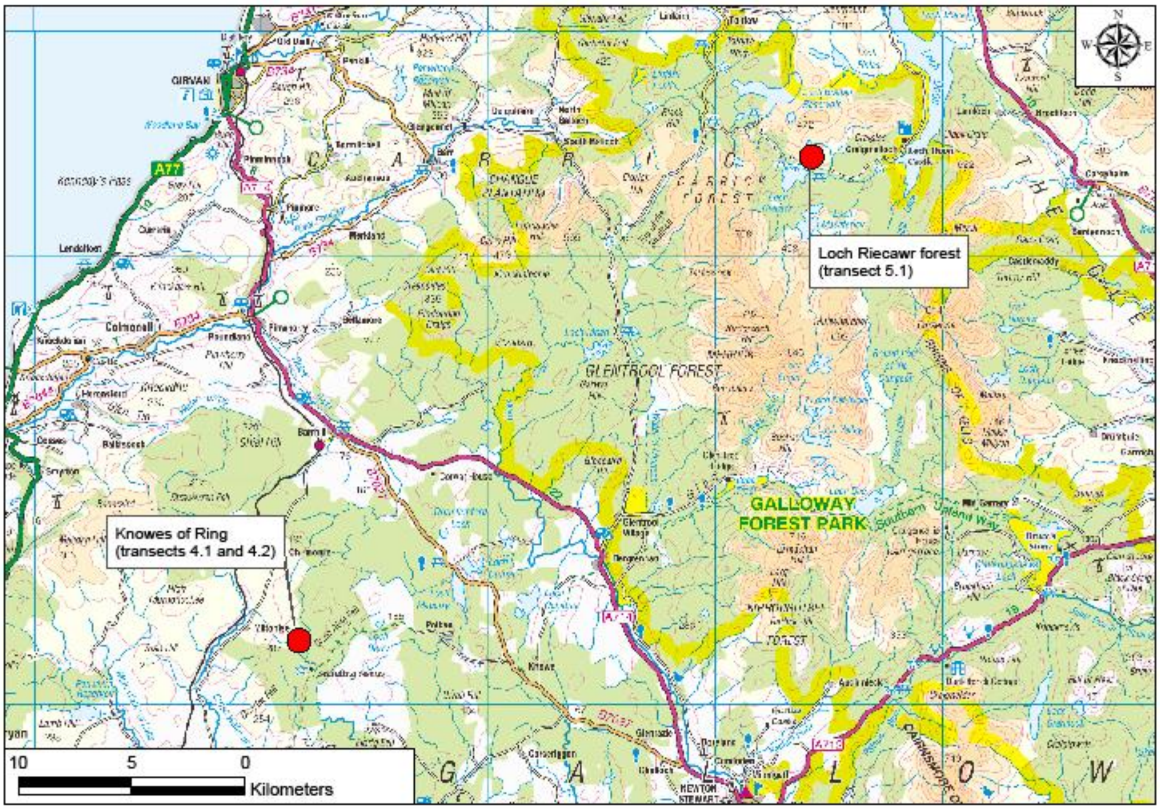
(Source: OSMM – May, 2014)

Annex 19: Location of transect 6.1 at Longbridge Muir



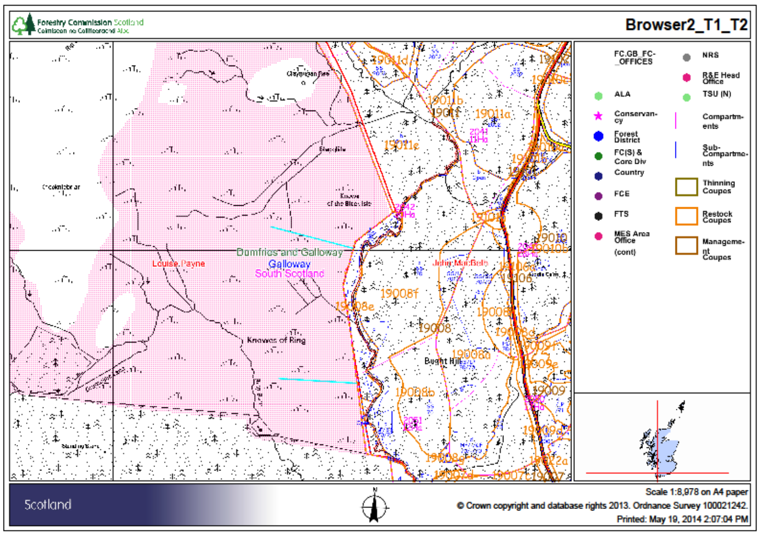
(Source: FC browser, OSMM – May, 2014)

Annex 20 : location of transects in Galloway



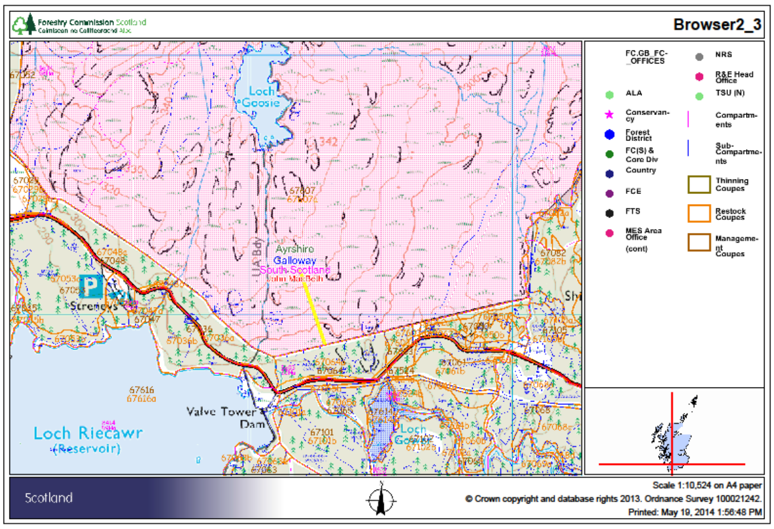
(Source: FC, LCM2007, OSMM – May, 2014)

Annex 21: location of transects 4.1 ad 4.1 at Knowes of Ring



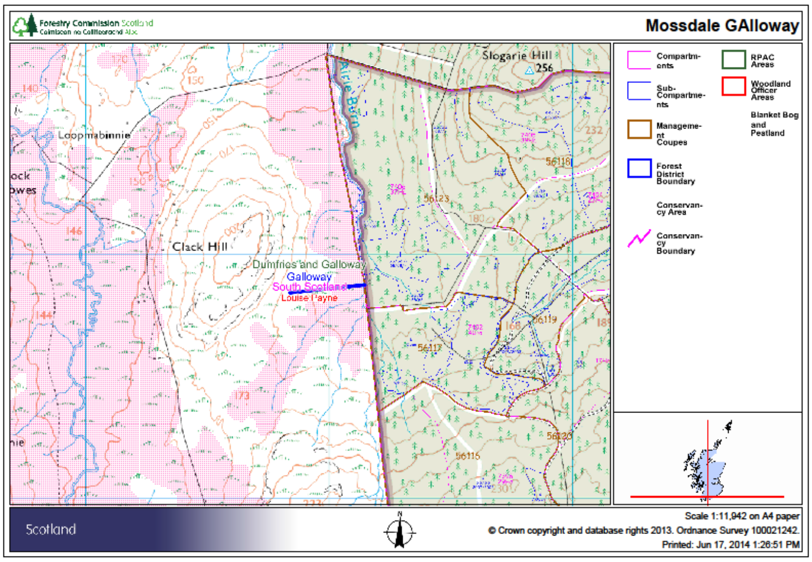
(Source: FC browser, OSMM – May, 2014)

Annex 22: Location of transect 5.1 at Loch Riecawr



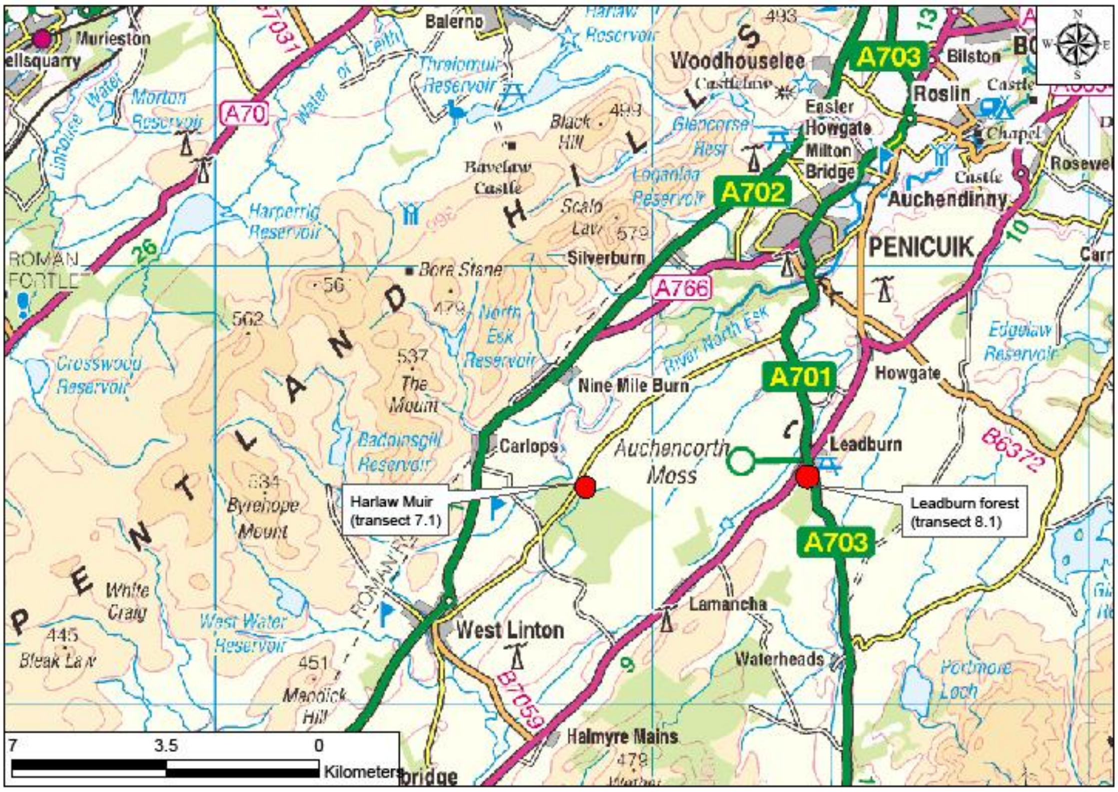
(Source: FC browser, OSMM – May, 2014)

