Recent findings on the native status and vegetation ecology of Scots pine in Ireland and their implications for forestry policy and management

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Abstract

It has been generally accepted that Scots pine (*Pinus sylvestris* L.) became extinct in Ireland c. AD 400. The species was reintroduced in the mid-17th century and has been widely planted. It has been included in the Native Woodland Scheme, which provides grants to establish or restore native woodlands. However, its native status in Ireland has been disputed and the vegetation ecology and conservation value of Irish pinewoods have been poorly understood.

These knowledge gaps have been addressed using an approach combining vegetation ecology and palaeoecology. Vegetation surveys were conducted at eighteen pinewoods in Ireland and six in Scotland. Cluster analysis was used to evaluate the floristic similarity between plots and classify them into groups. One of the Irish pinewoods was of unknown origin (Rockforest, Co. Clare). To reconstruct its vegetation history, a sediment core was extracted from Rockforest Lough. Pollen, macrofossil and dating analyses were conducted.

Cluster analysis identified four groups, representing distinct pinewood vegetation types. The vegetation of certain Irish groups and sites exhibited similarities with that of extant native pinewoods elsewhere in oceanic north-west Europe or fossil assemblages from ancient Irish pinewoods. While the vegetation of Irish pinewoods did not correspond to that of typical Scottish Caledonian forests, Coronation Plantation and the bog pinewoods at Clonfinane and All Saints Bog exhibited strong similarities with other native Scottish pinewoods of high conservation value. Natural regeneration of *P. sylvestris* was poor overall.

The pollen diagram from Rockforest Lough showed a continuously high *Pinus* pollen frequency (38-51% of total terrestrial pollen) from c. AD 350 to the present. Macrofossil evidence demonstrated local presence of *P. sylvestris* around Rockforest Lough c. AD 840. The available historical sources indicated a long history of woodland cover at Rockforest. A separate analysis of a peat core from nearby Aughrim Swamp also showed a continuous *Pinus* signal from c. AD 350 to the present.

The findings of the vegetation analysis suggest that *P. sylvestris* woodlands are an important resource for Irish biodiversity, particularly given the country's low native woodland cover. The palaeoecological data indicate that native *P. sylvestris* persisted at Rockforest from c. AD 350 to the present. The hypothesis that *P. sylvestris* became extinct in Ireland is rejected.

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These findings should inform evidence-based forest management and policy. They support the inclusion of *P. sylvestris* in the Native Woodland Scheme. In general, reintroduced *P. sylvestris* should be managed as a native species in Irish woodlands. The data presented should inform site and species selection.

The *P. sylvestris* population at Rockforest is of high conservation value but its rarity increases its extinction risk. It should be carefully managed and monitored and seed-sourcing must be compatible with the long-term viability of the population. Cooperation between forestry and nature conservation agencies is needed to ensure its continued survival and to develop opportunities for the restoration of native pinewoods in Ireland.

Keywords: Pinus sylvestris, *native status, vegetation ecology, palaeoecology, conservation.*

Introduction

Pinus sylvestris L. (Scots pine) is the most widely distributed pine species in the world (Vidaković 1991). Its native range covers c. 2,700 km north-south from northern Norway to southern Spain and 14,000 km east-west from Portugal to far eastern Russia (EUFORGEN 2009, Volosyanchuk 2002). *P. sylvestris* tolerates a very broad range of environmental conditions. It is found in many diverse habitats, forming stable vegetation communities on nutrient-deficient soils, indicating high competitive ability under these conditions. It acts as a pioneer species but is light-demanding and cannot tolerate heavy shade from other trees (Carlisle and Brown 1968). *P. sylvestris* forms habitats of high conservation value, including the Caledonian forests of Scotland, Boreal forests of the Western Taïga, lichen pine forests of Central Europe, Western Carpathian calcicolous pine forests of Eastern Europe and bog woodlands, which are all listed on Annex I of the Habitats Directive (92/43/EEC). It is one of the most commercially important forest trees (Volosyanchuk 2002), especially in northern Europe. Its timber is valued for its good strength to weight ratio. It is used particularly for construction and for furniture, pulp and paper (Houston Durrant et al. 2016).

Palaeoecological evidence indicates that *P. sylvestris* colonised Ireland by 10,500 cal BP (calibrated radiocarbon years before AD 1950)/8550 BC (Mitchell 2006), becoming an important component of certain habitats until a major decline began c. 4450 cal BP/2500 BC (Bradshaw and Browne 1987). It is believed to have been extirpated c. 1550 cal BP/AD 400 (McAulay and Watts 1961) and reintroduced in the mid-17th century (McCracken 1971). Earlier in the 20th century, extensive *P. sylvestris* plantations were established. More productive exotic species became favoured for commercial forestry after 1945 (O'Driscoll 1980). *P. sylvestris* now covers 7660 ha (1.1% of stocked forest area) (Forest Service 2017) and is naturalising.

Native pinewoods persisted in Scotland (Steven and Carlisle 1959). Some authors speculated that localised native *P. sylvestris* could persist in northern England (Edlin 1961, Turner and Hodgson 1981). Modelling indicates that this is bioclimatically plausible but further research is required (Manning et al. 2010). The apparent extinction of *P. sylvestris* in Ireland has long intrigued those with an interest in Ireland's natural history. As W.A. Watts (1984) stated,

> *Why a very widespread species living in many kinds of habitat from Algeria to north of the Arctic Circle should have failed to survive in Ireland is mysterious, especially as pine survives in Scotland in habitats similar to those from which it disappeared in Ireland. It is difficult to imagine any form of burning or exploitation which would cause complete extinction. Further, planted pines thrive today in Ireland and invade natural habitats readily. The problem is a challenging and interesting one deserving further study.*

Due to its extirpation and reintroduction, the native status of *P. sylvestris* in Ireland has been disputed. Relevant conservation and forest management policies are sometimes inconsistent. The Native Woodland Scheme (NWS) provides grants to plant *P. sylvestris* when establishing or restoring native woodland (Forest Service 2001) while the Irish Peatland Conservation Council considers it an invasive non-native species (Malone and O'Connell 2009). This highlights the need for clarification on the native status of *P. sylvestris* and the implications of its reintroduction for biodiversity conservation.

Recent research (McGeever and Mitchell 2016, Roche 2010, Roche et al. 2009, Roche et al. 2015, Roche et al. 2016, 2018) has partly addressed these knowledge gaps. This paper aims to provide a synthesis of this research on the vegetation ecology and native status of *P. sylvestris* in Ireland and to discuss implications for forest management and policy. Previously unpublished data on regeneration of *P. sylvestris* are presented.

Materials and methods

Vegetation ecology

Twenty stands were selected at eighteen Irish sites, comprising mature stands dominated or co-dominated by *P. sylvestris* and reasonably free of non-native or invasive species. Stands of planted, naturalised and unknown origin were included. For comparison, seven stands were selected at six native Scottish pinewood sites of high conservation value: five in Special Areas of Conservation (SACs) designated for the Annex I priority habitats Caledonian forest or Bog woodland and one in a Site of Special Scientific Interest (Glen Loy) containing a distinct genetic mitotype of *P. sylvestris* (Sinclair et al. 1998) (Figure 1a, b, Table 1).

