The development of a site classification for Irish forestry

Niall Farrelly[a*] and Gerhardt Gallagher[b]

Abstract

Criteria and site classification methods to assist in the identification of land that have potential for afforestation grant aid were evaluated in this study. The study examined the nature, fertility and productivity of unenclosed land to determine if opportunities existed for future afforestation. Local variability in soil nutrient regime and the changing nature of land-use in Ireland may have contributed to some of the observed variability in productivity potential. The results indicated that classifications based on historical enclosures provided limited scope for evaluating the potential suitability of sites for forestry. Therefore, alternative site classification methods, based on productive criteria, were evaluated. Results indicated that the classification of soil nutrient regime, supplemented with indicator plant analysis, showed the greatest potential. A new classification was developed, which was heavily influenced by ecological classifications but with supplementary classes to cover less fertile but still productive site types. The newly-developed classification has seven classes (referred to as site types A to G, in order of decreasing suitability). Sites classed from A to C were typically arable land, improved pasture and "rush-pasture", and offer the potential to diversify species selection. The D type, typically associated with bracken (*Pteridium aquilinium*), is considered potentially suitable for more diverse conifers including Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), western red cedar (*Thuga plicata* D. Don), and western hemlock (*Tsuga heterophylla* (Raf.). The wetter site types with rush (*Juncus* spp.) are suitable for Sitka spruce (*Picea sitchensis* (Bong.) Carr.) assuming a single application of phosphorus. The E site type is typically associated with pure *Molinia* spp. requiring phosphorous fertilisation to support productive Sitka spruce. The F type was considered unsuitable for pure Sitka spruce without the use of nursing mixtures of lodgepole pine (*Pinus contorta* Douglas ex Loudon). Site type G, the lowest classification level, was unsuitable for forestry.

Keywords: *Afforestation, soil nutrient regime, forest productivity, historical land use, field enclosures.*

Introduction

Significant progress has been made in the restoration of forest cover in Ireland over the past 100 years from 1% of the land area that existed in the early 1900's, to 11% in 2015. Further commitments to increase the forest area to approximately 1.2 million ha or 18% of land area were reaffirmed in the 2014 forest policy review document *Forest Products and People* (DAFM 2014). Its achievement will require the annual creation of 16,000 ha of new forests per year up to 2046. The availability of land for forestry expansion however, cannot automatically be assumed and will be highly

[a]Teagasc, Mellows Centre, Athenry, Co. Galway.
[b]53 Upper Beechwood Avenue, Ranelagh, Dublin 6.
[*]Corresponding author: niall.farrelly@teagasc.ie

dependent on what is currently considered marginal for agricultural production. Land is a valuable resource and areas suitable for forestry may not necessarily become available, especially if its current use is considered optimal or suitable for future expansion/intensification of agriculture. Other land may be readily available for afforestation in areas where farming activity levels and profit margins are low. The inclusion of a significant proportion of unenclosed land (c. 178,000 ha) which is not subject to National or EU designations but which shows good levels of potential productivity would also provide candidate areas (Farrelly and Gallagher 2015; this issue). To ensure satisfactory establishment and productivity, and to qualify for state afforestation grant aid, the limiting criteria are that land should have the ability to produce a commercial crop of Sitka spruce[1] (*Picea sitchesis* (Bong.) Carr.) with a minimum growth rate of General Yield Class (GYC) 14, as per to Edwards and Christie (1981) (Anon. 2011).

Much attention has been devoted to the performance of forests on unenclosed land. Historically, forestry has been associated with sub-marginal and marginal agricultural land in Ireland, as early land-use policy, overseen by the Land Commission, retained the best areas for food production (Gray 1963). The performance of tree crops on marginal land has been variable. Good quality crops of Sitka spruce and other species have been produced on the lower slopes of mountains and valleys, or on mineral soils derived from Ordovician or Silurian shale and mixed sandstone and shale, or where land was limited in its use for agriculture by the nature of the terrain (e.g. steep rocky slopes, or impeded drainage). Afforestation programmes, which had a stronger emphasis on creating rural employment, resulted in the afforestation of poorer peatland sites in the 1960's, which while able to support coastal provenances of lodgepole pine (*Pinus contorta* Douglas ex Loudon), were unsuitable for pure Sitka spruce crops without multiple fertiliser applications. It is likely that such experiences may have created an impression that peatland sites were inherently unproductive and associated with unthrifty crops. However, certain under-utilised, abandoned, and/or semi-improved land, not already in agricultural use and therefore currently unenclosed, may still provide suitable and productive sites for forestry.

The enclosure of land for agricultural use in Ireland

Historically field enclosures have been used as a basis of demarcation of property boundaries in continuous use for food or animal production. While enclosure of land for agricultural use has long characterised the Irish landscape, it was not until the post-plantation period during the agricultural revolution that the extent of land enclosure and field demarcation were most marked (Aalen and Whelan 1997). Differences in

[1] Sitka spruce was chosen as the benchmark species for afforestation grant aid by the Irish Forest Service to serve as an indicator of whether a commercially viable crop of tree species could be established at a site.