Annex 23: location of transects 14.1 and 14.2 at Mossdale



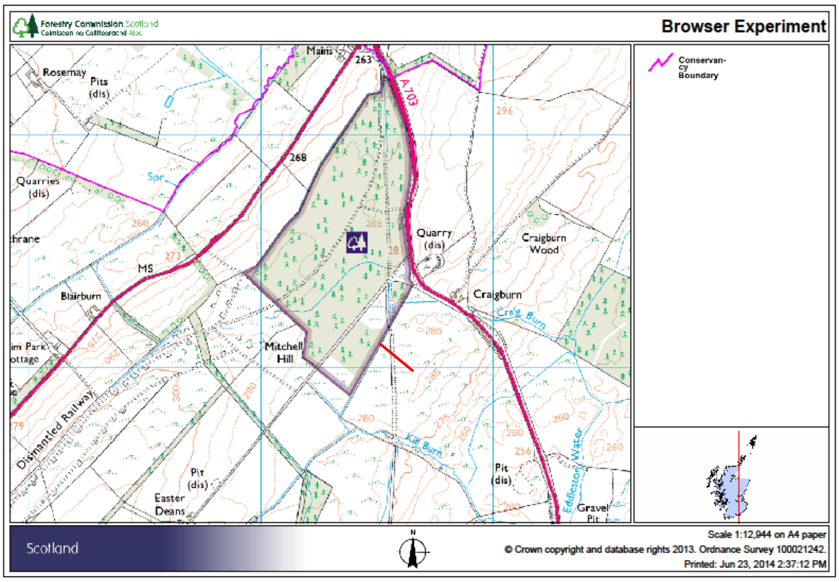
(Source: FC browser, OSMM – May, 2014)

Annex 24: location of transects near Edinburgh



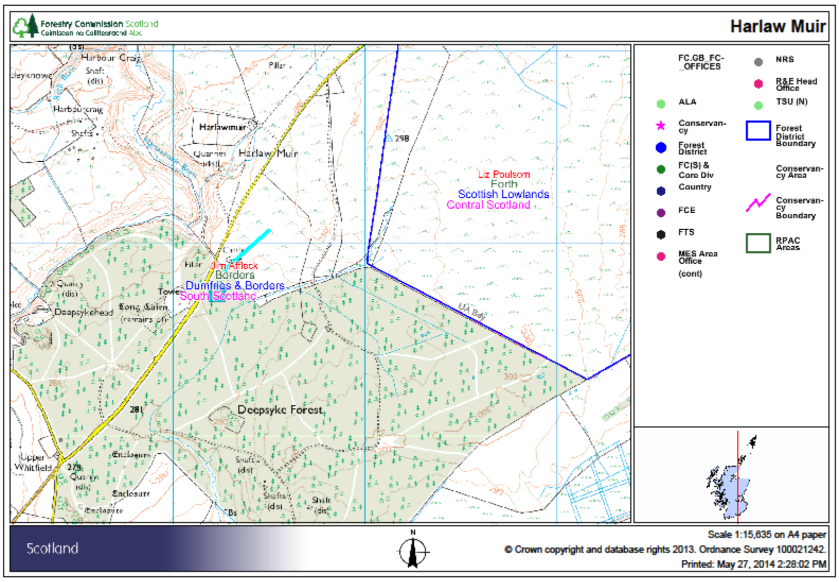
(Source: FC, LCM207, OSMM – May, 2014)

Annex 25: location of transect 8.1 at Leadburn



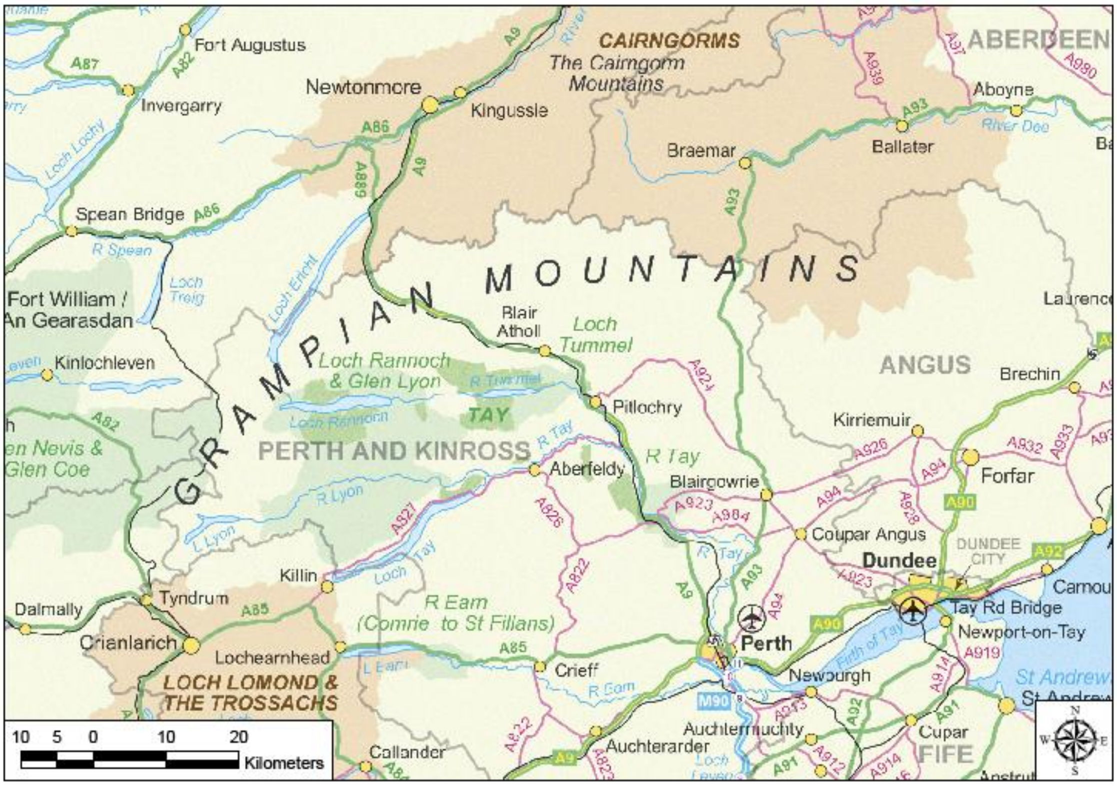
(Source: FC browser, OSMM – May, 2014)

Annex 26: location of transect 7.1 at Harlaw Muir



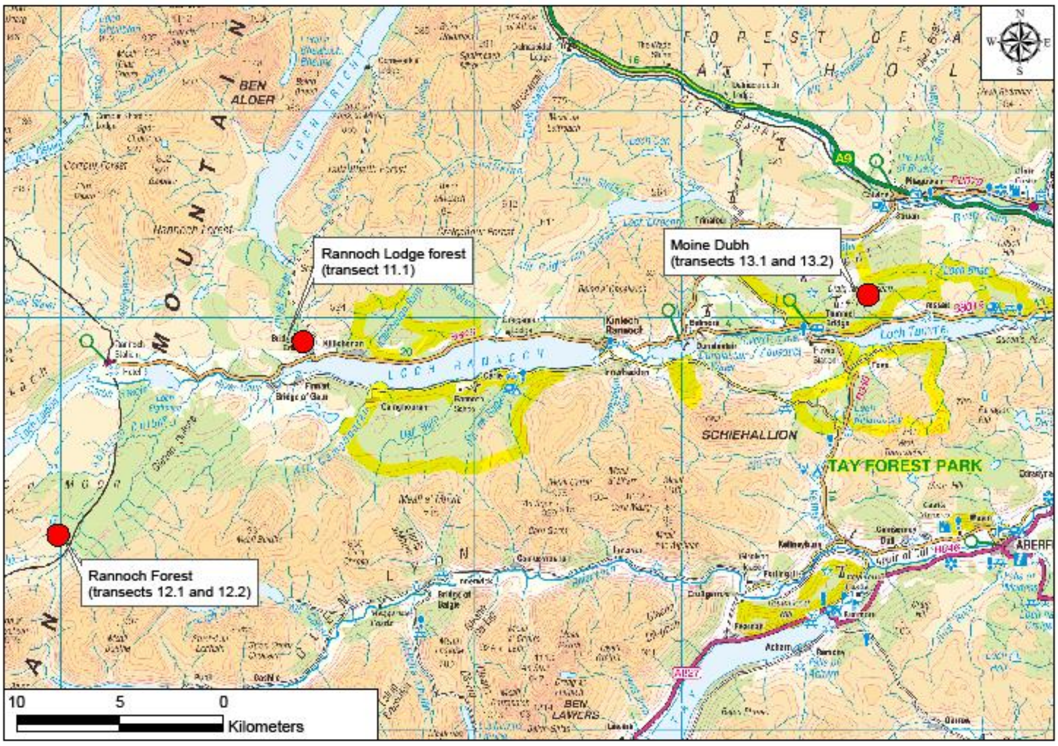
(Source: FC browser, OSMM – May, 2014)