Sites were surveyed from May-September 2006 and April-August 2007, using the method described by Roche et al. (2009). A circular 400 m^2 plot was subjectively placed, using the relevé method, to represent each vegetation type. Slope, altitude and structural data (species, Diameter at Breast Height (DBH), height, crown position

Table 1: *Location (Figure 1) and cluster analysis group (Figure 3) of the 27 survey plots.*

Plot number	Plot name	County/Region	Country	Grid references
Group 1				
I1	Dale Wood	Kerry	Ireland	V 88181 80714
I5	Glengarriff	Cork	Ireland	V 90894 56831
I7	Glenfarne	Leitrim	Ireland	H 02059 39747
I10	Derrycrag I	Galway	Ireland	R 73616 99077
I11	Derrycrag II	Galway	Ireland	R 73652 99029
I14	Torc	Kerry	Ireland	V 96482 83719
I18	Vale of Clara	Wicklow	Ireland	T 17212 92127
Group 2				
I2	Clonfinane Bog	Tipperary	Ireland	M 98815 03715
I6	All Saints Bog	Offaly	Ireland	N 01203 11216
S22	Glen Loy	Highland	Scotland	NN 09495 84288
S23	Glen Affric	Highland	Scotland	NH 19283 22800
S24	Beinn Eighe	Highland	Scotland	NH 00351 64685
S25	Abernethy I	Highland	Scotland	NH 96226 17443
S26	Abernethy II	Highland	Scotland	NH 97612 17191
S27	Black Wood of Rannoch	Perth & Kinross	Scotland	NN 56968 56176
Group 3				
I3	Rockforest	Clare	Ireland	R 34755 95013
I8	The Scalp	Dublin	Ireland	O 21719 20093
I13	Rockvale	Clare	Ireland	R 38955 98090
I19	Ballykine I	Mayo	Ireland	M 10849 57328
I20	Ballykine II	Mayo	Ireland	M 10657 57113
Group 4				
I4	Priest's Leap	Cork	Ireland	V 98853 59132
I9	Coronation Plantation	Wicklow	Ireland	O 09708 12792
I15	Knockastakeen	Tipperary	Ireland	R 93807 27204
I16	Trooperstown	Wicklow	Ireland	T 15932 96721
I17	Derrybawn	Wicklow	Ireland	T 12365 96360
S21	Cona Glen	Highland	Scotland	NM 97238 71210
Excluded outlier				
I12	Portumna Forest Park	Galway	Ireland	M 82680 03320

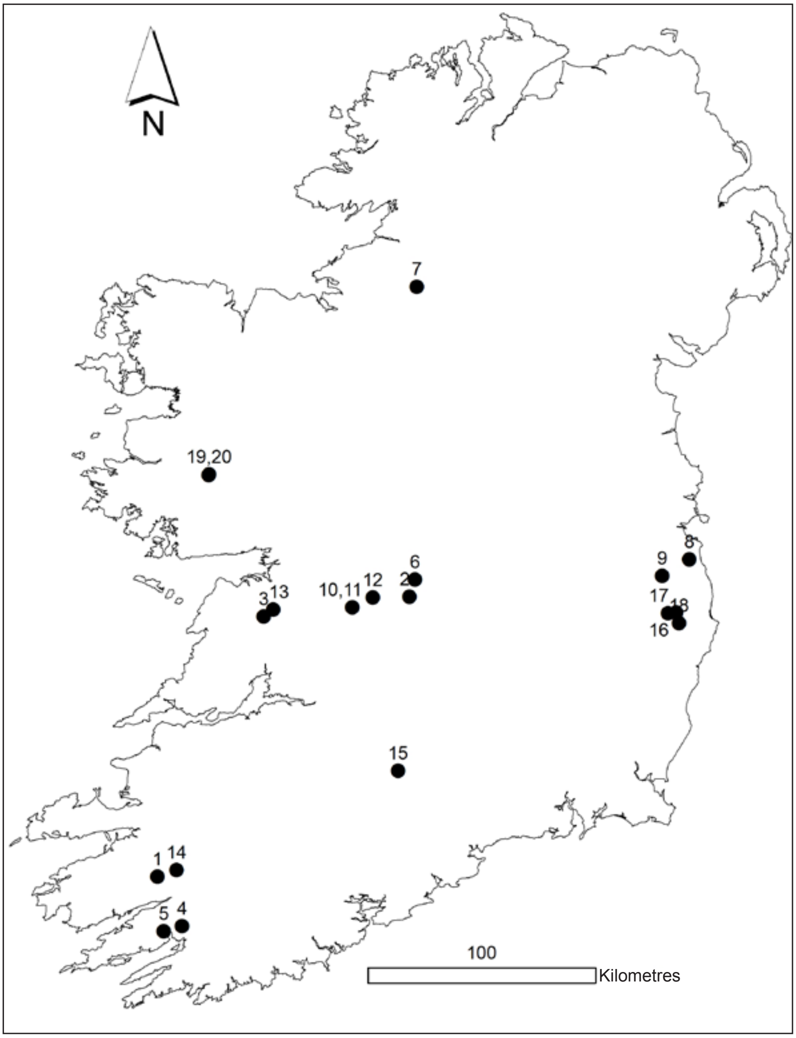

Figure 1a: *Location of the plots in Ireland (as listed in Table 1).*

and condition of trees of DBH ≥7 cm) were recorded. The species and number of stems of DBH <7 cm were recorded and categorised as follows: <25 cm (seedlings), 26-100 cm, 101-200 cm (saplings), 201-400 cm, >400 cm (poles). Grazing levels were assessed after Perrin et al. (2008). Five 2 m × 2 m quadrats were recorded, at the centre and cardinal points of the plot. Vascular plant cover was recorded on the Domin scale. Bryophyte data were recorded on a presence/absence basis. In total, 27 plots and 135 quadrats were recorded. Five 10 cm-deep soil samples were taken from each quadrat and bulked in the field. Soil pH was measured in the laboratory using a WTW pH 330 meter and combination electrode. Soil organic content was inferred from loss on ignition at 550 ^{o}C using a Thermolyne Type 6000 furnace.

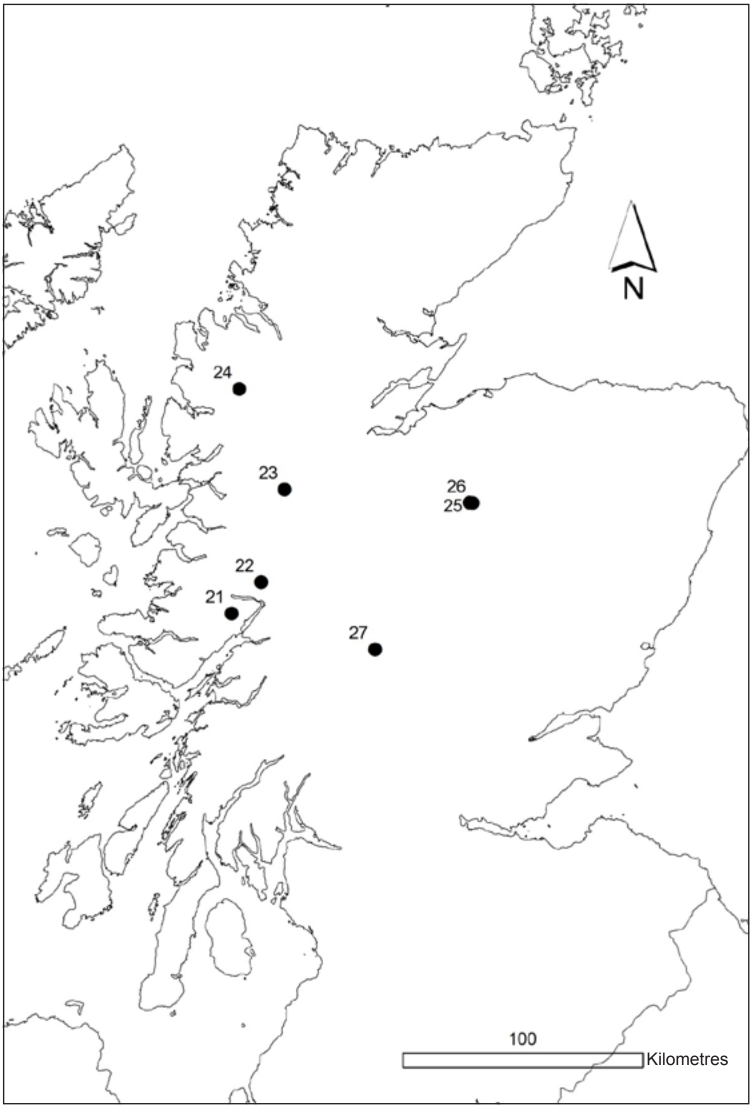

Figure 1b: *Location of the plots in Scotland (as listed in Table 1).*

Data preparation followed Roche et al. (2015). Multivariate analyses were conducted using PC-ORD 5 (McCune and Mefford 2005). Plot I12 (Portumna Forest Park) was identified as an outlier by Outlier Analysis and excluded from further analysis. Hierarchical, agglomerative, polythetic cluster analysis techniques were used for classification. Sørensen's (Bray-Curtis) distance measure was used with the Flexible Beta linkage method (β = -0.25). The similarity of plots was assessed by their grouping on the dendrogram. A Spearman Rank correlation was calculated to determine if a statistically significant relationship existed between *P. sylvestris* regeneration levels and canopy cover or grazing levels.