field enclosures between the richer east and the poorer west of Ireland are apparent. In Leinster, the necessity for the demarcation of property boundaries following the establishment of the landlord system in the 17th century, led to the development of regular enclosures. All land below 150 m in elevation that was not bog was enclosed in Leinster by 1850. Tillage enclosures tended to be smaller than pasture fields, the latter enclosed by stock-proof earthen banks and hedges often dominated by hawthorn (*Crategous monogyna* Jacq.), ash (*Fraxinus excelsior* L.) and furze (*Ulex europaeus* L.). In Munster, the pattern was for farms with irregular strips enclosed by walls or banks with exotic plant escapees such as fuscia (*Fuchsia magellanica* Lam.), butterfly bush (*Buddleja davidii* Franch.) and monbretia (*Crocosmia × crocosmiiflora* (Lemoine) N.E.Br.) in west Cork and Kerry, while in east Waterford through to Cork, substantial hedges composed of hawthorn, blackthorn (*Prunus spinosa* L.) and furze were evident. The Golden Vale, an area of rolling pasture land occurring in Limerick, Tipperary and Cork, was composed of larger fields, with hawthorn, blackthorn and ash evident in hedgerows. Areas with dairy enterprises tended to have smaller field sizes for the purposes of shelter, maintenance of fresh grass and management of meadows. In Connaught field formation culminated only in the 19th century and sizes varied in size and shape, from the regular to the highly irregular. In the lowlands, fields were laid out in blocks, large fields with flimsy dry stone walls, often one stone thick. On hillsides, fields were arranged in parallel strips or in ladder-like formation running down the slopes with farmsteads arranged in lines along new roads. The trend in Ulster followed the pattern described for Connaught, with only the best land being enclosed by the end of the 18th century; later land was enclosed with regular small to medium fields bounded by hedged banks. Regular field systems in the lowlands with neatly pruned hedges were common and narrower ladder farms were utilised in the uplands of Donegal, the Antrim Glens and the Sperrin mountains. Little change in field systems occurred until the 1950's when farm mechanisation increased substantially. The pressure to remove boundaries and enlarge fields grew steadily and was directly supported initially by Government grants and by European incentives from the 1960's onwards. Banks and walls were bulldozed and the stones and earth spread over the fields; some were replaced with stone and wire fences, more easily re-arranged for the purposes of strip grazing. Over more recent decades, there has been a significant reduction in field boundary lengths resulting in larger farms. Recent incentives to promote farming in harmony with the environment (i.e. the Rural Environmental Protection Scheme) have resulted in some boundaries being restored or replanted. Historically, land beyond agricultural cultivation and reclamation, considered unsuitable for domestic livestock rearing, was often fenced out or ex-closed. Roughly 20% of the land area of Ireland is thought to be outside of permanent enclosures (Aalen and Whelan 1997).

Potential of unenclosed land

Farrelly and Gallagher (2015, this issue) concluded that 850,000 ha of unenclosed land was biologically unsuitable for forestry expansion, being comprised of deep peat, raised bogs, fens, bare rock and outcrops or currently subject to National and EU designations and policies. However, they concluded that an area of almost 180,000 ha of unenclosed land had good potential for afforestation. While the division of land probably indicates some degree of improvement effort which may influence soil fertility, in itself this does not provide sufficient information to determine if land is inherently suitable or unsuitable for afforestation. Other more objective methods are therefore required for the assessment of suitable sites for forestry (Gallagher 1972, Farrelly 2011, Farrelly and Gallagher 2013).

Much information regarding the suitability of hill and mountain land (much of it unenclosed) for afforestation has been available from Gallagher's 1972 study where marginal and submarginal land of north Co. Wicklow was surveyed and mapped in order to identify various categories of land suitable for forestry development. These included hill farm land adjoining enclosed fields often characterised by grass, bracken and furze. Land above the last wall, ditch or fence defining the boundary between the farm and the open mountain (e.g. upper slopes or hilltops) was often indicated as being suitable for afforestation. Grass slopes with little or no peat and areas lying down-slope from heaths, perhaps indicative of animal grazing and *Molinia* swards perhaps suggested past tree cover. Other areas, due to their geographic/topographic and natural disposition on more favourable south facing slopes located on soils derived from better quality parent material, were deemed favourable for forestry. Other land, with vegetation associated with higher levels of improvement (i.e. soft rush (*Juncus effusus* L.), birch (*Betula* spp.) and furze (*Ulex* spp.), may have been used in the past for stock rearing and then "abandoned" and allowed to revert to scrub and may also indicate suitable sites. Farrelly (2011), in his study of site quality and the productivity of Sitka spruce in Ireland, found that the effect of even limited soil conditioning from past grazing or more limited anthropogenic activities, markedly altered the availability of nutrients in unenclosed land, providing satisfactory conditions for Sitka spruce growth.

Potential methods of classifying suitable site types for afforestation

It is clear from the above that there is a need to more thoroughly examine criteria to describe the nature of unenclosed land and its potential forest productivity, as underpinned by scientific measures of site quality. A range of effective site classification methods are available for the assessment of site quality and forest productivity (e.g. Carmean 1975, Farrelly et al. 2009). These include vegetation-based site classification schemes, such as those proposed by Mark Loudon

Anderson (Anderson 1960), that have been used as an aid to tree species selection in state land acquisition enterprises during the 1960's. Other classifications based on a historic land use from assessments of Ordnance Survey maps (OCarroll 2012) have since been widely used to identify areas of improved soil fertility and were used as the basis for fertiliser prescriptions (OCarroll 1975). More sophisticated soil and vegetation based methods are used to assess site quality and have been used in the Biogeoclimatic Ecosystem Classification (BEC) in British Columbia and the Ecological Site Classification (ESC) in Great Britain (Pojar et al. 1987, Pyatt et al. 2001. The latter method has been adapted to assess site quality and species choice for Ireland, including information on the potential effects of climate change on tree growth responses (CLIMADAPT) by Ray et al. (2009). Both these classification systems are based on multiple factors but rely on a local assessment of soil quality, notably soil moisture and nutrient regime. Soil nutrient regime[2] (SNR) can be assessed using vegetation and/or soil morphological characteristics and can be used to produce a reliable classification of soil fertility (Wilson 2013). The use of the indicator plants to determine soil fertility can produce similar results to those derived from expensive laboratory analysis of soil samples (Wilson et al. 2001, 2005). Such assessments of soil fertility make use of indicator value scale produced by Ellenberg (1988) to describe the soil preferences of vascular plants in Central Europe using a scale that ranges from 1 to 9. More recently indicator values for vascular plants in Britain have been produced and Ellenberg's original values have been revised based on an extensive analysis of conditions in Great Britain, referred to as Hill-Ellenberg values (Hill et al. 1999). While three indicator values explain soil moisture (F-value), soil reaction or base status (R-value) and nitrogen (N-value) status, the combined values for base status and nitrogen (R+N value) are often used as a composite indicator of soil nutrient status (Pyatt et al. 2001). The assessment procedure follows a numerical procedure to produce a unit-less weighted average indicator value which provides a reliable classification of the nutrient status of soils (Wilson 2013).