Annex 27: location of transects in Tayside



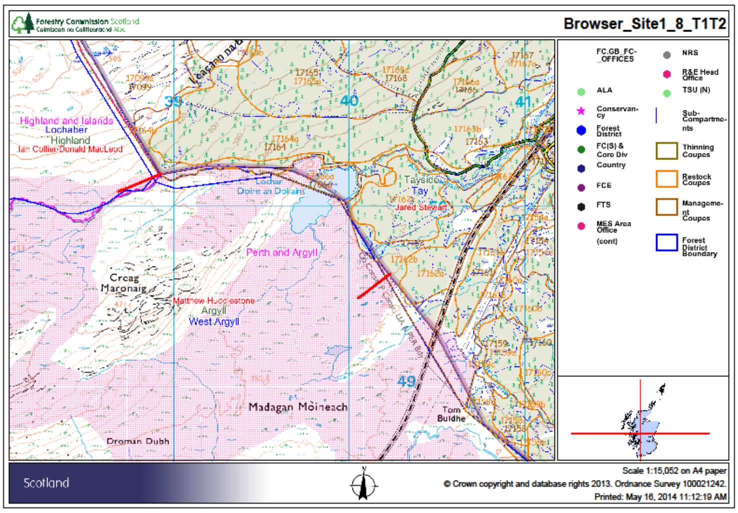
(Source: OSMM – May, 2014)

Annex 28: location of transects in Tayside (2)



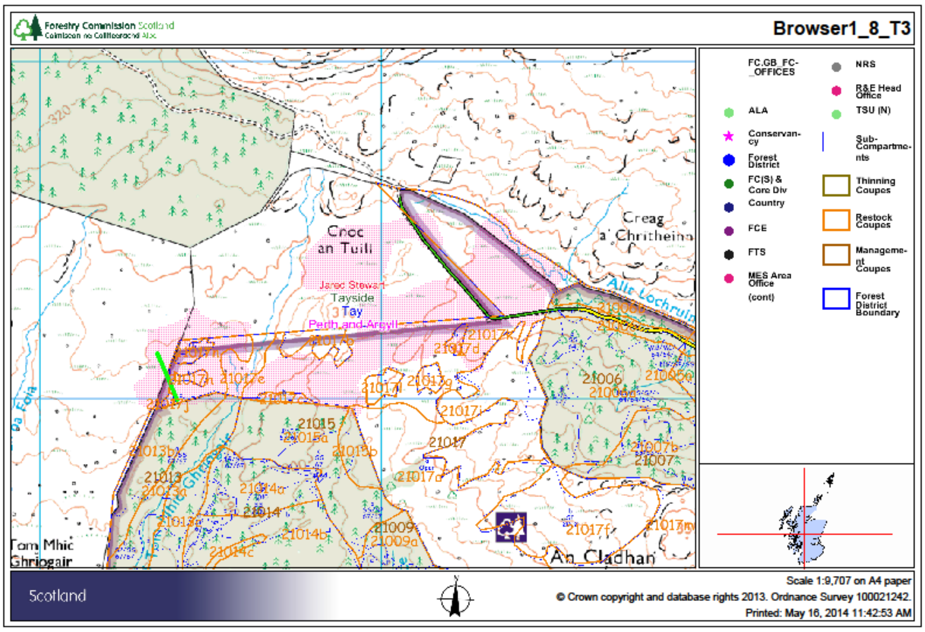
(Source: FC, OSMM – May, 2014)

Annex 29: location of transects 12.1 and 12.2 in Rannoch forest



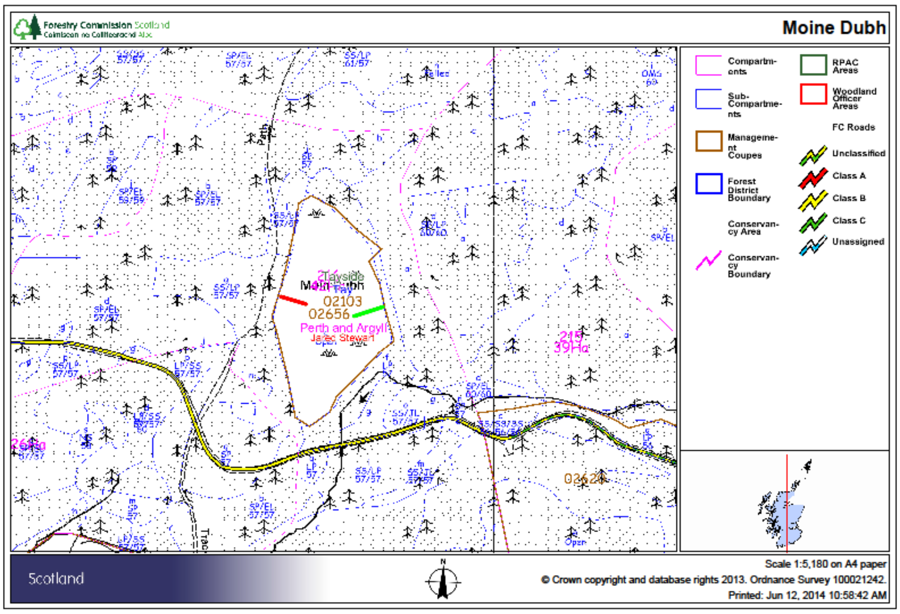
(Source: FC browser, OSMM – May, 2014)

Annex 30: location of transect 11.1 in Rannoch Lodge forest



(Source: FC browser, OSMM – May, 2014)

Annex 31: location of transects 13.1 and 13.2 in Moine Dubh



(Source: FC browser, OSMM – May, 2014)

Annex 32: form for field surveys

GENERAL FEATURES

N° plot: |__ı__||__ı__||2014||__ıı__||ı__||__|

(date: DD|MM|YEAR | N° surveyed peatland| N° Transect | N° Plot)

Author: Vitaline Azambourg Date: ___/___/2014
Name of the peatland/ forest: ……………………………….
Region: ……………………………………………………
Council boundaries: ………………………………………
Conservancy boundaries: …………………………………

General topography:
☐ watershed mire mesotope ☐ spur mire mesotope ☐ seepage:flush
☐ valleyside mire mesotope ☐ ladder fen mesotope ☐ saddle mire
Aspect (grades) : ………………..
Slope (grades) : ……………………
Altitude (m): ………………………
Seclusion (grades): …………………..
Prevailing direction of wind (grades): ……..

Peatland Type:
☐ Blanket bog ☐ intermediate mire ☐ Raised bog
Peat depth: ………………
Habitat code: ………………

Hydrological features:
☐ Heavily drained bog ☐ Drains at the edge of the plantation ☐ Non-drained bog

Management clues:
☐ Current grazing signs ☐ Paths (human, deer, sheep) ☐ Fences ☐ Mowing signs

Nearby plantation:
☐ Sitka Spruce ☐ Lodgepole Pine ☐ Mixed

Level of healthiness:
☐ Healthy planting ☐ other: ………………………

Distance to the edge/tree canopy (m):
☐ 1 ☐ 5 ☐ 10 ☐ 20 ☐ 50 ☐ 75

Deer browsing pressure (for the whole transect; see attached page on botanical and deer pressure for a whole transect): ………………

MICROTOPE DISTRIBUTION

Percentage coverage of each microhabitat
T5: peat mounds……………....%
T4: erosion hags……………..%
T3: tall hummocks…………..%
T2: high ridge………………..%
T1: low ridge…………………%
T1/A1: water's edge…………%
A1: Sphagnum hollows………%
A2: mud-bottom hollows…….%
TA2: erosion gullies…………%
A3: drought-sensitive………..%
A4: permanent pool…………%

BOTANICAL SURVEY

Strata data	Bryophytes	Vascular plants (H<1m)	Shrubs	Seedlings (1<H<20 cm)		Saplings (20<H<50)		Trees	
				SS	LP	SS	LP	SS	LP
Canopy cover (%)									
Number	/	/	/						
Average Height	/	/	/						
Average Diameter (cm)	/	/	/	/					

Reminder: abundance-dominance indexes (Cover =C) by Braun-Blanket:
i : one individual
1 : 1<C<5%
2 : 5<C<25%
3 : 25<C<50%
4 : 50<C<75%
5 : C>75%
+ : non abundant species and C <1%

GENERAL FEATURES FOR THE WHOLE TRANSECT

N° plot: |__|__||__|__||2014||__|__|__||__|__||__|__|

(date: DD|MM|YEAR | N° surveyed peatland| N° Transect | N° Plot)

Author: Vitaline Azambourg .... Date: ___/___/2014

PELLETS COUNT

Type of habitat: ……………………………………………..