Native status

Rockforest Lough (Irish Grid Reference R 356 953) is located 10 km north-east of Corofin in the Burren, Co. Clare (Figure 2). It is a permanent lake, c. 8 ha in area and lies at 16 m above sea level on karstic Carboniferous limestone. At Shannon Airport, Co. Clare, annual mean air temperature is 10 °C and mean rainfall is 1,400-1,600 mm (1981-2010). The prevailing winds (1946-2010) are south-westerly (Walsh 2012). Rockforest pinewood (site of plot I3) is located c. 500 m to the south-west and was formerly part of the Rockforest Estate. The woodland is located in the state-owned Burren National Park and the East Burren Special Area of Conservation, which is protected under the Habitats Directive.

Pollen, macrofossil and dating analyses were conducted on a core which was taken from Rockforest Lough on 18-19 June 2008 using the method described by Roche (2010) and Roche et al. (2018). Pollen extraction and identification followed standard methods (Moore et al. 1991). A minimum of 400 identifiable terrestrial pollen and spores were counted from each sample. A percentage pollen diagram

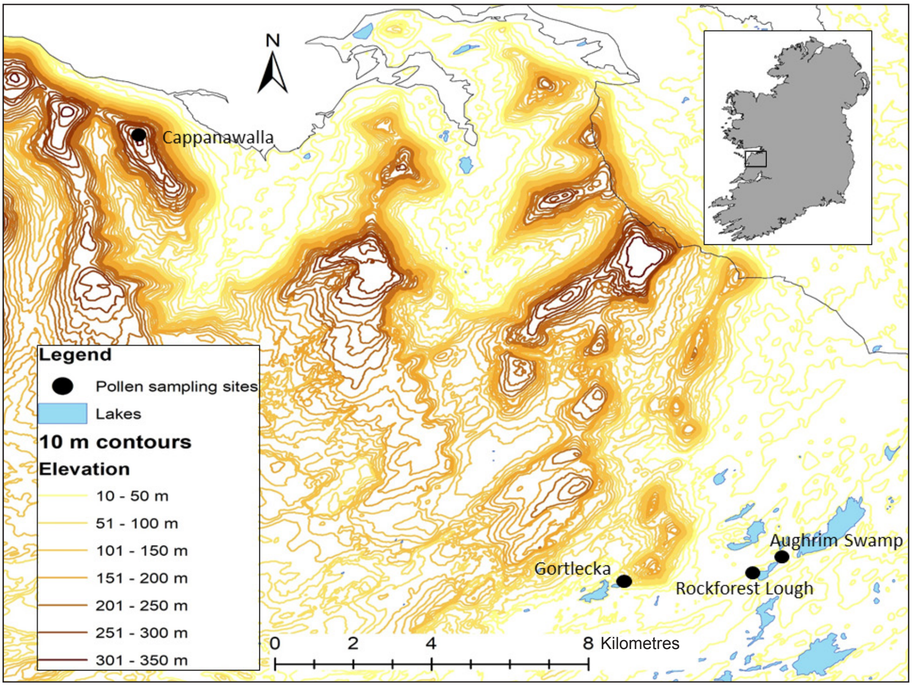

Figure 2: *Location of Rockforest Lough and other pollen sampling sites mentioned.*

was produced using TILIA V2.0.19 (Grimm 1991). The pollen sum calculation was total terrestrial pollen and spores, including indeterminate grains. The latter were included to reduce overestimation of *Pinus* abundance as, with its distinctive appearance, its pollen was unlikely to be indeterminate.

Terrestrial plant macrofossils were hand-picked or sieved from the sediment to avoid the hard-water effect i.e. overestimation of age when the material to be dated originates underwater and contains bicarbonate derived from old, inert sources e.g. limestone bedrock (Shotton 1972). Samples were radiocarbon-dated using accelerator mass spectrometry (AMS). Spheroidal Carbonaceous Particle (SCP) extraction followed a method adapted from Rose (1990, 1994). SCPs, produced from fossil fuel combustion and preserved in lake sediments, provide a historical record of atmospheric pollutant deposition. SCP concentration profiles are consistent and often regionally characteristic such that the main profile features can be used for sediment dating. A chronology was generated using Bchron (V3.1.4 with the IntCal13 calibration curve) (Haslett and Parnell 2008).

Results

Vegetation ecology

Cluster analysis produced four reasonably well-defined groups (Figure 3, Table 1). The dendrogram reveals the hierarchical structure of these groups and the level of floristic similarity among plots. Groups 1 and 3 contained Irish plots only,

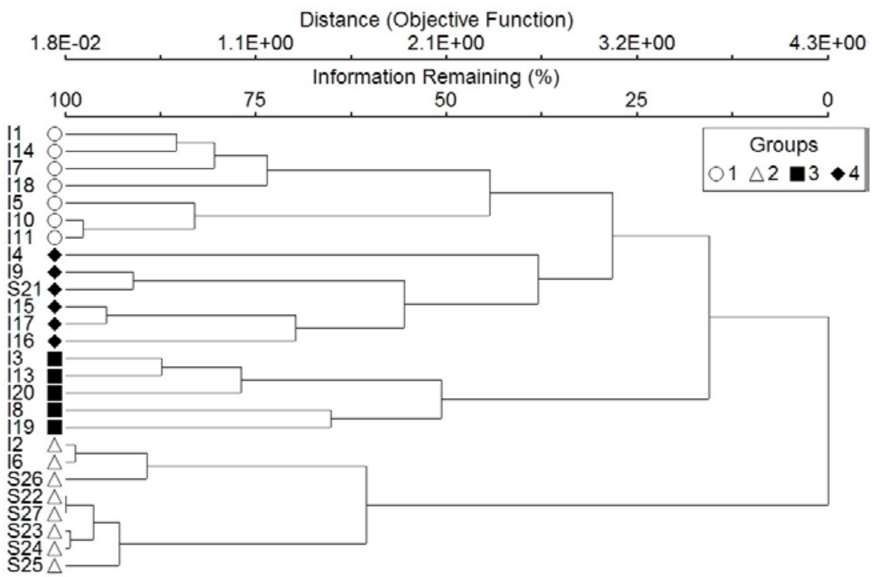

Figure 3: *Cluster dendrogram of the plots listed in Table 1, labelled with four groups.*

while Groups 2 and 4 contained both Irish and Scottish plots. The Irish plots I2 (Clonfinane Bog), I6 (All Saints Bog) and I9 (Coronation Plantation) showed the highest similarity to Scottish plots.