Other soil-based classifications based on traditional soil survey methods have been widely used to assess soil quality and gained much favour in the 1970's and 80's in Ireland (O' Flanagan and Bulfin 1970, Bulfin et al. 1973, Carey et al. 1985, Bulfin 1987, Conry and Clinch 1989). The classification of soils into great groups or to soil series level is also useful for assessing soil quality and provides information on the inherent fertility status of a soil, available water capacity, associated vegetation, parent material type, drainage, texture, depth and structure. For example, Bulfin et al. (1973) estimated rates of Sitka spruce production based on a map of soil series from the Leitrim Resource Survey carried out by An Foras

[2] Soil nutrient regime as described by Klinka et al. (1984).

Taluntais (now Teagasc) in the 1970s. While soil classification is an excellent proxy for site fertility, it requires a detailed survey and considerable expertise to classify soils especially to soil series level. Farrelly (2012), in a study of soil quality and Sitka spruce productivity showed that more detailed classification of soils into soil subgroups (twenty classes) was more successful in explaining variability in yield than the currently used, more expensive analytical measures of soil quality (i.e. soil pH, soil P, K, Mg and N), due to the spatial variability of soil properties.

Objective of the study

The objective of the study was to examine the nature, fertility and productivity of unenclosed land and identify if opportunities exist for future afforestation. A further objective was to examine if criteria or site classification methods exist that can be used to assess whether a site would be capable of producing a commercial crop and qualify for afforestation grant aid. To be of any practical use in forest management, a site classification method must (1) explain at least 50% of the variation in yield class; (2) be based on a few easily measured variables (Blyth and MacLeod 1981); and (3) be capable of reliably and consistently classifying areas for afforestation grant aid. The ultimate objective of the study was to develop a site-level classification specifically for use in Irish forestry.

Materials and methods

Characterisation of historical agricultural land use

To examine the productivity of land and its relationship with historical land enclosure, an assessment was made of a representative sample of land planted with Sitka spruce[3] (including both enclosed and unenclosed areas) across Ireland (Farrelly 2011). Stands were selected for study from the entire range of pure Sitka spruce crops that were even-aged, uniformly stocked, and at post establishment stage (stand age ranged from 15 – 82 years) and covered both Coillte (State owned) and privately owned forests. In total, 201 stands were visited between October 2006 and April 2009. Prior to field visits, information on historical land use was assessed from Ordnance Survey of Ireland (OSI) 6-inch and 25-inch maps covering four editions published from 1829 to 1948 (Table 1). Details regarding field enclosures and land use were derived from each OSI map edition and subsequent editions were compared in an effort to identify the degree of change in land use from first to last edition (i.e. over 120 years). Stands were designated according to enclosure type and fertility class based on this assessment of map ornament according to OCarroll's (2012) simple site fertility classification (A, B, C, X). Further information about field size and elevation were also recorded from the OSI maps.

[3] Sitka spruce is used as a benchmark species for afforestation grant aid by the Irish Forest Service.

Table 1: *The various editions of the Ordnance Survey of Ireland (OSI) 6-inch and 25-inch maps published from 1829 to 1948.*

OSI Map Edition	Approximate date
OS 6-inch 1st edition	(c. 1829-1841)
OS 25-inch 1st edition	(c. 1897-1913)
OS 6-inch sub edition	(c. 1913-1848)
OS 25-inch final edition	(c. 1913-1948)

Collection of field data

Stands were visited and sample plots 0.04 ha (20 × 20 m) were randomly located a minimum of 10 m from stand edges. Soil type was categorised into great group and sub-group according to Gardiner and Radford (1980) by digging a soil pit at the centre of each plot as far as the C horizon (parent material) or to the depth of an impermeable layer, whichever was encountered first. Vegetation occurring on plots was assessed using the indicator-plant procedure according to Pyatt et al. (2001). All plant species present within the sample plot, except those growing on decaying wood and or exposed rock, were identified and their percentage cover was estimated with the aid of species abundance charts (Klinka et al. 1984). Plants that could not be identified were collected for later identification. Species occurring in the tree layer (not including the planted crop), shrub layer, ground layer and epiphyte layer were recorded. Grass species were also recorded, where possible. The total vegetation cover was calculated for the plot by summing the percentage cover of all species in plots. In some sample plots no vegetation cover was present due to dense canopy cover, in other cases, the total percentage cover could exceed 100% cover, where layered vegetation was present (e.g. presence of shrub and field layers). Each species was then allocated a Hill-Ellenberg indicator value for nutrient (N), and soil reaction (R) (Hill et al. 1999). For each plant the abundance was multiplied by the combined R and N value (R+N), summing by the products and dividing by the sum of the abundances for each plot to calculate the weighted average mean indicator value (mR + mN). There was sufficient vegetation cover at 145 plots to calculate abundance-weighted mean indicator values. For the purposes of this study, (SNR) was calculated for all plots (and classified as very poor, poor, medium, rich or very rich) using a combination of soil morphological properties (Klinka et al. 1984) and by converting mean indicator values (where available) to the appropriate soil nutrient classes for ESC in Great Britain (see Pyatt et al. 2001, p. 26). Relationships between SNR and historical land use were also examined to assess the nutritional status of enclosed and unenclosed land.

Assessing forest productivity

Within each plot, top height[4] (the mean height of the 100 largest diameter trees breast height per hectare) was estimated as the mean height of the four largest DBH trees (Edwards and Christie 1981). Height was measured by using a Vertex IV Hypsometer and transponder. Crop age was obtained from management records. GYC was assessed using top height and crop age curves for Sitka spruce according to Edwards and Christie (1981).

Data analysis

The General Linear Model (GLM) procedure in SAS (SAS 2009) was used to examine the strength of relationships between GYC and site classification criteria (i.e. soil group, fertility class, mean indicator values (mR + mN) and SNR). Differences between the categories of the various qualitative variables were tested by comparing differences between least squares means.

Site classification procedure

To develop a practical site classification method for use in Irish forestry, only classifications that explained at least 50% of the variation in yield class and/or offered the possibility of delineating minimum productivity thresholds were selected. In addition, further criteria were added, which included the classification of site types that require fertiliser inputs to support tree growth. It may be necessary to consider combinations of two or more classifications to achieve these criteria. A description of soil and vegetation types found associated with each of the site types is also provided.