Deer browsing pressure:

N° plot	1	2	3	4	5	6	7	8
N° dung groups								

TREE SURVEYS

Plot within the transect	Species	Type (seed., sap., tree)	Height	Diameter	Browsing signs	Other
1						
2						
3						
4						
5						
6						

BOTANICAL SURVEY

Names/abundance	1	2	3	4	5	6
Bryophytes						
Sphagnum angustifolium						
Sphagnum auriculatum ssp denticulatum						
Sphagnum auriculatum ssp inundatum						
Sphagnum capillifolium ssp capilifolium						
Sphagnum capillifolium ssp rubellum						
Sphagnum compactum						
Sphagnum contortum						
Sphagnum cuspidatum						
Sphagnum fallax = recurvum						
Sphagnum fimbriatum						
Sphagnum flexuosum						
Sphagnum fuscum						
Sphagnum girgensohnii						
Sphagnum imbricatum ssp. Austinii						
Sphagnum imbrictum ssp. Affine						
Sphagnum lindbergii						
Sphagnum magellanicum						
Sphagnum majus						
Sphagnum molle						
Sphagnum palustre						
Sphagnum papillosum						
Sphagnum platyphyllum						
Sphagnum pulchrum						
Sphagnum quinquefarium						
Sphagnum riparium						
Sphagnum russowii						
Sphagnum squarrosum						
Sphagnum strictum						
Sphagnum subnitens						
Sphagnum subsecundum						
Sphagnum tenellum						
Sphagnum teres						
Sphagnum warnstorfii						

Aulacomnium palustre *brachythecium rutabalum* *Bryum pseudotriquetrum* *Calliergon cuspidatum* *Calypogeia fissa* *Campylium stellatum* *Cephalozia macrostachya* *Cladopodiella fluitans* *Cratoneuron commutatum* *Ctenidium molluscum* *Dicranella palustris* *Dicranum scoparium* *Drepanocladus exannulatus* *Drepanocladus fluitans* *Drepanocladus revolvens* *Eurhynchium praelongum* *Fissidens adianthoides* *Hylocomium splendens* *Hypnum cupressiforme* *Hypnum jutlandicum* *Jungermannia exsertifolia* *Marchantia alpestris* *Marsupella aquatica* *Marsupella marginata* *Odontoschisma sphagni* *Orthodontium lineare* *Philonotis fontana* *Plagiothecium undulatum* *Pleurozia purpurea* *Pleurozium schreberi* *Pohlia ludwigii* *Pohlia nutans* *Polytrichum commune* *Racomitrium fasciculare* *Racomitrium lanuginosum* *Rhizomnium pseudopunctatum* *Rhytidiadelphus loreus* *Rhytidiadelphus squarrosus* *Scapania uliginosa* *Scapania undulata* *Scorpidium scorpioides*						
Vascular plants/shrubs						

Carex acutiformis *Carex appropinquata* *Carex aquatilis* *Carex bigelowii* *Carex chordorrhiza (rare)* *Carex curta* *Carex demissa* *Carex diandra* *Carex dioica* *Carex disticha* *Carex echinata* *Carex elata* *Carex flacca* *Carex hostiana* *Carex lasiocarpa* *Carex lepidocarpa* *Carex limosa* *Carex magellanica* *Carex nigra* *Carex panicea* *Carex paniculata* *Carex pulicaris* *Carex rariflora* *Carex rostrata*						
Juncus acutiflorus *Juncus articulatus* *Juncus biglumis* *Juncus bulbosus* *Juncus bulbosus/kochii* *Juncus conglomeratus* *Juncus effusus* *Juncus inflexus* *Juncus squarrosus* *Juncus subnodulosus* *Juncus triglumis*						
Other vascular plants						
Agrostis capillaris *Agrostis canina* *Agrostis canina ssp. canina* *Agrostis stolonifera* *Alchemilla filicaulis ssp. Filicaulis* *Alopecurus alpinus* *Anemone nemorosa* *Aneura pinguis* *Angelica sylvestris* *Anthoxanthum odoratum* *Arrhenatherum elatius* *Calluna vulgaris* *Caltha palustris* *Cardamine flexuosa* *Cardamine pratensis* *Centaurea nigra*						

Cirsium arvense *Cirsium dissectum* *Cirsium palustre* *Crepis paludosa* *Deschampsia cespitosa* *Drosera rotundifolia* *Eleocharis multicaulis* *Epilobium hirsutum* *Epilobium palustre* *Epipactis palustris* *Equisetum palustre* *Erica cinerea* *Erica tetralix* *Eriophorum angustifolium* *Eriophorum latifolium* *Eriophorum vaginatum* *Eupatorium cannabinum* *Festuca ovina* *Festuca rubra* *Festuca vivipara* *Filipendula ulmaria* *Galium debile* *Galium palustre* *Galium saxatile* *Gallium palustre* *Gallium uliginosum* *Geum rivale* *Holcus lanatus* *Iris pseudacorus* *Lotus uliginosus* *Lychnis flos-cuculi* *Lycopus europaeus* *Lysimachia vulgaris*						
Mentha aquatica *Menyanthes trifoliata* *Molinia caerulea* *Montia fontana* *Myrica gale* *Nardus stricta* *Narthecium ossifragum* *Oenanthe crocata* *Peucedanum palustre* *Phalaris arundinacea* *Phleum alpinum* *Phragmites australis* *Pinguicula vulgaris* *Poa trivialis* *Potentilla erecta* *Potentilla palustris* *Ranunclus acris* *Ranunculus flammula* *Ranunculus repens* *Ranunculus sceleratus* *Rhynchospora alba* *Rumex acetosa* *Sanguisorba officinalis* *Schoenus nigricans*						

Scirpus cespitosus *stellaria alsine* *Succisa pratensis* *V. uliginosum* *Vaccinium myrtillus* *Vaccinium vitis-idaea* *Valeriana dioica* *Valeriana officinalis* *vicia cracca* *Viola palustris*						
seedlings						
Pinus contorta - Lodgepole pines						
Picea sitchensis - Sitka spruce						
saplings						
Pinus contorta - Lodgepole pines						
Picea sitchensis - Sitka spruce						
Trees						
Pinus contorta - Lodgepole pines						
Picea sitchensis - Sitka spruce						

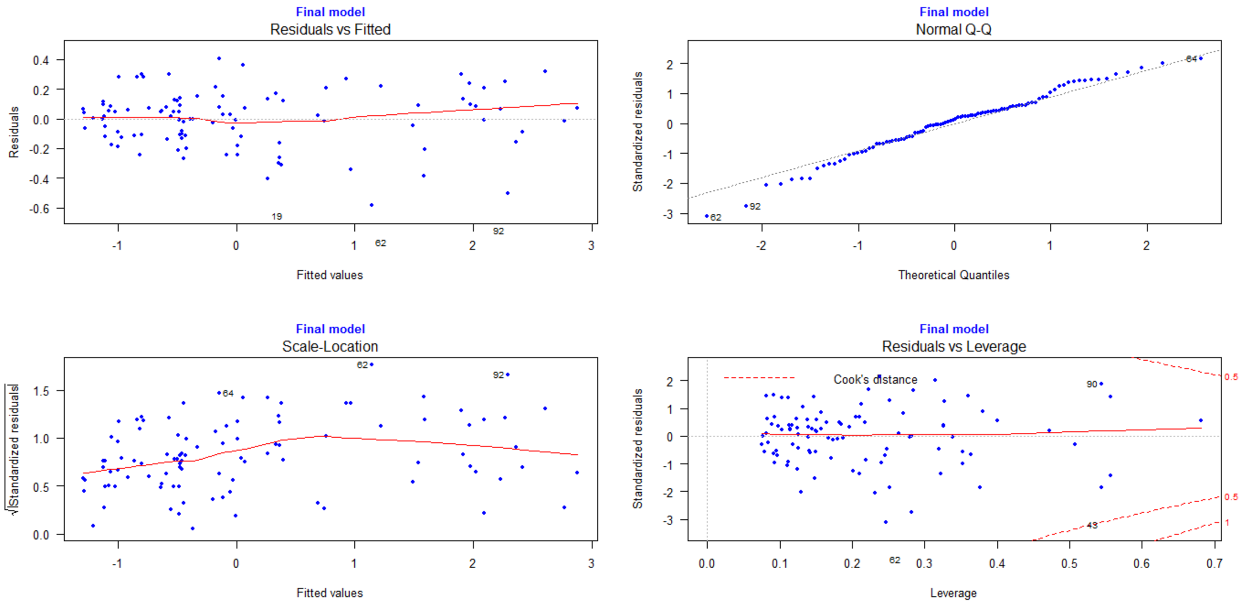
Annex 33: statistical analysis for F1 models according to variables (Rstudio)

```
Summary

lm(formula = F1 ~ R + N + Habitat.code + S + bryophytes.cover.... + 
    Prec + Tjan + distribution.of.T2.... + distribution.of.A1.... + 
    Distance.to.the.edge..meters. + distribution.of.A3...., data = Fecol)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.57988 -0.11656  0.01742  0.11637  0.40379 

Coefficients:
                               Estimate Std. Error t value Pr(>|t|)    
(Intercept)                    4.917398   2.389337   2.058 0.042968 *  
R                              0.527394   0.108081   4.880 5.61e-06 ***
N                              0.685771   0.124396   5.513 4.53e-07 ***
Habitat.codeM17               -0.174835   0.248370  -0.704 0.483601    
Habitat.codeM18               -0.086629   0.139623  -0.620 0.536793    
Habitat.codeM19                0.126647   0.132477   0.956 0.342070    
Habitat.codeM20               -0.021127   0.136319  -0.155 0.877241    
Habitat.codeM23                0.474849   0.210711   2.254 0.027069 *  
Habitat.codeM24                1.157151   0.179442   6.449 9.02e-09 ***
Habitat.codeM25                0.379392   0.141835   2.675 0.009127 ** 
Habitat.codeM3                -0.164895   0.191866  -0.859 0.392774    
Habitat.codeM5                 0.260363   0.258607   1.007 0.317188    
Habitat.codeM6                 0.025010   0.145840   0.171 0.864288    
Habitat.codeM9                 0.822067   0.171584   4.791 7.90e-06 ***
Habitat.codeS27                1.449605   0.204458   7.090 5.61e-10 ***
S                             -2.451707   0.471594  -5.199 1.60e-06 ***
bryophytes.cover....           0.003420   0.001327   2.578 0.011847 *  
Prec                          -0.003869   0.001122  -3.448 0.000919 ***
Tjan                          -1.051405   0.465250  -2.260 0.026656 *  
distribution.of.T2....         0.002862   0.001168   2.450 0.016573 *  
distribution.of.A1....         0.003017   0.001702   1.773 0.080203 .  
Distance.to.the.edge..meters.  0.002428   0.001354   1.794 0.076790 .  
distribution.of.A3....         0.010743   0.006042   1.778 0.079356 .  
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.2146 on 77 degrees of freedom
Multiple R-squared:  0.9728,	Adjusted R-squared:  0.9651 
F-statistic: 125.4 on 22 and 77 DF,  p-value: < 2.2e-16
```