Table 2 summarises the environmental, structural and floristic characteristics of the groups. It follows the standard format of the British National Vegetation Classification (NVC; Rodwell 1991) with species frequency and abundance values arranged in columns. Frequency refers to how often a species is found across plots and is denoted by Roman numerals (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80%, V = 81-100%). Abundance refers to the cover of a species within a plot. The range of abundance is denoted in brackets by values on the Domin scale (+ = <1%, 1 = 1-4% few individuals, 2 = 1-4% several individuals, 3 = 1-4% many individuals, 4 = 5-9%, 5= 10-24%, 6 = 25-32%, 7 = 33-49%, 8 = 50-74%, 9 = 75-94%, 10 = 95-100%). Species are sorted into blocks according to their pattern of occurrence among the groups. Constant species have an overall frequency of IV-V. General associates have an overall frequency of I-III with no marked affiliation to any group. Preferential species are more frequent in one group. Differential species are exclusive to one group. For brevity, species with low frequency and abundance (not exceeding I and 3, respectively, in any group) were omitted.

P. sylvestris regeneration (DBH <7 cm) occurred in only eight plots (29.6% of plots) (Table 3). *P. sylvestris* regeneration levels had no statistically significant correlation with canopy cover (r = -0.268) or grazing levels (r = -0.054).

Native status

The sediment core from Rockforest Lough comprised homogeneous brown algal mud. Macrofossils were scarce; a *P. sylvestris* needle and wood fragment were found at 66 and 153 cm depth respectively (Table 4). The SCP record began at 13 cm. A rapid increase and sub-surface peak appeared at 8 cm and 7 cm respectively (Figure 4). Based on mean dates from Irish SCP profiles (Rose et al. 1995), these features were assigned to the 1880s, 1960s and 1981 respectively (Table 4). A second rapid increase at 4 cm was assigned to 1985, when Moneypoint Power Station, c. 50 km to the south-west, was commissioned. The age-depth model excluded an anomalously old AMS date from bulked organic material at 72-74 cm. The chronology is well-constrained in the upper metre but less so below as fewer dates were obtainable (Table 4, Figure 5). Sediment accumulation was relatively constant in the upper metre (0.7 mm yr^{-1}) but much lower below (0.1 mm yr^{-1}). Pollen analysis was confined to the upper 112 cm due to increased uncertainty in the chronology below the AMS date at 104-107 cm.

Table 2: *Synoptic table of floristic, environmental and structural data (± standard deviation unless otherwise stated) for groups derived by cluster analysis (Figure 3).*

Groups	1		2		3		4		Overall	
Number of plots	7		8		5		6		26	
Mean species richness	28.7 ± 10.8		19.5 ± 4.9		47.2 ± 15.1		29.5 ± 8.0		29.6 ± 13.4	
Mean altitude (m)	89.9 ± 48.7		157.0 ± 95.5		45.8 ± 58.7		225.7 ± 81.9		133.4 ± 96.4	
Mean slope (degrees)	13.1 ± 11.3		5.5 ± 7.2		7.6 ± 12.5		15.5 ± 8.3		10.3 ± 10.1	
Mean soil pH (0-10 cm)	3.53		3.63		4.40		3.72		3.70	
Mean soil organic content (%)	67.3 ± 26.8		80.6 ± 29.6		47.7 ±22.1		51.5 ± 29.4		64.0 ± 30.4	
Mean stocking density (trees ha^{-1})	1042.9 ± 564.9		553.1 ± 396.7		585.0 ± 540.4		462.5 ± 275.6		670.2 ± 487.5	
Mean canopy height (m) ± SE	17.3 ± 4.3		13.9 ± 5.8		10.3 ± 7.0		15.7 ± 3.3		14.5 ± 5.5	
Mean canopy cover (%)	56.2 ± 10.5		43.5 ± 7.5		35.5 ± 14.9		44.8 ± 8.4		45.7 ± 12.1	
Constant species										
Pinus sylvestris	V	(5-8)	V	(6-8)	V	(4-7)	V	(7-8)	V	(4-8)
Vaccinium myrtillus	V	(1-7)	V	(2-8)			V	(4-8)	IV	(1-8)
Calluna vulgaris	III	(1-3)	V	(5-8)	III	(4-5)	IV	(+-5)	IV	(+-8)
Pteridium aquilinum	IV	(+-5)	II	(1-6)	III	(3-5)	V	(+-7)	IV	(+-7)
Sorbus aucuparia	V	(1-5)	III	(+-3)	II	(1-2)	V	(+-5)	IV	(+-5)
General associates										
Blechnum spicant	V	(+-4)	I	(1)			V	(+-3)	III	(+-4)
Oxalis acetosella	III	(2-4)			I	(5)	III	(2-4)	II	(2-5)
Deschampsia flexuosa			III	(+-3)	I	(1)	III	(4)	II	(+-4)
Quercus × rosacea	I	(5)					I	(6)	I	(5-6)
Hymenophyllum wilsonii	I	(3)					I	(3)	I	(3)
Quercus robur	II	(3-4)			II	(1-5)			I	(1-5)
Fagus sylvatica	I	(3)			I	(1)			I	(1-3)
Agrostis canina	I	(1)			II	(+)	II	(1-3)	I	(+-3)
GROUP 1										
Preferential species										
Ilex aquifolium	V	(1-8)			III	(1-5)	II	(1-2)	III	(1-8)
Quercus petraea	V	(+-6)			I	(4)			II	(+-6)
Betula pubescens	V	(+-5)	II	(5-6)	I	(5)	II	(+-4)	III	(+-6)
Luzula sylvatica	III	(3-7)					II	(+-1)	II	(+-7)
Polypodium vulgare	III	(+-1)			II	(+-1)			I	(+-1)
Dryopteris dilatata	II	(1-3)			I	(4)			I	(1-4)
Differential species										
Rhododendron ponticum	III	(+-2)							I	(+-2)
GROUP 2										
Differential species										
Vaccinium vitis-idaea			IV	(1-6)					II	(1-6)
Erica tetralix			IV	(+-4)					I	(+-4)
Empetrum nigrum			IV	(+-3)					I	(+-3)
Eriophorum vaginatum			II	(4-6)					I	(4-6)
Andromeda polifolia			II	(1)					I	(1)
Vaccinium oxycoccus			II	(1)					I	(1)

GROUP 3										
Preferential species										
Corylus avellana	I	(2)			V	(4-8)			II	(2-8)
Hedera helix	III	(+-4)	I	(+)	V	(3-5)	III	(+)	III	(+-5)
Lonicera periclymenum	III	(+-4)			V	(1-4)	I	(1)	II	(+-4)
Rubus fruticosus agg.	III	(+-4)	II	(+-1)	V	(1-4)	I	(1)	III	(+-4)
Festuca ovina	I	(1)	I	(+)	IV	(1-5)	II	(+-4)	II	(+-5)
Crataegus monogyna					IV	(+-5)	I	(+)	I	(+-5)
Anthoxanthum odoratum	I	(+)	I	(1)	IV	(+-2)	II	(1-7)	II	(+-7)
Viola riviniana/reichenbachiana	I	(2)			IV	(+-1)	II	(+-1)	II	(+-2)
Differential species										
Fraxinus excelsior					IV	(2-6)			I	(2-6)
Teucrium scorodonia					IV	(1-4)			I	(1-4)
Brachypodium sylvaticum					IV	(+-4)			I	(+-4)
Prunus spinosa					III	(2-4)			I	(2-4)
Fragaria vesca					III	(+-3)			I	(+-3)
Rosa spinosissima					III	(+-3)			I	(+-3)
Succisa pratensis					III	(+-2)			I	(+-2)
Sesleria caerulea					II	(4-5)			I	(4-5)
Rubus saxatilis					II	(4)			I	(4)
Geranium sanguineum					II	(2-3)			I	(2-3)
Geranium robertianum					II	(1)			I	(1)
Carex flacca					II	(1)			I	(1)
Thymus polytrichus					II	(+-3)			I	(+-3)
Lotus corniculatus					II	(+-2)			I	(+-2)
Hypochaeris radicata					II	(+-1)			I	(+-1)
Potentilla sterilis					II	(+-1)			I	(+-1)
Arum maculatum					II	(+)			I	(+)
Epipactis helleborine					II	(+)			I	(+)
Hypericum pulchrum					II	(+)			I	(+)
Taraxacum agg.					II	(+)			I	(+)
Filipendula ulmaria					I	(4)			I	(4)
GROUP 4										
Preferential species										
Galium saxatile	I	(+)					V	(+-4)	II	(+-4)
Molinia caerulea	II	(1-5)	II	(1-3)	I	(5)	III	(4-9)	II	(1-9)
Agrostis capillaris	II	(1)			II	(+-5)	III	(3-4)	II	(+-5)
Potentilla erecta	II	(+-1)	I	(+)	II	(1)	III	(1-3)	II	(+-3)
Betula pendula			I	(5)			II	(3-4)	I	(3-5)