Results

Characterisation of historical land use

The data suggest that there has been a considerable change in land use in Ireland over the last two centuries, most likely due to population expansion in pre-famine times up to 1845, followed by land abandonment as population pressure lapsed in the middle to late 19th century. Of the 201 sites examined, land use in 1829-1841 was classified as shown in Table 2. An examination of land use on the 1913 to 1948 maps indicated that, of the 113 sites classified as being bog or uncultivated ground on the 1829 to 1841 maps, only 79 of the sites remained so on the 1913-1948 maps, i.e. 23 sites had been permanently enclosed and were used in cultivation, eight sites were enclosed and used for rough pasture and three sites were classified as being woodland by 1913-1948 (Table 3). It was also evident that some land previously classed as being enclosed (i.e. as cultivated ground) on the 1st edition of the OS maps had been abandoned by 1913-1948 and had reverted to rough pasture (22 sites). Of the 18 sites classified in 1829-1842 as being enclosed with bog or uncultivated

[4] Referred to as dominant height in USA and Canada.

Table 2: *The number of sites classified according to the OSI 6-inch 1st ed. categories (1829-1841).*

OSI 6-inch map ornament (1829-1841)	No. of sites
Bog or uncultivated ground	113
Enclosed land with bog or uncultivated ground[a]	18
Enclosed with cultivated ground	54
Woodland and scrub	16

[a] This indicated that land was stock proof but relatively unimproved otherwise.

ground, five had been reclaimed by 1913-1948. Deforestation was evident as two of the sites no longer had woodland present by 1913-1948 map edition.

Average field size (from OSI 1913-1948 maps: recorded in acres but converted to hectares) was 12.6 ha; in 75% of cases, field size was found to be less than 20 ha and larger fields were found to be mainly associated with old demesnes (Table 4). The area of land outside permanent enclosures was recorded (on the maps) in 23% of cases, indicating an effort to map holdings. Where an area was recorded it ranged from 9 to 910 ha, with an average size of 124 ha. On average, land in permanent enclosure was found at elevations from 9 to 362 m (Table 4). Land outside permanent enclosure was found to occur from 34 to 583 m in elevation.

The range of soils found on unenclosed land was quite variable, with all major soil groups being found. Of the sites sampled, 52% of the soils were classified as blanket peats and lithosols, so had an extremely limited potential for agriculture and forestry use. A further 35% of the sites sampled were found to have soils with more potential for forestry (i.e. the peaty gleys, peaty podzols, and basin peats). A further 15% of sites visited contained soils that were classified as being very suitable for a range of forest species and were likely to result in very high timber

Table 3: *Land use change from 1829-1842 to 1913-1948, based on data from historic OSI maps.*

OSI map ornament (1829-1841) classification		OSI map ornament (1913-1948) classification			
		Unenclosed with rough pasture or whin	Enclosed cultivated fields	Enclosed with rough pasture	Woodland
Bog or uncultivated ground	(113)	79	23	8	3
Enclosed bog or uncultivated	(18)		5	11	2
Enclosed with cultivated ground	(54)		26	22	6
Woodland and scrub	(16)		1[a]	1[a]	14
Total for 1913-1948	**(201)**	**79**	**55**	**42**	**14**

[a] Indicates deforestation.

Table 4: *The numbers of samples with areas recorded and the range in elevation on OSI 25-inch maps, according to enclosure type in Ireland (based on a sample of 201 stands).*

Closure type	No. with area (%)		Field size (ha)			Elevation (m)		
			Min	Max	Mean	Min	Max	Mean
Enclosed	108	(100%)	0.32	153	14	9	362	161
Outside enclosure	18	(23%)	9	910	124	34	583	265
Woodland	6	(43%)	1	24	11	20	116	64

yields (i.e. brown earths, brown podzolics, gleys and podzols) (Table 5). An analysis of the vegetation composition of unenclosed sites (Table 6) indicated that 25% of sites examined had vegetation associated with cutover raised bog (i.e. bracken, gorse, birch) and grassland. Over half of the sites examined (52%) were classified as having vegetation associated with blanket and raised bogs and lithosols, and thus were considered to have very limited forestry potential.

Relationship between forest productivity and site classification

All site classification methods successfully predicted the productivity of Sitka spruce ($P < 0.001$), but some methods were better than others. Soil classification according to great group showed a significant relationship with GYC ($P < 0.05$; $R^2_{adj} = 0.30$) but was insufficient for delineating minimum productivity thresholds (i.e. as no soils showed

Table 5: *The range in soil groups and suitability for forestry of land outside permanent enclosure, as assessed on OSI 25-inch maps.*

Suitability for forestry[a]		Soil groups	No. of sites	Proportion
Very limited	(GYC ≤14)	Blanket peat high level	29	36.7%
		Blanket peat low level	8	10.1%
		Lithosol	4	5.1%
Moderate	(GYC 14-20)	Peaty gley	10	12.7%
		Peaty podzol	8	10.1%
		Peaty-ironpan-podzol	2	2.5%
		Basin peat cutover	7	8.9%
Wide	(GYC 20+)	Acid-brown earth	2	2.5%
		Brown earth	2	2.5%
		Brown podzolic	3	3.8%
		Gley	1	1.3%
		Podzol	2	2.5%
		Rendzina	1	1.3%

[a] Assessed using general yield class (GYC) in $m^3 ha^{-1} yr^{-1}$.

Table 6: *Vegetation types on land outside agricultural enclosure assessed on OSI 25-inch maps and their suitability for Sitka spruce afforestation (source Farrelly and Gallagher 2013).*

Suitability for forestry	Vegetation type/habitat	No.	Proportion
Very Limited	Lowland blanket bog	8	10.1%
	Upland blanket bog	28	35.4%
	Raised bog	2	2.5%
	Rock complex	3	3.8%
Limited [a]	Dry mineral soils with shrub/heath	9	11.4%
	Wet mineral soils with shrub/heath	9	11.4%
Moderate	Cutover raised bog	4	5.1%
Wide	Dry grassland	12	15.2%
	Wet grassland	4	5.1%

[a] Other species (i.e. Scots pine, western hemlock, etc.) may be more suited to these site conditions, where Sitka spruce may prove unthrifty.