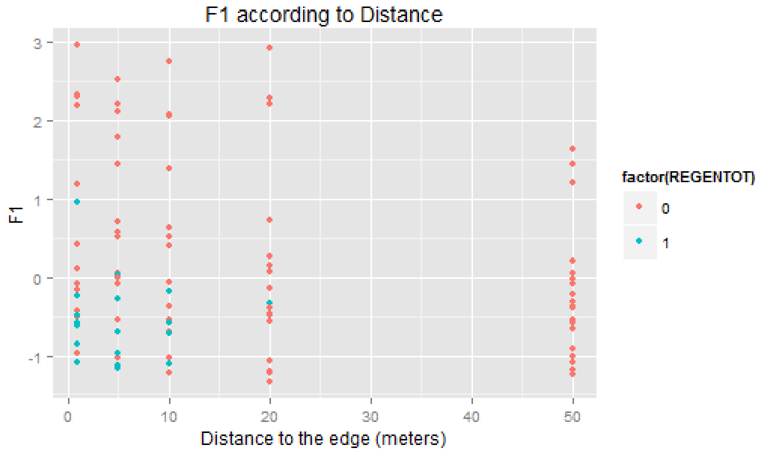
```
Anova analysis

                             Step  Df    Deviance Resid. Df Resid. Dev        AIC
1                                  NA          NA        99 130.552945   28.66087
2                             + R  -1 116.9787420        98  13.574203 -195.69990
3                             + N  -1   2.3495995        97  11.224604 -212.70620
4                  + Habitat.code -12   5.0687848        85   6.155819 -248.77724
5                             + S  -1   1.2536417        84   4.902177 -269.54907
6          + bryophytes.cover....  -1   0.2359492        83   4.666228 -272.48191
7                          + Prec  -1   0.3756259        82   4.290602 -278.87431
8                          + Tjan  -1   0.1583469        81   4.132255 -280.63468
9        + distribution.of.T2....  -1   0.1595642        80   3.972691 -282.57264
10       + distribution.of.A1....  -1   0.1613048        79   3.811386 -284.71772
11 + Distance.to.the.edge..meters.  -1   0.1200675        78   3.691319 -285.91864
12       + distribution.of.A3....  -1   0.1455685        77   3.545750 -287.94204
```