Table 3: *Number of* Pinus sylvestris *stems of DBH <7 cm, where present in survey plots, categorised by height class (cm).*

Plot number	Site name	<25	26-100	101-200	201-400	>400	Total
Group 1							
I10	Derrycrag I					1	1
I11	Derrycrag II	1					1
Group 2							
I6	All Saints Bog		6	13	21	12	52
S25	Abernethy I		18	4	2	2	26
S26	Abernethy II	5					5
Group 3							
I3	Rockforest	1	1				2
I13	Rockvale				1		1
I20	Ballykine II	1	14	16	9	1	41

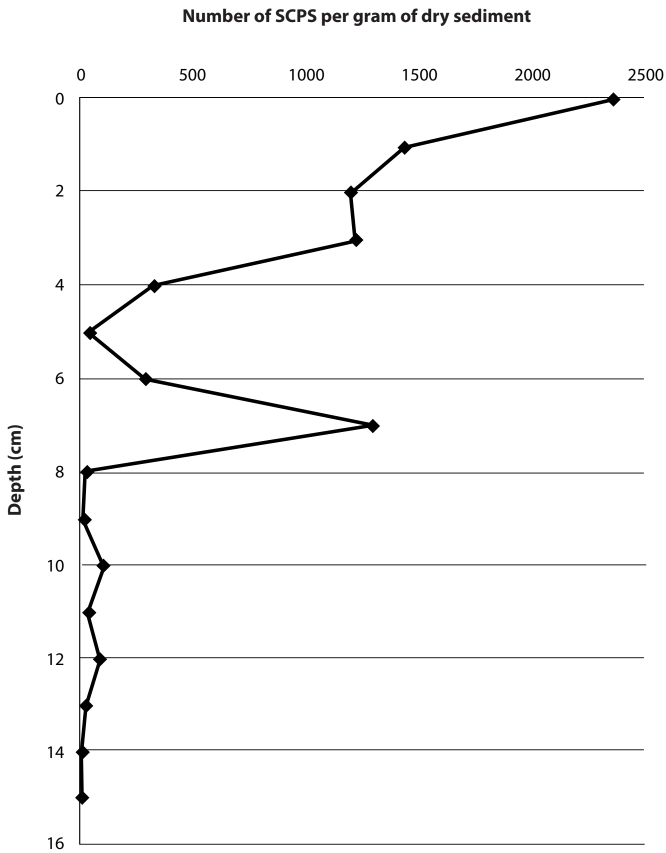

Figure 4: *Rockforest Lough Spheroidal Carbonaceous Particle (SCP) concentration profile.*

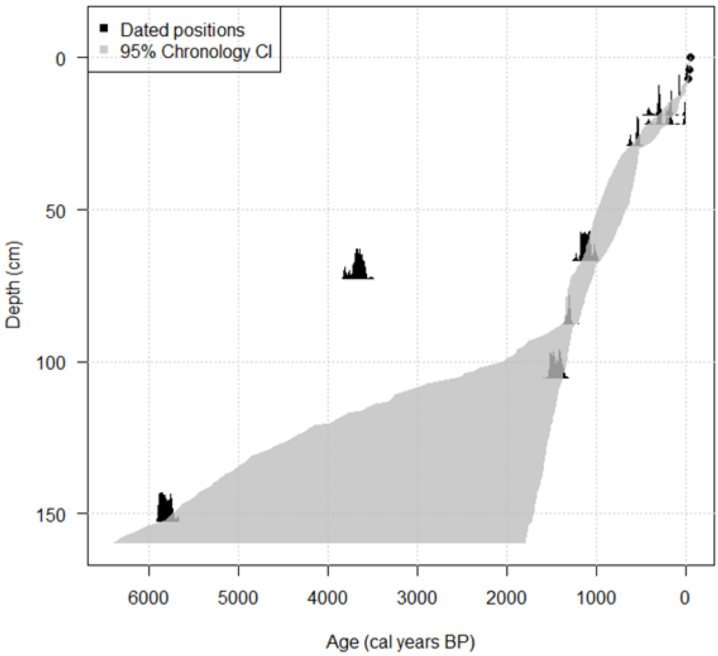

Figure 5: *Bchron age-depth model for Rockforest Lough, showing the 95% confidence interval, based on dates given in Table 4.*

The pollen diagram (Figure 6) spans from c. 1600 cal BP/AD 350 to the present. Arboreal pollen dominates throughout, ranging from 54.6-73.0%. The *Pinus* signal is continuously high, never less than 38.2%. Maximum values occur at the base of the profile (51.3%). *Corylus* is a significant component throughout. *Fagus* appears in the upper half of the profile. Gramineae dominate the non-arboreal component, gradually increasing from 3.5-10.3%. A discontinuous Cerealia signal is present. Common names of taxa are given in Figure 6.

Discussion

Vegetation ecology

Cluster analysis of the Scottish and Irish plots identified four distinct groups, which are summarised and discussed in relation to the NWS Framework (DAFM 2018). The vegetation of Irish pinewoods was described by Roche et al. (2009) and compared with native pinewoods elsewhere in oceanic north-west Europe by Roche et al. (2015).

Group 1 was composed entirely of Irish plots (Table 1) of planted origin. These were classified by Roche et al. (2009) as *Vaccinium myrtillus-Ilex aquifolium*, an acid pine-oak woodland type. They tended to occur on sloping terrain, on soils with a low mean pH (3.53) and reasonably high mean organic content (67.3%).

Table 4: *Spheroidal Carbonaceous Particle (SCP) and Accelerator Mass Spectrometer (AMS) dates from Rockforest Lough*.

Core	Depth (cm)	Laboratory reference	Sample description	^{14}C year BP[1]	Calendric age (AD)	IntCal 2.5% (cal year BP)	IntCal 50% (cal year BP)	IntCal 97.5% (cal year BP)
			SCPs					
RFB	4	-	2nd rapid increase	-	1985	−9	−37	−35
RFB	7	-	Sub-surface peak	-	1981 ± 2	−36	−30	−24
RFB	8	-	Rapid increase	-	1965 ± 5	−2	0	2
RFB	13	-	Start of record	-	1885 ± 5	92	10	108
			Macrofossils					
RFB	19	Beta-247933	Wood	240 ± 40	-	2	284	423
RFB	22	Beta-247934	Plant material	230 ± 40	-	2	264	418
RFB	29	Beta-247935	Wood	520 ± 40	-	508	538	631
RFB	66–68	Beta-252787	Plant material	1180 ± 40	-	989	1107	1229
RFC	72–74	Beta-252788	Organic material	3410 ± 50	-	3511	3662	3819
RFC	88	Beta-253480	Plant material	1380 ± 40	-	1198	1300	1359
RFC	104–107	Beta-252790	Plant material	1540 ± 40	-	1347	1438	1522
RFC	153	Beta-252791	*Pinus* wood	5050 ± 40	-	5676	5814	5898

Diversity was relatively low, with a mean species richness of 28.7. Typical species included *P. sylvestris, Quercus petraea*, *Betula pubescens, Sorbus aucuparia, Ilex aquifolium, Vaccinium myrtillus* and *Blechnum spicant*. The highly invasive non-native *Rhododendron ponticum* was a differential species, occurring exclusively within Group 1. Structurally, the plots were relatively tall and dense, with the highest mean stocking density (1042.9 trees per ha), canopy height (17.3 m) and canopy cover (56.2%) in the dataset (Table 2). *P. sylvestris* regeneration was poor; single individuals were recorded in I10 and I11 (Derrycrag I, II) (Table 3). *P. sylvestris* is light-demanding and sensitive to grazing and browsing (Carlisle and Brown 1968) so the statistically insignificant correlation between regeneration levels and canopy cover or grazing levels was unexpected. It may be due to the high proportion of zero values (70.5% of plots) in the regeneration data. As the plots were located beneath the canopy, shading may have impeded regeneration. Grazing and browsing may also have checked regeneration but the inconclusive correlation analysis prevented further exploration of the relationships between these variables.