GYC <14). The simple site classification (fertility class) based on map ornament was only moderately more successful at explaining the variability in yield ($P < 0.05$; $R^2_{adj} = 0.325$). The classification showed that productivity reduced with declining land management. Higher levels of productivity were found on land classified as enclosed and cultivated (fertility class A), with an average GYC of 25.2 m^3 ha^{-1} yr^{-1}. Productivity was found to be significantly lower ($P < 0.05$) on enclosed land with furze (fertility class B) where GYC was 19.5 m^3 ha^{-1} yr^{-1}. On land with no evidence of enclosure with rough pasture and/or outcropping rock (fertility class C), GYC was 15.6 m^3 ha^{-1} yr^{-1} (the confidence interval (0.05 level) was 14.2 – 17.0 m^3 ha^{-1} yr^{-1}) (Figure 1). However, there was considerable variability in yield on unenclosed land (fertility class C) with levels of production varying from GYC 4 – 30 m^3 ha^{-1} yr^{-1} (the median value was 16 m^3 ha^{-1} yr^{-1}) and 64% of sites had yields in excess of 14 m^3 ha^{-1} yr^{-1} (Figure 2). As the method was insufficient for delineating minimum productivity thresholds (i.e. with a GYC ≤14), its usefulness was limited.

The use of indicator species improved the relationship with GYC and explained slightly more of the variability in yield ($P < 0.05$; $R^2_{adj} = 0.36$) (Table 7). Higher GYC values were associated with increasing mean indicator values indicating increasing yield with increasing fertility (Figure 3). More interestingly, the method showed potential for delineating minimum productivity thresholds, with the minimum threshold for GYC of 14 occurring at the combined mean indicator value (i.e. mR + mN) value of 5[5] or above. Soil nutrient regime derived from a combination of soil

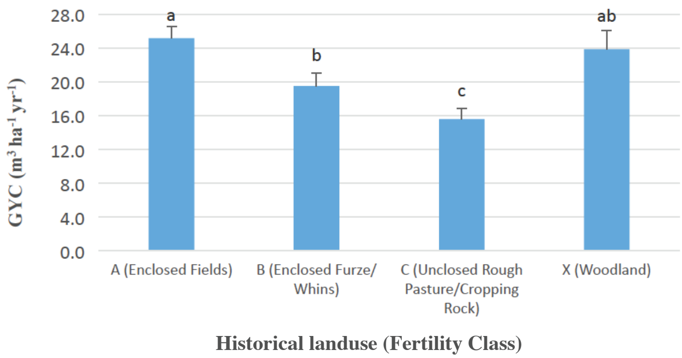

Figure 1: *Potential productivity of Sitka spruce, using general yield class (GYC), in relation to historical land use as per OCarroll's (1975) fertility classification. Error bars represent 95% confidence intervals (different lowercase letters denote significant differences between groups).*

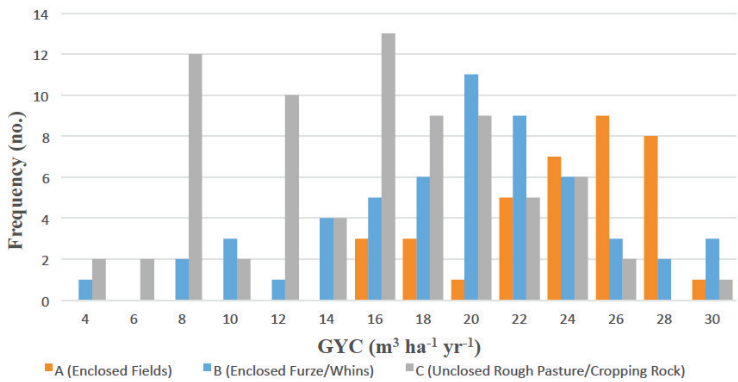

Figure 2: *The variability in yield class of Sitka spruce in relation to historical land use as per OCarroll's (1975) site fertility classification based on OSI map classifications.*

morphological properties and mean indicator values showed the strongest relationship with GYC of all variables examined ($P < 0.05$; $R^2_{adj} = 0.51$) (Table 7). GYC increased significantly as site types moved from very poor to very rich (i.e. sites with increasing nitrogen availability) ($P < 0.05$), with the maximum achievable GYC occurring on very rich sites (Figure 4).

Nutrient status in relation to historical land use

SNR had a close relationship with historical land use type. Figure 5 shows that considerable variability in fertility exists associated with both enclosed and unenclosed land. SNR was found to range from very poor (VP) to rich (R) on unenclosed land,

[5] The methodology results in a unit-less scale of index values from 1 to 9.

Table 7: *Significance and strength of relationships between mean indicator values (mR+mN) and soil nutrient regime and general yield class.*

Indicator species (mR+mN)						
Source	df	SS	Mean square	F	Pr >F	VE[a] (%)
Model	1	2250.1	2250.06	79.22	<0.001	36.0
Error	143	4061.8	28.40			
Soil Nutrient Regime						
Source	df	SS	Mean square	F	Pr >F	VE[a] (%)
Model	5	4658.2	931.64	40.77	<0.001	51.1
Error	195	4456.3	22.85			

[a] Percent of the variation explained by the source variable.

with poor being the most frequent category. For enclosed sites SNR ranged from very poor to rich, but was most commonly medium. While it was clear that the effect of historical land use (and its effects on nutrient and soil condition) may markedly alter increased availability of nitrogen, sufficient variability existed to suggest that the fertility status of unenclosed land could be highly variable. The possibility of using soil type to classify SNR is demonstrated in Table 8; however, some soils show considerable variability in SNR.