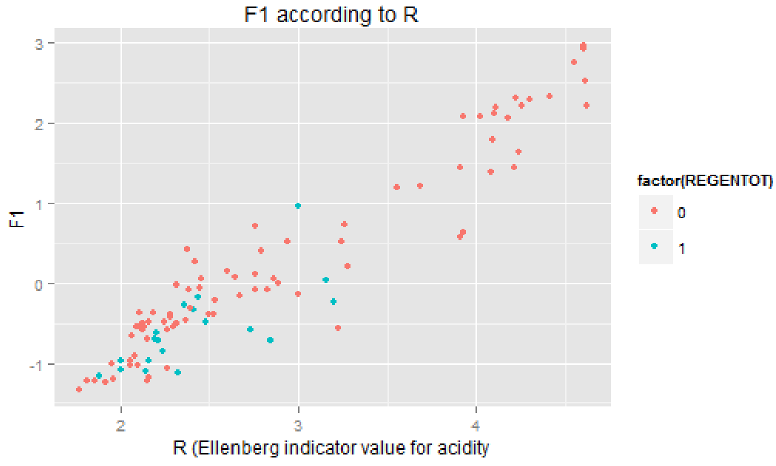
```
Anova Table (Type II tests)

Response: F1
                              Sum Sq Df F value    Pr(>F)    
R                             1.0964  1 23.8104 5.614e-06 ***
N                             1.3995  1 30.3912 4.529e-07 ***
Habitat.code                  5.3989 12  9.7703 3.013e-11 ***
S                             1.2446  1 27.0271 1.604e-06 ***
bryophytes.cover....          0.3060  1  6.6460 0.0118466 *  
Prec                          0.5474  1 11.8875 0.0009191 ***
Tjan                          0.2352  1  5.1070 0.0266560 *  
distribution.of.T2....        0.2763  1  6.0005 0.0165734 *  
distribution.of.A1....        0.1447  1  3.1431 0.0802034 .  
Distance.to.the.edge..meters. 0.1482  1  3.2173 0.0767904 .  
distribution.of.A3....        0.1456  1  3.1612 0.0793564 .  
Residuals                     3.5458 77                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

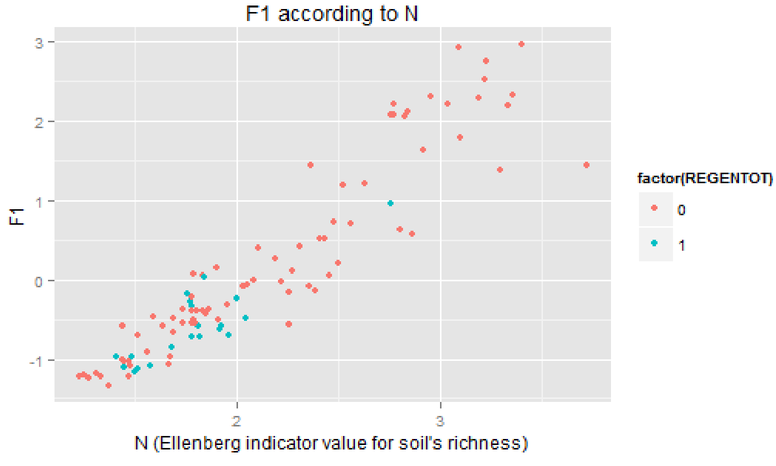
Residuals graphs for the proposed model:

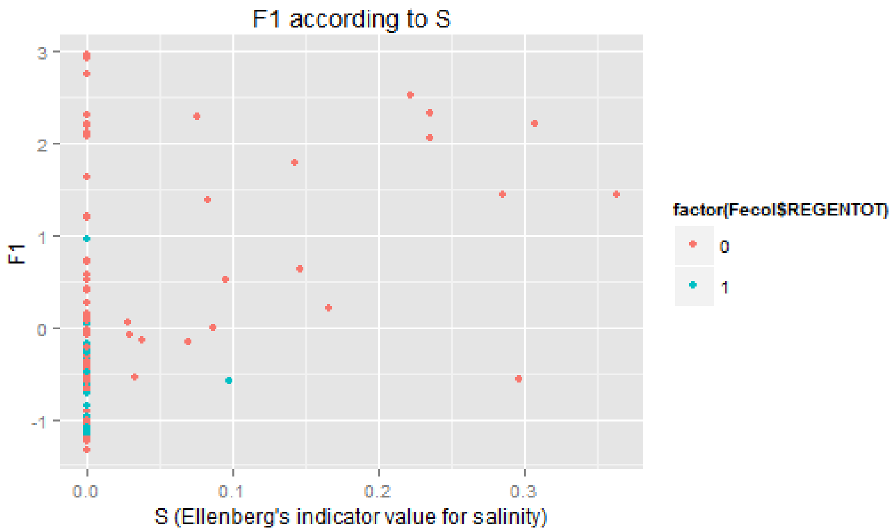


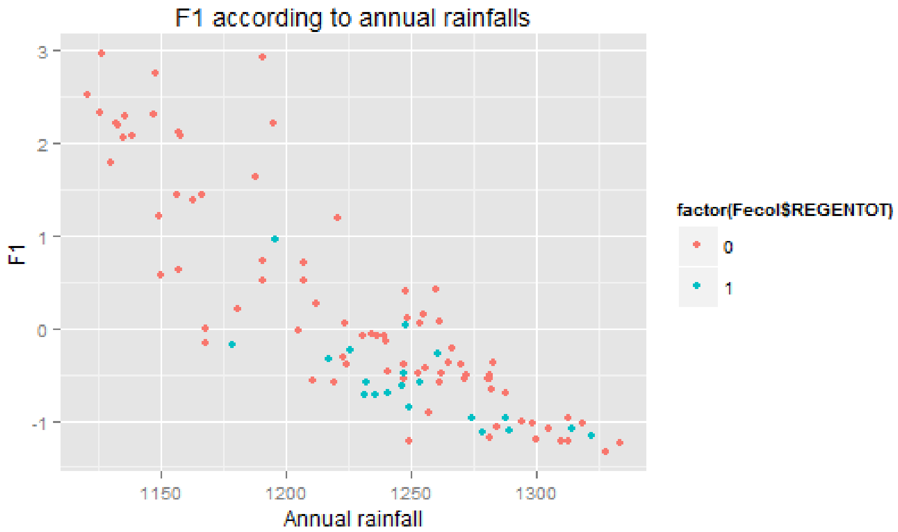
Annex 34: graph of F1 according to the selected variables taken into account in the model

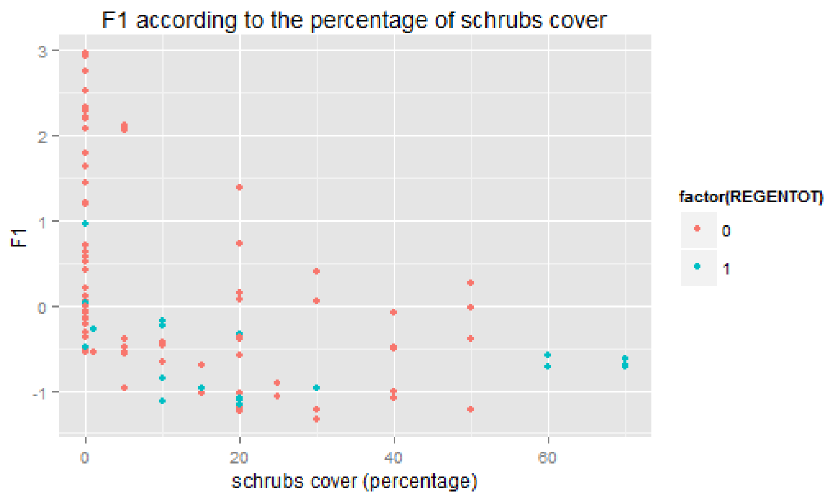


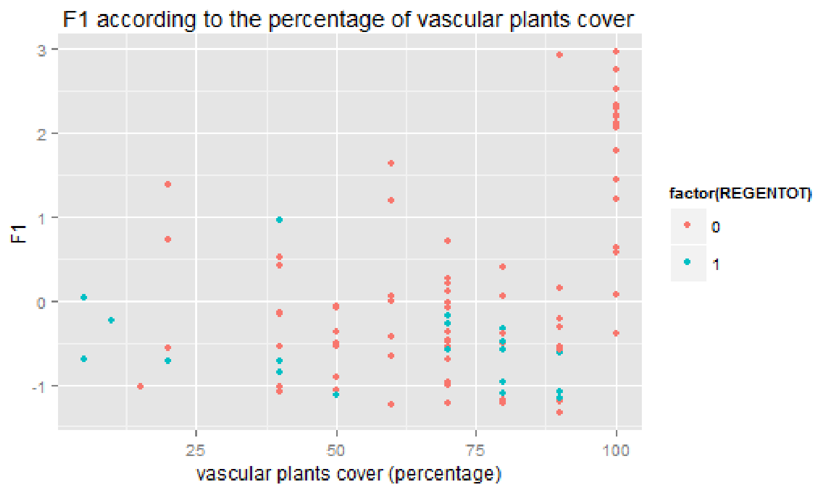


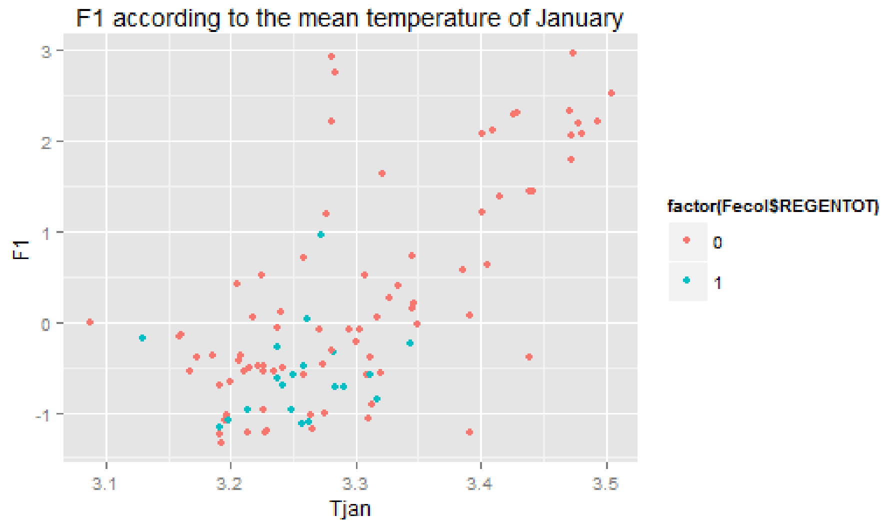