Notwithstanding the dominance of *P. sylvestris* in the canopy, the vegetation of Group 1 is similar to the acidophilous oakwoods of the WL1 *Quercus petraea-Luzula sylvatica* group of the Irish Vegetation Classification, which corresponds to the Annex I habitat Old sessile oakwoods (NBDC 2019). Indeed, before 2000-1500 years ago certain Irish Atlantic oakwoods comprised mixed pine-oak woodland. High spatial

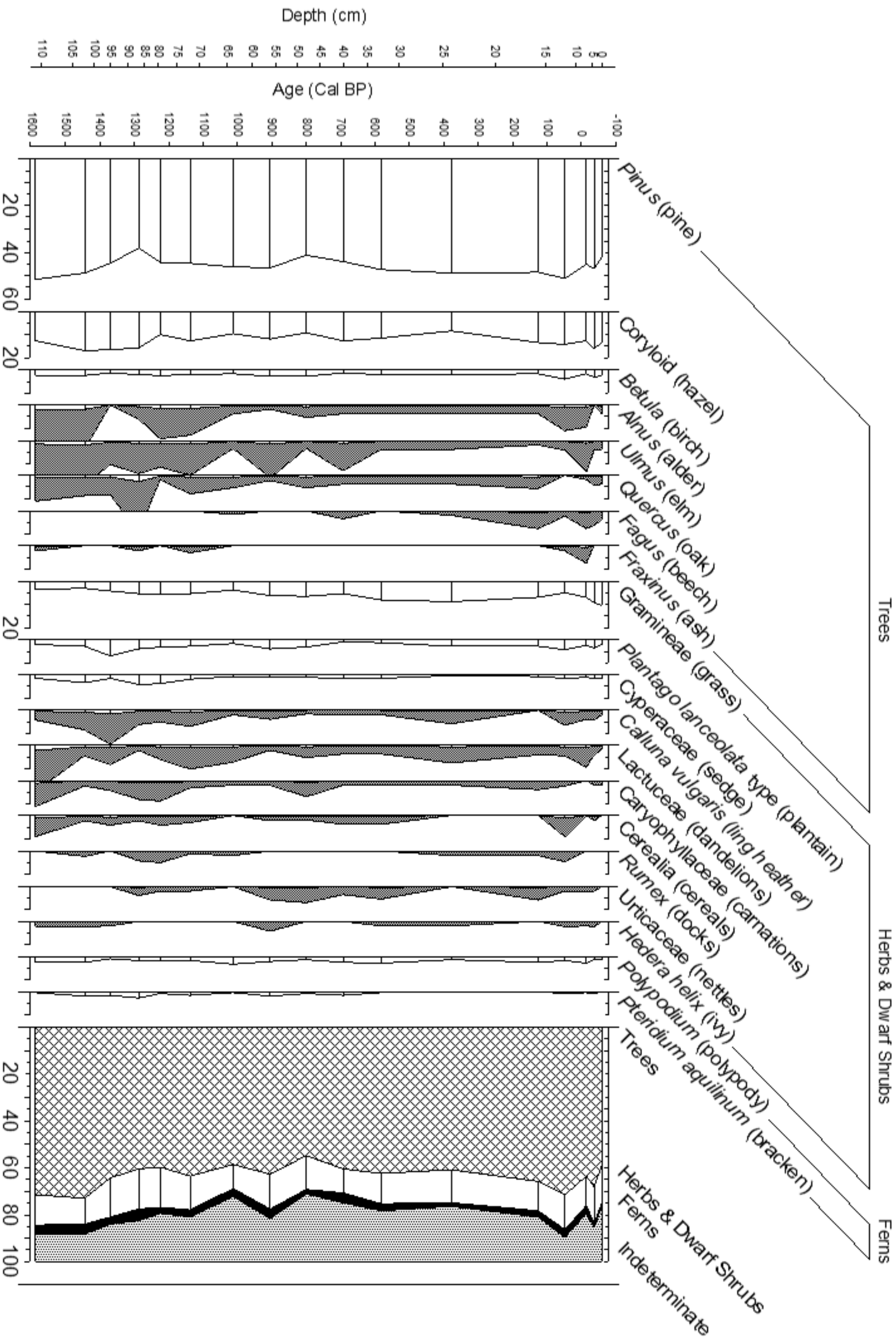

Figure 6: *Percentage pollen diagram of selected taxa from Rockforest Lough (shading = exaggeration × 10).*

resolution pollen analysis of samples taken from small hollows within woodlands, with a pollen source area within a 100 m radius, provides data on woodland dynamics at the stand scale. An analysis of long-term changes and drivers of biodiversity in these oakwoods identified the loss of *P. sylvestris* as one of the most significant changes in their biodiversity (Mitchell 2013). Though planted in origin, Group 1 is a modern analogue of these ancient pine-oak woodlands (Roche et al. 2015). It corresponds to Scenario 1 of the NWS Framework (DAFM 2018), which specifies a mix of 30% *Quercus petraea*, 30% *P. sylvestris*, 15% *Betula pubescens*, 15% *Sorbus aucuparia* and 10% *Ilex aquifolium* on upland valley sides and hillsides with free-draining slopes on podzolised soils.

Group 2 comprised two Irish and six Scottish plots (Table 1). They tended to occur on soils with a relatively low mean pH (3.63) and high mean organic content (80.6%). Diversity was low, with a mean species richness of 19.5. Structurally, the plots were moderately tall and relatively open, with a mean canopy height of 13.9 m and canopy cover of 43.5%. Group 2 contained two stable sub-groups, recognisable by their long stems in the dendrogram (Figure 3). One comprised the Irish plots I2 (Clonfinane Bog) and I6 (All Saints Bog) and the Scottish plot S26 (Abernethy II), indicating a direct correspondence between these reintroduced stands and a native stand of high conservation value. I2 and I6 were classified by Roche et al. (2009) as *Calluna vulgaris-Eriophorum vaginatum*, a pinewood type of relatively intact raised bogs. Inspection of the floristic data showed that *P. sylvestris* dominated the canopy. *Betula pubescens* was abundant in I2 and I6 but absent from S26. Typical species included *Calluna vulgaris, Vaccinium myrtillus, Erica tetralix* and *Empetrum nigrum*. Differential species included the bog species *Eriophorum vaginatum, Andromeda polifolia* and *Vaccinium oxycoccus* which, in this wooded setting, are strongly indicative of Bog woodland. This is a priority Annex I habitat of international conservation importance (EC 2013). Ireland hosts a significant proportion of the world's raised bogs, but woodlands on relatively intact raised bogs are rare even here (Fossitt 2000). *P. sylvestris* regeneration was relatively good. Five seedlings occurred in S26. I6 had the highest level of *P. sylvestris* regeneration in the dataset, with 52 saplings and poles. While no *P. sylvestris* regeneration occurred in plot I2, it was noted on open bog surrounding the woodland. Palaeoecological studies have shown that I2 and I6 are non-relict stands, which naturalised in the last 200 years (Heery 1993, O'Connell and Doyle 1990). However, they are modern analogues of the bog pinewoods which occurred sporadically on several midland raised bogs until medieval times (McNally and Doyle 1984, O'Connell 1988, Roche et al. 2015). As raised bog is a priority Annex I habitat and is unsuitable for afforestation, the NWS Framework is not applicable in this case. However, on cutover or cutaway bog or bog remnants which are unsuitable for bog restoration, pine-birch woodland may be an appropriate rehabilitation target, especially where hydrological conditions are suitable for the development of bog woodland.