Subdivision of very poor SNR sites

It was recognised that the changing land use patterns and variability in nutrient regimes associated with unenclosed land may require a sub-classification of sites already classified as being very poor. This was to accommodate sites which were

Table 8: *Classification of the range in soil nutrient regime (SNR) and corresponding site types (A to G) for great soil groups in Ireland based on 70% of soils within a soil group achieving the stated soil nutrient regime.*

Great soil group	**Range in SNR**[a]	**Site type**
Basin peat	P-R	D-B
Blanket peat	VP-P	G-D
Brown earth	M-VR	C-A
Brown podzolic	M	C
Gley	P-R	D-C
Grey brown podzolic	R-VR	B-A
Lithosol	P	D
Podzol	P-M	D-C
Rendzinas	R	B

[a] SNR classes: VP, very poor; P, poor; M, moderate; R, rich; VR, very rich.

weakly ericaceous (dominated by *Molinia caerulea)* but may have potential for Sitka spruce which are currently classified as very poor SNR within the ESC scheme (Pyatt et al. 2001). The indicator value given to *Molinia caerulea* within ESC is perhaps too low as traditional foresters had believed that it indicated conditions suitable for pure spruce with limited P and N (Cadman 1953, Anderson 1960, Condon 1961, Wilson 2013). Furthermore its indicator value of 5 appears at or near the threshold for production of Sitka spruce with GYC 14 in Figure 3. Therefore, it was necessary to further subdivide the very poor SNR sites as follows:

1. sites that were weakly ericaceous being mesotrophic in nature that may profit from the addition of one or more applications of fertilisers (*Molinia caerulea*, *Carex, Juncus* spp. present);

2. sites classified as being oligotrophic in nature (*Calluna vulgaris, Molinia* spp. present); and

3. sites that were considered infertile or dystrophic (*Trichophorum germanicum*, *Narthecium ossifragum, Eriophorum vaginatum* present, i.e. deep peats).

This vegetation-based classification scheme coresponds with a similar scheme proposed by Taylor and Tabbush for evaluating ericaceous sites to provide guidance on fertiliser requirements to support tree growth and are described in Forestry Commission Bulletin 124 (Taylor and Tabbush 1990).

Development of the classification

Both the classification of SNR and the use of indicator plant analysis show potential

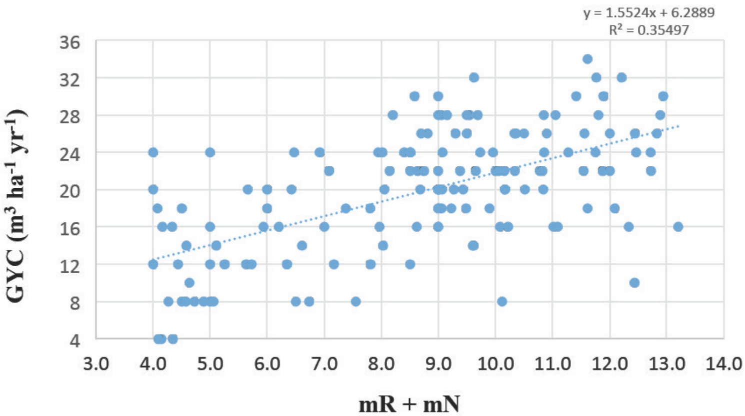

Figure 3: *Regression equation and strength of the relationship (R^2) between Sitka spruce general yield class (GYC) and mean indicator values (mR + mN) for vascular plants in Ireland. Corresponding mR + mN values for GYC 14 are approximately 5.*

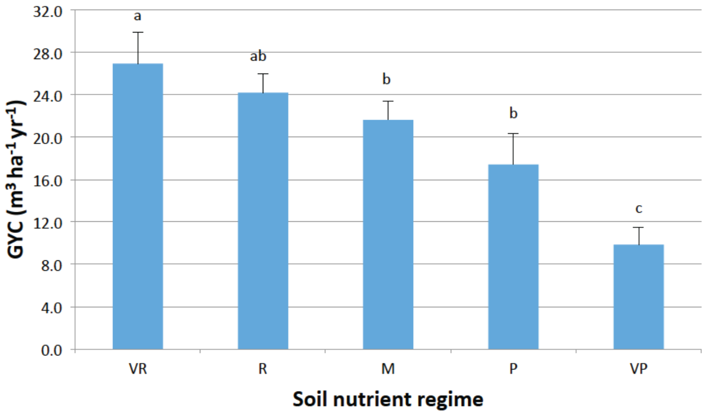

Figure 4: *Productivity of Sitka spruce (GYC) in relation to soil nutrient regime. Error bars represent 95% confidence intervals (different lowercase letters denote significant differences between groups). Soil nutrient regime classes: VR, very rich; R, rich; M, medium; P, poor, VP, very poor.*

for use as they are based on a few easily measurable variables and show potential to classify areas for afforestation grant aid. Considering the success of the SNR criterion in explaining more than 50% of the variability in GYC of Sitka spruce it was selected as the main component of the proposed site classification. Therefore SNR classes A to D, covering very rich to poor site types (as outlined by Pyatt et al. 2001), are proposed. The very poor SNR class (which had a mean indicator value of <5.7) should be replaced by three additional classes (E to G) based on the relationship between mean indicator values

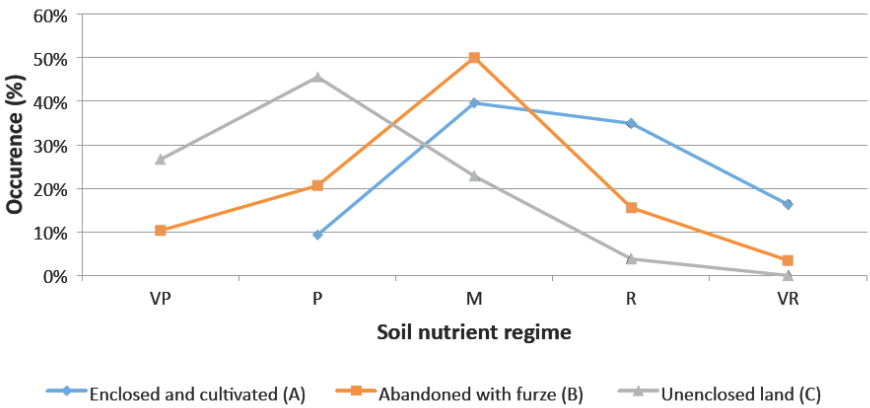

Figure 5: *The occurrence of soil nutrient regimes at sampled sites associated with historical land use (in %) as per OCarroll's (1975) site fertility classification based on OSI map classifications. Soil nutrient regime classes: VR, very rich; R, rich; M, medium; P, poor, VP, very poor.*