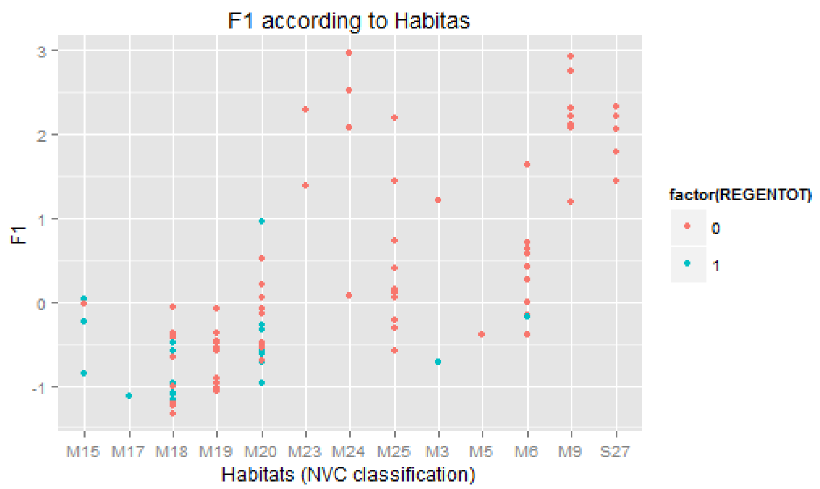

F1 according to S
F1
S (Ellenberg's indicator value for salinity)
factor(Fecol$REGENTOT)
0
1

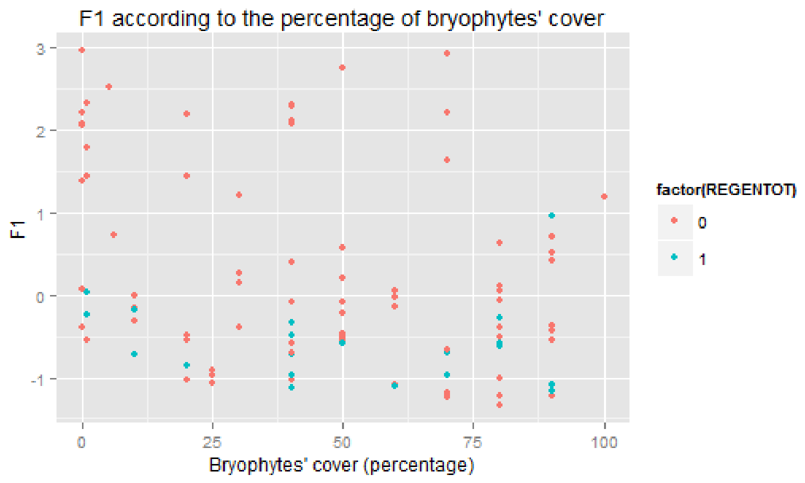

F1 according to annual rainfalls
F1
Annual rainfall
factor(Fecol$REGENTOT)
0
1

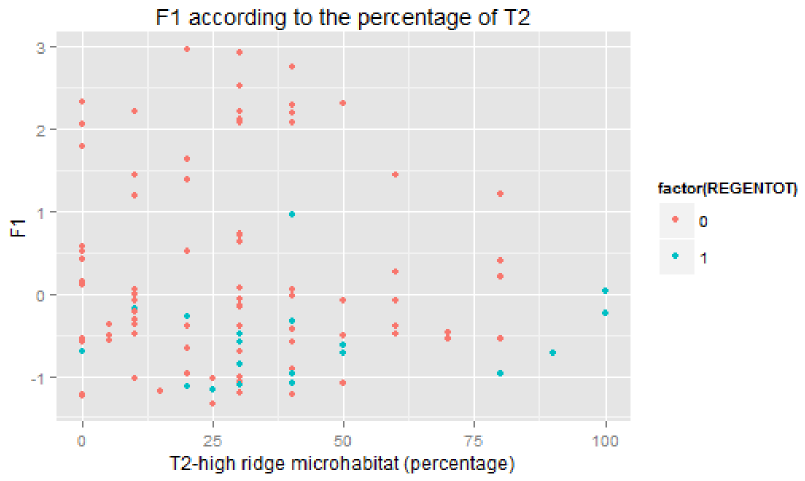

F1 according to the percentage of schrubs cover
F1
schrubs cover (percentage)
factor(REGENTOT)
0
1

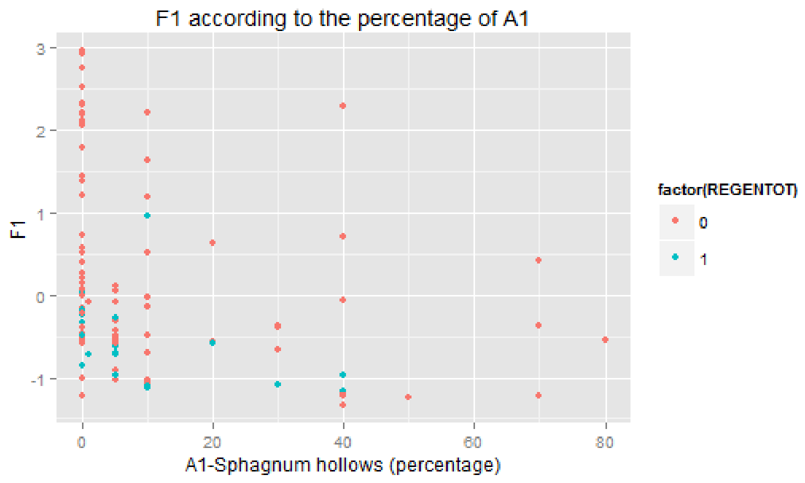

F1 according to the percentage of vascular plants cover
F1
vascular plants cover (percentage)
factor(REGENTOT)
0
1

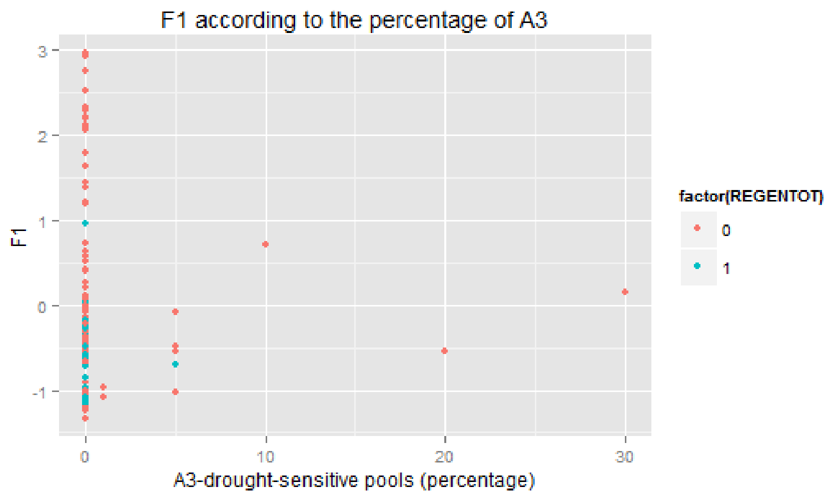

F1 according to the mean temperature of January
F1
Tjan
factor(Fecol$REGENTOT)
0
1


F1 according to Habitas
F1
M15 M17 M18 M19 M20 M23 M24 M25 M3 M5 M6 M9 S27
Habitats (NVC classification)
factor(REGENTOT)
0
1

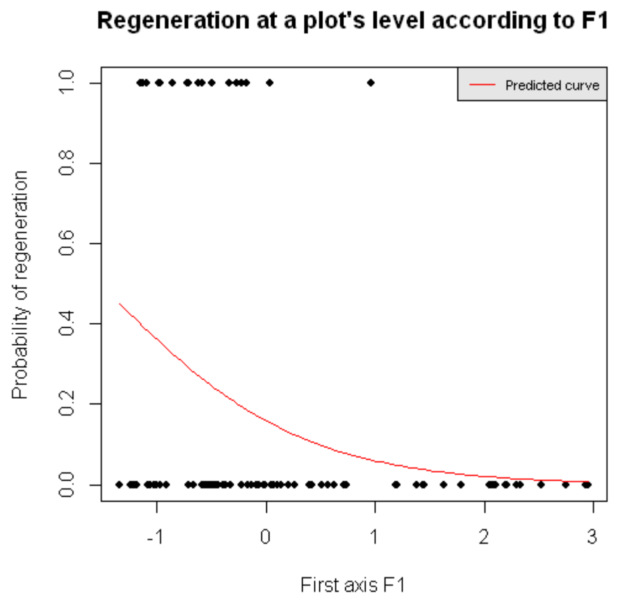

F1 according to the percentage of bryophytes' cover
F1
Bryophytes' cover (percentage)
factor(REGENTOT)
0
1


F1 according to the percentage of T2
F1
T2-high ridge microhabitat (percentage)
factor(REGENTOT)
0
1


F1 according to the percentage of A1
F1
A1-Sphagnum hollows (percentage)
factor(REGENTOT)
0
1



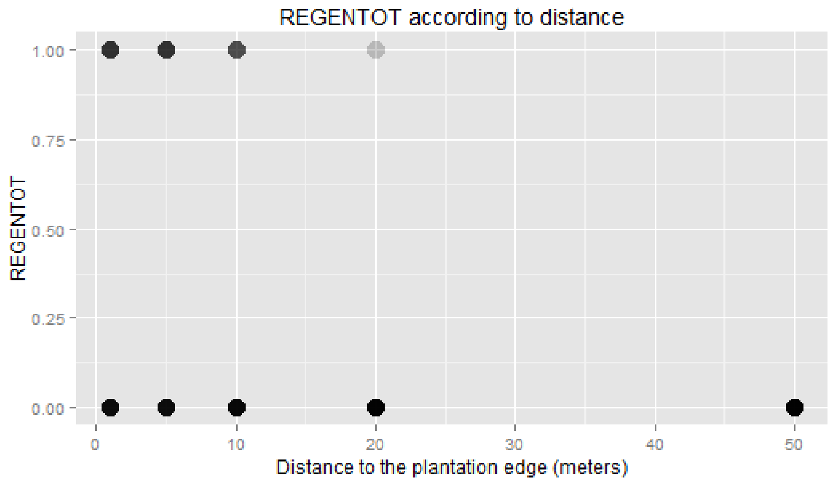
Annex 35: statistical results for predicting REGENTOT according to F1

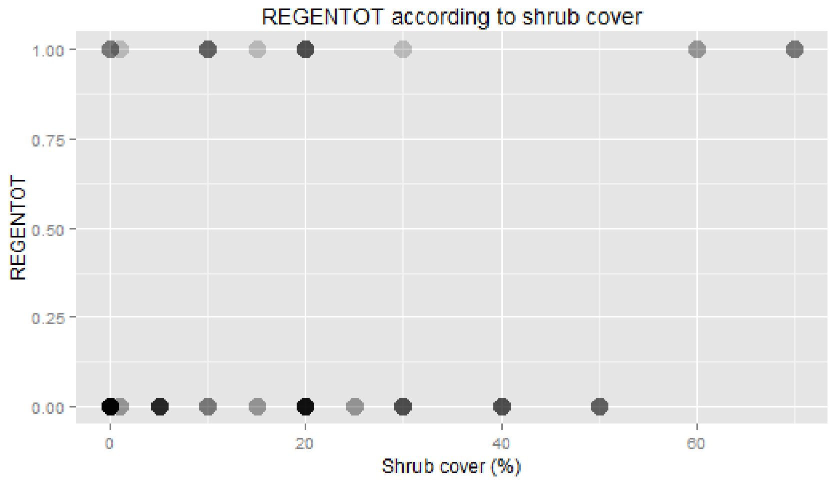


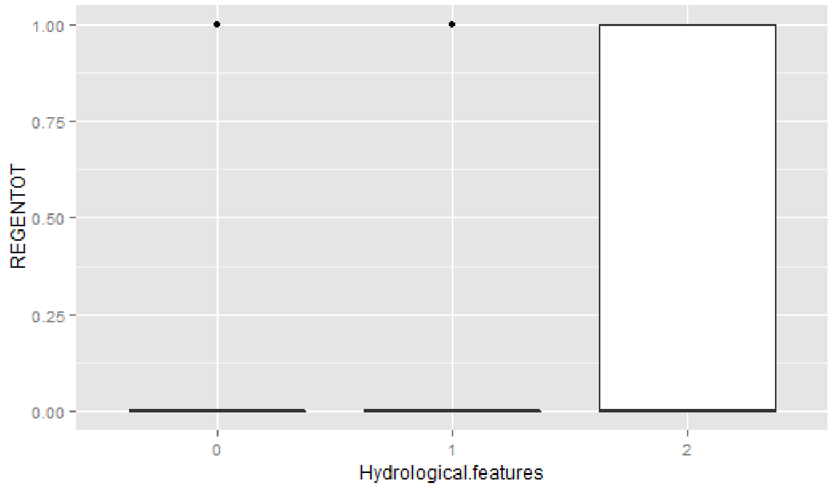