The second sub-group comprised five Scottish plots. They showed a high level of similarity (Figure 3). The canopy was wholly dominated by *P. sylvestris*. Typical species included *C. vulgaris, Vaccinium myrtillus* and *Deschampsia flexuosa. Vaccinium vitis-idea* was a differential species. These are constant species of the W18 *Pinus sylvestris-Hylocomium splendens* community of the British NVC (Rodwell 1991). W18 corresponds to the priority Annex I habitat Caledonian forest (EC 2013). The dendrogram indicates that the vegetation of the Irish plots does not directly correspond to the typical vegetation of Caledonian forest (Figure 3). Regeneration was poor even in the Caledonian forest plots, being absent from all but one (S25 Abernethy I).

Group 3 contained Irish plots only (Table 1). These were classified by Roche et al. (2009) as *Corylus avellana-Brachypodium sylvaticum*, a basiphilous pinewood type. They tended to occur on less acidic soils, with a mean pH of 4.40, and/or on rocky terrain. Substrates comprised limestone pavement (I3 Rockforest, I13 Rockvale, I20 Ballykine II), soil overlying limestone (I19 Ballykine I), and granite outcrops (I8 The Scalp). Soil organic content was relatively low (47.7%). With the exception of I8, they occurred on gentle slopes in the lowlands. Diversity was relatively high, with a mean species richness of 47.2. Typical species included *P. sylvestris, Corylus avellana, Crataegus monogyna, Hedera helix, Lonicera periclymenum* and *Rubus fruticosus* agg. Differential species include *Fraxinus excelsior, Prunus spinosa, Teucrium scorodonia* and *Brachypodium sylvaticum*. I19 comprised planted high forest; the remaining plots were apparently self-seeded, including one from a putatively native pinewood (I3 Rockforest) (McGeever and Mitchell 2016, Roche 2010, Roche et al. 2016, 2018) which is discussed in the following section. Structurally, the plots were generally relatively low and open, with the lowest mean canopy height (10.3 m) and canopy cover (35.5%) in the dataset (Table 2). *P. sylvestris* regeneration occurred only within the plots on limestone pavement. I13 and I3 contained one and two stems respectively, while I20 contained 41 stems, distributed across all height classes. This is likely due to the very open, scrubby structure of these plots, which exhibited moderate, low and no grazing respectively.

Roche et al. (2015) found that Group 3 had floristic similarities with Bjørndalen's (1985) basiphilous native pinewoods in oceanic south-west Norway. High proportions of Group 3 differential, preferential and constant species (74.4%, 80.0% and 100.0% respectively) also occurred in the Norwegian plots. Links with the NWS Framework (DAFM 2018) are limited to some similarities in species composition with Scenario 3 (oak-ash-hazel woodland). In any case, limestone pavement is a priority Annex I habitat and is unsuitable for afforestation.

Group 4 contained one Scottish plot and five Irish plots (Table 1), four of which were classified by Roche et al. (2009) as *Galium saxatile-Agrostis capillaris*, an upland pinewood vegetation type. The Irish plots were of planted origin. Group 4 tended to occur on relatively acidic soils and sloping ground in the uplands. Mean soil organic content was relatively low (51.5%). Diversity was relatively low, with a mean species richness of 29.5. The canopy was wholly dominated by *P. sylvestris.* Typical species included *Vaccinium myrtillus, Pteridium aquilinum, Sorbus aucuparia, Blechnum spicant* and *Calluna vulgaris.* The ground flora was grassy in character and, like many Irish upland habitats (Perrin et al. 2014), may have been highly modified by grazing. The species composition overlapped with that of Group 1, but Group 4 was differentiated by a lack of *Quercus petraea* and higher cover of *Galium saxatile, Molinia caerulea, Agrostis capillaris* and *Potentilla erecta*. Structurally, the plots were relatively tall and open, with a mean canopy height of 15.7 m and the lowest mean stocking density (462.5 trees per ha) in the dataset (Table 2). *P. sylvestris* regeneration was absent.

I9 (Coronation Plantation, planted AD 1831) showed relatively high similarity to S21 (Cona Glen) in western Scotland (Figure 3), indicating a direct correspondence between this reintroduced stand and a native stand of high conservation value. They differed from other plots in their high *Molinia caerulea* cover, exceeding 50%. Rodwell et al. (2000) noted that pinewoods with abundant *M. caerulea* are occasional in the Scottish Highlands. Coronation Plantation is of conservation value due not only to its similarity to a native Scottish pinewood type but also because it supports numerous species of conservation importance, particularly breeding birds (NPWS 2005). No regeneration occurred in the plot and active conservation management is needed to ensure the long-term viability of this site.

As the canopy of Group 4 plots generally contains pure *P. sylvestris*, this group does not correspond strongly to the mixed NWS Framework scenarios (DAFM 2018). However, Group 4 occurs in similar environmental conditions to Scenario 5A (Pioneer birch woodland on modified and improved, infertile upland acid brown earths and peaty podzols).

Native status

Pollen diagrams should be interpreted with an awareness of their methodological limitations. The pollen of some taxa can only be identified to genus or family level. Wind-pollinated plants, particularly trees, tend to be overrepresented in the pollen record. McGeever and Mitchell's (2016) study of modern pollen deposition in the Rockforest area concluded that a *Pinus* pollen value of 5% indicated local presence of *P. sylvestris*. *Pinus* macrofossils, if present, provide further and more definitive evidence of local presence (Froyd 2005). Pollen source area varies according to the nature of the coring site. At c. 8 ha in size, Rockforest Lough probably samples pollen mainly from a source area of 300-800 m (after Sugita 1994). Pollen preservation quality varies amongst taxa and sampling sites. Sediment deposition rates may vary over time and statistical error is inherent in age-depth models (Figure 5). Despite these caveats, pollen analysis, particularly when combined with macrofossil analysis and high-resolution dating, can provide reliable evidence of the former presence and relative frequency of species, especially forest trees.

The Rockforest Lough pollen profile is relatively static. Arboreal pollen dominates throughout. The most significant feature is the continuously high *Pinus* signal, which fluctuates somewhat but never falls below 38.2%. *Corylus* was also frequent throughout. This indicates a pine-hazel woodland with an open structure, as *P. sylvestris* is light-demanding (Carlisle and Brown 1968). The rise in Gramineae from 1600 cal BP/AD 350 to the present indicates a gradual opening up of the woodland and expansion of open grassland. *Pinus* fell to a minimum (38.2%) c. 1300 cal BP/AD 650 but still dominated. A *P. sylvestris* needle found at 66 cm depth demonstrates that the species was locally present at 1110 cal BP/AD 840. The non-native *Fagus* peaks c. 125 cal BP/AD 1825. The Cerealia signal, though discontinuous, indicates arable farming in the surrounding area. The vegetation dynamics of the pollen profile are discussed in more detail in Roche (2010) and Roche et al. (2016, 2018).