Table 9: *Site classification for forestry in Ireland, as proposed by Farrelly and Gallagher (2013).*

Site type	Forestry potential	Nutrient class	Soil groups included	Mean indicator value[a]	Yield class $m^3 ha^{-1} yr^{-1}$	Fertilizer requirement[a]	Species suitability[b]
A	Very wide	Extremely fertile (hyper eutrophic)	Grey brown podzolics, brown earths, some reclaimed fen peats	>11.7[c]	>26	None	SS and diverse broadleaved spp. and conifers
B	Wide	Very fertile (eutrophic)	Grey brown podzolics, brown earths, some brown podzolics, some gleys, reclaimed podzols and peats	9.7-11.6[c]	22-26 (24)	None	SS and diverse broadleaved spp. and conifers
C	Moderately wide	Moderately fertile (sub eutrophic)	Brown earths, brown podzolics, gleys, some peaty gleys, some reclaimed podzols and peats	7.7-9.6[c]	18-22 (20)	None	SS and diverse conifers
D	Somewhat limited	Poor to moderately fertile (mesotrophic)	Peaty gleys, peaty podzols, lithosols, cutover blanket peats	5.7-7.6[c]	14-18 (16)	P	SS, NS, WRC, WH, MP, DF, GF
E	Limited	Moderately infertile (sub mesotrophic)	Flushed blanket peats, gleys, peaty podzols, lithosols, some peaty gleys	5.0-5.6[c]	14	P,P	LP, SS
F	Very limited	Very infertile (oligotrophic)	Blanket peats, some peaty gleys, peaty podzols, lithosols	4.0-4.9[d]	10-12	P,P,N	LP
G	Extremely limited	Extremely infertile (dystrophic)	Intact blanket peats/raised bogs	<4.0[4]	-		

[1] Fertiliser requirement: P -phosphorus requirement at planting; P,P -Phosphorus requirement at planting and thereafter; P,P,N -Phosphorus and (possibly) nitrogen requirement at planting and/or thereafter. [a] average weighted indicator value for base reaction and Nitrogen
[b] SS -Sitka spruce; WRC -western red cedar; WH -western hemlock; NS -Norway spruce; DF -Douglas fir; GF -grand fir; MP -Macedonian pine; LP -lodgepole pine.
[c] mR + mN values as proposed by Pyatt et al. (2001).[d] mR + mN values as proposed by Farrelly and Gallagher (2013).

and Sitka spruce GYC, and a vegetation-based classification scheme that coincides with the British scheme for evaluating ericaceous sites (Taylor and Tabbush 1990):

E. sites with mean indicator values of ≥5 and <5.7 suitable for Sitka spruce, and are weakly ericaceous.

F. sites with mean vegetation indicator values between 4 and 5 which require two or more applications of mineral fertiliser to support tree growth (Taylor and Tabbush 1990).

G. sites with mean vegetation indicator values <4 that are the most infertile sites where pure spruce stands should not be planted.

A new site classification for Irish forestry

This forest site classification is outlined in Table 9 with key indicator species groups presented in Table 10. A more detailed description of each site types follows:

Site type A

This type incorporates all land managed under intensive agricultural systems. Cultivated and fertilised fields, used for tillage, crops, and pasture grazing are included (as well as areas reclaimed for grazing). Soil types are grey brown podzolics and calcareous brown earths with some reclaimed fen peats. Sites tend to be mainly well drained. Vegetation is mainly composed of mixed grassland including *Agrostis* spp., *Lolium perenne, Dactylis glomerata, Poa annua, Trifolium* spp., *Cirsum* spp. *Rumex* spp., *and Urtica dioca*.

Site type B

This type incorporates all land moderately suitable for tillage crops and pasture grazing, but also suitable for a wide range of forest crops. Sites are generally cultivated fields. Vegetation is grassland (dry and wet grassland). Soils include the less fertile grey brown podzolics (slightly degraded) and calcareous brown earths, acid brown earths and some reclaimed podzols/basin peat soils. Soil drainage varies from being well to poorly drained. Vegetation is predominantly mixed grassland, included *Holcus lanatus, Festuca rubra, Brachypodium sylvaticum, Cynosurus cristatus, Poa pratensis*. *Juncus effusus* may be present but never dominates.

Site type C

This type incorporates all land moderately to poorly suited for tillage, but moderately suitable for pasture grazing and for forestry. Soils include acid brown earths/brown podzolics/podzols and typical surface water gleys, peaty gleys and reclaimed peats. Vegetation is predominantly poorer grassland composed of *Agrostis* spp., *Deschampsia cespitosa, Brachypodium sylvaticum, Holcus lanatus, Festuca rubra,* *Cynosurus cristatus, Poa pratensis and Oxalis acetosella* species. *Ulex europaeus* L. often re-invades following reduced management. On the wet grassland sites or areas of reclaimed peatland, *Juncus effusus* becames dominant.

Site type D

This type incorporates all land poorly suited for tillage, moderately to poorly suited to pasture and somewhat limited for forestry. Land may some show evidence of improvement. Soils are peaty gleys, peaty podzols, flushed/improved blanket peats, some brown podzolics and gleys. Dense bracken (*Pteridium aquilinum*) is a key indicator and often forms a dense cover on hillsides. Sweet vernal grass (*Anthoxanthum odoratum*) occurs on old hill pastures. Wetter areas include rushes (*Juncus acutiflorus, J. conglomeratus and J. bulbosus)* and are suitable for Sitka spruce. Ericaceous species are largely absent.