```
glm(formula = REGENTOT ~ F1, family = binomial(link = "logit"),
    data = Fecol)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.0940  -0.7515  -0.5227  -0.1734   2.3609

Coefficients:
            Estimate Std. Error z value    Pr(>|z|)
(Intercept)  -1.6657     0.3351  -4.971 0.000000666 ***
F1           -1.0959     0.4102  -2.672     0.00755 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 100.080  on 99  degrees of freedom
Residual deviance:  88.244  on 98  degrees of freedom
AIC: 92.244

Number of Fisher Scoring iterations: 6
```

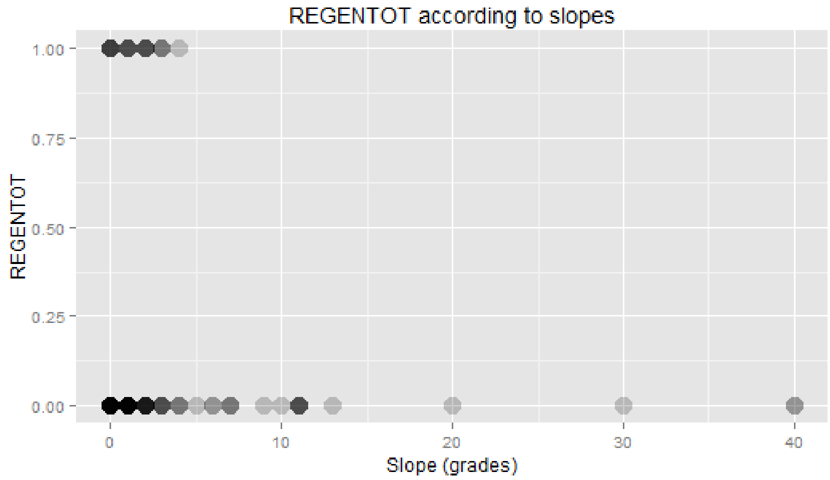
```
> anova(glm2, test='Chisq')
Analysis of Deviance Table

Model: binomial, link: logit

Response: REGENTOT

Terms added sequentially (first to last)


     Df Deviance Resid. Df Resid. Dev  Pr(>Chi)
NULL                    99    100.080
F1    1   11.836        98     88.244 0.0005808 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

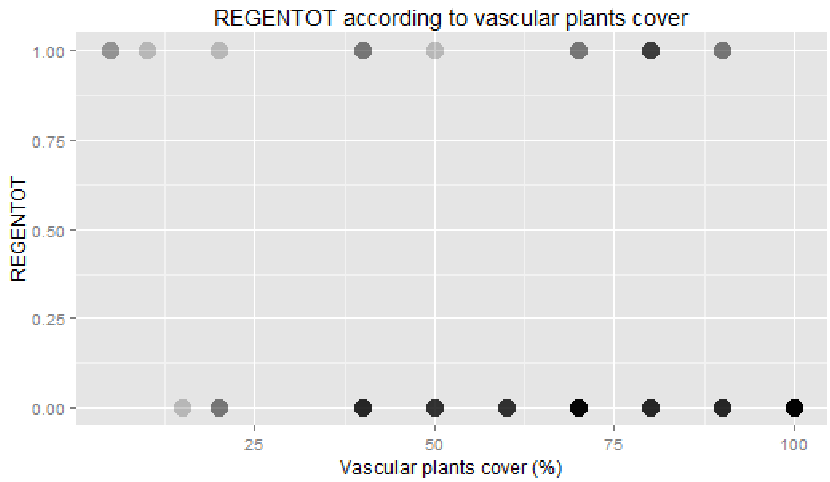
Annex 36: graphs of REGENTOT according to the selected variables






1.00
0.75
0.50
0.25
0.00
REGENTOT
0
1
2
Hydrological.features


REGENTOT according to slopes
1.00
0.75
0.50
0.25
0.00
REGENTOT
0
10
20
30
40
Slope (grades)


REGENTOT according to vascular plants cover
1.00
0.75
0.50
0.25
0.00
REGENTOT
25
50
75
100
Vascular plants cover (%)

Annex 37: Tukey multiple-comparison test for habitat types

```
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = REGENTOT ~ Habitat.code, data = Tbet)

$Habitat.code
                 diff          lwr         upr     p adj
M17-M15  2.500000e-01 -1.12279272  1.62279272 0.9999897
M18-M15 -4.500000e-01 -1.12252834  0.22252834 0.5377801
M19-M15 -7.500000e-01 -1.45205761 -0.04794239 0.0254164
M20-M15 -3.690476e-01 -1.03890188  0.30080664 0.8038889
M23-M15 -7.500000e-01 -1.81336067  0.31336067 0.4520779
M24-M15 -7.500000e-01 -1.61823035  0.11823035 0.1623680
M25-M15 -7.500000e-01 -1.47641363 -0.02358637 0.0364821
M3-M15  -2.500000e-01 -1.31336067  0.81336067 0.9998391
M5-M15  -7.500000e-01 -2.12279272  0.62279272 0.8125344
M6-M15  -6.500000e-01 -1.37641363  0.07641363 0.1269619
M9-M15  -7.500000e-01 -1.51960395  0.01960395 0.0634715
S27-M15 -7.500000e-01 -1.57367563  0.07367563 0.1114607
M18-M17 -7.000000e-01 -1.95818531  0.55818531 0.7934724
M19-M17 -1.000000e+00 -2.27421380  0.27421380 0.2848241
M20-M17 -6.190476e-01 -1.87580561  0.63771037 0.8979805
M23-M17 -1.000000e+00 -2.50381908  0.50381908 0.5477460
M24-M17 -1.000000e+00 -2.37279272  0.37279272 0.3996823
M25-M17 -1.000000e+00 -2.28779373  0.28779373 0.3003579
M3-M17  -5.000000e-01 -2.00381908  1.00381908 0.9952163
M5-M17  -1.000000e+00 -2.73646070  0.73646070 0.7539117
M6-M17  -9.000000e-01 -2.18779373  0.38779373 0.4670656
M9-M17  -1.000000e+00 -2.31264091  0.31264091 0.3291407
S27-M17 -1.000000e+00 -2.34505668  0.34505668 0.3671093
M19-M18 -3.000000e-01 -0.73744178  0.13744178 0.4978693
M20-M18  8.095238e-02 -0.30268176  0.46458652 0.9999487
M23-M18 -3.000000e-01 -1.21060768  0.61060768 0.9955975
M24-M18 -3.000000e-01 -0.97252834  0.37252834 0.9476831
M25-M18 -3.000000e-01 -0.77554935  0.17554935 0.6296471
M3-M18   2.000000e-01 -0.71060768  1.11060768 0.9999214
M5-M18  -3.000000e-01 -1.55818531  0.95818531 0.9998137
M6-M18  -2.000000e-01 -0.67554935  0.27554935 0.9660697
M9-M18  -3.000000e-01 -0.83922228  0.23922228 0.7934724
S27-M18 -3.000000e-01 -0.91393157  0.31393157 0.9030374
M20-M19  3.809524e-01 -0.05236698  0.81427175 0.1440164
M23-M19  3.202566e-17 -0.93262900  0.93262900 1.0000000
M24-M19  3.202566e-17 -0.70205761  0.70205761 1.0000000
M25-M19  4.270089e-18 -0.51646656  0.51646656 1.0000000
M3-M19   5.000000e-01 -0.43262900  1.43262900 0.8310012
M5-M19   4.270089e-18 -1.27421380  1.27421380 1.0000000
M6-M19   1.000000e-01 -0.41646656  0.61646656 0.9999797
M9-M19   8.753682e-17 -0.57563112  0.57563112 1.0000000
S27-M19  3.202566e-17 -0.64614433  0.64614433 1.0000000
M23-M20 -3.809524e-01 -1.28958691  0.52768214 0.9668616
M24-M20 -3.809524e-01 -1.05080664  0.28890188 0.7687989
M25-M20 -3.809524e-01 -0.85271243  0.09080767 0.2447827
M3-M20   1.190476e-01 -0.78958691  1.02768214 0.9999997
M5-M20  -3.809524e-01 -1.63771037  0.87580561 0.9979674
M6-M20  -2.809524e-01 -0.75271243  0.19080767 0.7112864
M9-M20  -3.809524e-01 -0.91683579  0.15493103 0.4392313
S27-M20 -3.809524e-01 -0.99195347  0.23004871 0.6470579
M24-M23  0.000000e+00 -1.06336067  1.06336067 1.0000000
M25-M23 -2.775558e-17 -0.95109870  0.95109870 1.0000000
M3-M23   5.000000e-01 -0.72786314  1.72786314 0.9735212
M5-M23  -2.775558e-17 -1.50381908  1.50381908 1.0000000
M6-M23   1.000000e-01 -0.85109870  1.05109870 1.0000000
M9-M23   5.551115e-17 -0.98448068  0.98448068 1.0000000
S27-M23  0.000000e+00 -1.02730401  1.02730401 1.0000000
M25-M24 -2.775558e-17 -0.72641363  0.72641363 1.0000000
M3-M24   5.000000e-01 -0.56336067  1.56336067 0.9246546
M5-M24  -2.775558e-17 -1.37279272  1.37279272 1.0000000
M6-M24   1.000000e-01 -0.62641363  0.82641363 0.9999996
M9-M24   5.551115e-17 -0.76960395  0.76960395 1.0000000
S27-M24  0.000000e+00 -0.82367563  0.82367563 1.0000000
M3-M25   5.000000e-01 -0.45109870  1.45109870 0.8487860
M5-M25   0.000000e+00 -1.28779373  1.28779373 1.0000000
M6-M25   1.000000e-01 -0.44911709  0.64911709 0.9999897
M9-M25   8.326673e-17 -0.60509756  0.60509756 1.0000000
S27-M25  2.775558e-17 -0.67252834  0.67252834 1.0000000
M5-M3   -5.000000e-01 -2.00381908  1.00381908 0.9952163
M6-M3   -4.000000e-01 -1.35109870  0.55109870 0.9660697
M9-M3   -5.000000e-01 -1.48448068  0.48448068 0.8766819
S27-M3  -5.000000e-01 -1.52730401  0.52730401 0.9054828
M6-M5    1.000000e-01 -1.18779373  1.38779373 1.0000000
M9-M5    8.326673e-17 -1.31264091  1.31264091 1.0000000
S27-M5   2.775558e-17 -1.34505668  1.34505668 1.0000000
M9-M6   -1.000000e-01 -0.70509756  0.50509756 0.9999965
S27-M6  -1.000000e-01 -0.77252834  0.57252834 0.9999989
S27-M9  -5.551115e-17 -0.71896304  0.71896304 1.0000000
```