Rockforest Wood is mentioned in historical sources with regard to woodland cover and human activity. Its ancient name was Coill Ó Flanchada. The Wars of Thomond affected County Clare in the 12th-14th century. A strategically important pass, Bealach an Fhiodhfail, then the main route from Clare to Galway, now the Corofin to Gort road, went through the wood (Frost 1893). In 1311 a battle was fought at the entrance to the wood to contest the pass. A defeated force fled through it in 1314 (MacCraith 1929). The Annals of the Four Masters record that in 1599 Red Hugh O'Donnell's army massed at the eastern edge and marched through the centre of Coill Ó Flanchada, via Bealach an Fhiodhfail (O'Donovan 1851). In 1655, the Down Survey showed that the only timber woods in this barony (Inchiquin) lay in this parish (Kilkeedy), occurring in nearly every townland. Covering 850 ha, they likely formed one of the county's largest woods (Westropp 1909). Henry Pelham's Grand Jury Map of County Clare (1787) depicts woodland at Rockforest but little in the surrounding area. Rockforest House was built in the late 18th century (Weir 1999). By 1808, over 30 ha of poor, rocky soil had been planted with *Acer, Alnus, Betula, Fagus, Fraxinus, Larix, Picea, Pinus pinaster, Pinus sylvestris, Quercus, Ulmus* and other species (Dutton 1808). A "finely planted demesne" extended almost a mile along the road (Lewis 1837). The Ordnance Survey six inch maps (1840, 1899) show the area as wooded (Roche 2010). Selective felling and scrub clearance occurred in the 20th century (J. Cunningham, pers. comm.). Though fragmentary in nature, the available historical sources imply continuous presence of woodland cover at Rockforest despite ongoing human activity. These are usually dated with a high level of certainty, but dating of palaeoecological data is inferred from age-depth models, making it prone to statistical error. These data should be compared cautiously.

The consistently high arboreal pollen signal and available historical sources both suggest that Rockforest has a long history of woodland cover. This contrasts with patterns seen in contemporaneous Irish pollen profiles. Prior to the Great Famine of 1845, Ireland's population reached almost nine million, causing severe land-use pressure. Poorer land was cleared for agriculture over much of Ireland (Cole and Mitchell 2003). Elsewhere in the Burren, arboreal pollen frequencies were just 4% from 250-100 cal BP/AD 1700-1850 at Cappanawalla (Figure 2) (Feeser and O'Connell 2009). This contrast may relate to the management of the Rockforest Estate. Nationally, the woodland resource steadily diminished until the 20th century, excepting remnants within estates (Everett 2014). Rockforest appears to be one such estate.

The *Pinus* curve from Rockforest Lough is consistently high. Its minimum value (38.2%) greatly exceeds McGeever and Mitchell's (2016) 5% threshold, indicating that *P. sylvestris* was locally present as a significant component of the vegetation. Furthermore, macrofossil evidence demonstrates local presence of *P. sylvestris* around Rockforest Lough during the Neolithic at 5810 cal BP/3860 BC and the early medieval period at 1110 cal BP/AD 840. The latter is most significant as the species was presumed extinct in Ireland during that period (Bradshaw and Browne 1987). The later macrofossil (1110 ± 120 cal BP/AD 840) is contemporaneous with the last recorded *Pinus* macrofossils from Gortlecka (1050 ± 160 cal BP/AD 900) (Watts 1984), 3.3 km west of Rockforest Lough (Figure 2). Watts expressed concern that this date appeared too young but this new evidence suggests that it was accurate.

The later Rockforest macrofossil coincides with a *Pinus* pollen frequency of 45%. The subsequent *Pinus* signal remains high to the present. Though *Pinus* had been planted on the Rockforest Estate by 1808 (Dutton 1808), its pollen was previously strongly represented. Rockforest Wood, located 500 m upwind of the coring site, matches the vegetation recorded in the pollen profile and is the likely source of this signal. *P. sylvestris* appears to have persisted at Rockforest through the late Holocene to the present.

These findings are supported by McGeever and Mitchell's (2016) analysis of a radiocarbon-dated peat core from Aughrim Swamp, 650 m north-east of Rockforest Lough (Figure 2). It too shows a continuous *Pinus* signal from c. 1600 cal BP/AD 350 to the present. A decline began c. 1550 cal BP/AD 400, reaching c. 8% c. 1350 cal BP/AD 600 but *Pinus* recovered quickly, reaching sustained levels of c. 15-25%, before declining to c. 5% at the top of the core.

Substantial deforestation occurred in the Burren and *Pinus* declines there have been attributed to human activity (Feeser and O'Connell 2009) but the palaeoecological data and historical sources indicate that Rockforest was an exception to this pattern. The area was subject to continued human activity but the disturbance does not appear to have eradicated *P. sylvestris*.

Conclusions

The widely accepted hypothesis that *P. sylvestris* became extinct in Ireland has been rejected. At 8°57' W, Rockforest appears to be the western limit of the natural range of *P. sylvestris*, previously thought to be in Portugal at 8°09' W (EUFGIS 2019).

The Irish survey sites, excepting Rockforest, are thought to contain *P. sylvestris* of reintroduced origin. The vegetation of certain plots and groups resembled that of extant native pinewoods elsewhere or fossil assemblages from Ireland's ancient pinewoods. This suggests that reintroduced *P. sylvestris* woodlands are an important resource for Irish biodiversity, particularly given the country's low native woodland cover.

These findings should inform evidence-based forest management and policy. They provide support for the inclusion of *P. sylvestris* in the NWS and the retention of reintroduced *P. sylvestris* in woodlands managed for conservation. It is recommended that reintroduced *P. sylvestris* is managed as a native species in Irish woodlands. However, where woodland has colonised formerly open bog due to human-induced degradation (e.g. drainage), it may be removed to facilitate bog restoration (EC 2013). The floristic and environmental data presented should inform site and species selection. The data from the bog woodlands of Group 2 may be informative in setting rehabilitation targets for the after-use of cutaway bogs.

Natural regeneration of *P. sylvestris* was poor overall and requires further research in the Irish context. Exclosures within and, importantly, on the edges of *P. sylvestris* stands would permit an assessment of both vegetation change and regeneration under current climatic conditions in the absence of grazing. This would be most relevant to the upland pinewoods of Group 4 as regeneration was absent and the ground flora was grassy in nature, indicating that it has been heavily modified by grazing.

O Tuama (2017) questioned the omission of *P. sylvestris* woodland from a recent description of Irish native woodland types (Cross and Collins 2017). The Irish pinewood plots should be analysed using the ERICA tool (NBDC 2019) to quantify their level of similarity to the types defined by the Irish Vegetation Classification, put them in context among Irish native woodland types and clarify whether a separate *P. sylvestris* type is warranted.

It has been suggested that further evidence is required before the hypothesis that *P. sylvestris* survived to the present in Ireland is accepted (O'Connell and

Molloy 2019). Relevant palaeoecological research is ongoing (F.J.G. Mitchell, unpublished). Genetic research (C. Kelleher, unpublished) on the Irish *P. sylvestris* stands described here, including Rockforest, is anticipated to provide new insights into the genetic diversity of these populations.

Further research and conservation measures are needed at Rockforest. *P. sylvestris* has been placed on the waiting list of the Irish Red Data List, pending further research to enable assessment (Wyse Jackson et al. 2016). The population is of high conservation value but its rarity increases its extinction risk. Reintroduced *P. sylvestris* in the vicinity may threaten its genetic integrity. Rockforest should be carefully managed and monitored, particularly given the scarcity of *P. sylvestris* regeneration (Table 3). Off-site conservation has commenced; *P. sylvestris* propagated from Rockforest seed has been planted at two other sites by NPWS (S. Callaghan, pers. comm.). Rockforest has been listed as a genetic conservation unit (EUFGIS 2019) and a "source identified" seed stand for *P. sylvestris* by the Forest Service (B. Clifford, pers. comm.). Commercial seed collection is underway (B. Carey, pers. comm.). However, seed-sourcing must be compatible with the long-term viability of the population on-site. Coordinated action between forestry and conservation agencies is needed to ensure the continued survival of native *P. sylvestris* at Rockforest and to develop opportunities for the restoration of native pinewoods in Ireland.

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