Site type E

Site class E incorporates all land poorly suited for pasture and are moderately to poorly suited for extensive grazing. Soils are mostly peaty or peat soils. Purple moor grass (*Molinia caerulea*) is one of the key species represented in this site type. Other species indicative of this site type are *Carex* spp., *Deschampsia flexuosa,* Mat-grass (*Nardus stricta*) and western gorse (*Ulex galii*). Sites must have either have pure swards of *M. caerulea* with a proportion of "better" plant species, such as *Juncus effusus, J. squarrosus, Anthoxanthum odoratum, Agrostis* spp. *or Rubus fruticosus* L., the presence of which increases the fertility of the site.

Site type F

Site class F incorporates all land classified as having extremely limited potential for agriculture and forestry. Soils are mostly peats. Vegetation is typical of blanket bogs or wet/ dry heath being strongly ericaceous, with *Calluna vulgaris, Vaccinium myrtillus* L.*, Molinia caerulea, Erica tetralix* L.*, E. cinerea* L.*, Juncus squarrosus*, *Eriophorum angustifolium* present

Site type G

Site class G incorporates all land classified as having no potential for agriculture or forestry and considered unplantable. Soils included intact blanket bogs or raised bogs. Sites are characterised by very poor drainage and a watertable at or near the surface. Water pools occur frequently on the surface of blanket bogs and the presence of *Racomitrium mosses* and *Cladonia* spp. (lichens) and *Drosera* spp. (sundews) are characteristic. *Narthecium ossifragrum*, *Eriophorum vaginatum*, *Trichophorum germanicum* are generally abundant. *Calluna vulgaris* and *Erica tetralix* are usually present and *Schoenus nigricans* is nearly always present on lowland blanket bogs in the west of Ireland.

Table 10: *Characteristic ground vegetation species for use as indicators of site types A to G.*

Site type	**Characteristic ground vegetation species**	**Comon name**	**Mean Indicator value**[a]
A	*Dactylis glomerata*	Cocksfoot	13
	Lolium multiflorum	Italian ryegrass	14
	Cirsium vulgare	Spear thistle	12
	Urtica dioca	Stinging nettle	15
	Rubus fructicusus	Bramble	12
B	*Holcus lanatus*	Yorkshire fog	11
	Dryopteris affinis	Scaly male fern	10
	Primula versis	Primrose	10
	Rubus ideas	Raspberry	10
	Filipendula ulmaria	Meadow sweet	10
C	*Juncus effusus*	Soft rush	8
	Deschampsia caespitosa	Tufted hair grass	9
	Digitalis purpurea	Foxglove	9
	Luzualla sylvatica	Great woodrush	8
	Ranunculus flammula	Lesser spearworth	8
D	*Juncus acutifloris*	Sharp flowered rush	6
	Anthoxanthum odoratum	Sweet vernal grass	7
	Pteridium aquilinum	Bracken	6
	Luzualla campestris	Field woodrush	7
	Blechnum spicant	Hard fern	6
E	*Molinia caerulea*	Purple moor grass	5
	Nardus stricta	Mat grass	5
	Ulex galeii	Western gorse	5
	Carex binervis	Green ribed sedge	5
	Deschampsis flexuousa	Wavy hair grass	5
F	*Calluna vulgaris*	Heather	4
	Vaccinium myrtillis	Bilberry	4
	Molinia caerulea	Purple moor grass	5
	Juncus squarrosus	Heath rush	4
	Erica cinerea	Bell heather	4
G	*Trichophorum germanicum (caespitosum)*	Deer grass	4
	Erica tetralix	Cross leaved heath	3
	Eriophorum vaginatum	Hares tail cotton grass	3
	Narthecium ossifragum	Bog asphodel	3
	Drosera rotundifolium	Common sundew	3

[a] Average weighted indicator value for base reaction and nitrogen (mR+mN).

Conclusions and recommendations

The results from this study suggest that favourable sites in terms of productivity exist on unenclosed land, perhaps attributable to the residual effect of soil conditioning associated with historical land-use or local variability in soil nutrient availability[6]. Classifications based on historical boundaries do not fully reflect local nutrient levels and offer only limited scope to differentiate unenclosed sites (with favourable characteristics for tree growth) from areas with more limited agricultural potential. The newly developed system proposed in this study has been heavily influenced by the Canadian (BEC) and British (ESC) classifications of SNR, but includes some modifications to include additional classification of poorer site types found in Ireland. It satisfies the requirement of being able to explain at least 50% of the variation in GYC, is based on a few easily measurable variables and can be used to reliably and consistently classify areas for afforestation grant aid. The classification of soil nutrient regime in this study showed the strongest relationship with the GYC of Sitka spruce ($R^2 = 0.51$) and was derived from soil morphological properties and mean indicator values. The procedure gives greater weight to soil properties in the calculation of SNR when vegetation cover is low or absent (Farrelly 2011). There was a weaker relationship between mean indicator values and GYC of Sitka spruce ($R^2 = 0.36$). While the calculation of mean indicator values was based on vegetation data from 146 plots, in some cases vegetation cover on plots was low (<10%) or available from only a few indicator species. This probably reflects that the reliability of this method is less where vegetation cover on plots is <10% cover (Pyatt 2001).Therefore, the calculation of SNR using a combination of soil properties and vegetation types is recommended (Table 9 and 10) as this will accommodate sites where vegetation cover is limited or modified by grazing or burning practices. Assessment of vegetation by abundance-weighted scoring techniques will allow for more precise assessment especially on difficult sites. The system may succeed in alleviating the difficulties encountered with the assessment of unenclosed sites for their suitability for forestry.

Data from this study showed that some unenclosed land had soil and vegetation characteristics favorable for forestry development, covering an area of up to ~178,000 ha (Farrelly and Gallagher 2015, this issue). Site types D and E are likely to be more suitable than those vegetated predominantly by ericaceous species. Site types F and G are deemed unproductive and they occur on deep peat sites, making them unsuitable for afforestation grant aid. Site classification methods such as those presented here offer the potential to more accurately assess the potential of land for afforestation with a view to matching more carefully to tree species requirements. Such land capable of achieving the minimum threshold for afforestation grant aid may be considered

[5] Nutrient availability is expressed as soil nutrient regime.

suitable for planting. The methodology proposed here can be carried out by qualified foresters who have undertaken specific silvicultural training, preferably with the aid of a field guide.

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