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# Regeneration of native broadleaved species on clearfelled conifer plantations in upland Britain ☆

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ABSTRACT

In upland areas of Great Britain, large tracts of non-native conifer plantations have been established on poor quality agricultural land. There is now considerable interest in the conversion of some of these plantations to a more natural woodland comprised of native tree species. We studied the tree regeneration and ground flora on 15 upland sites (altitudes ranging from 120 m to 380 m above sea level) that had been clearfelled of conifers. Regeneration of native tree species was successful where a clearcut site was adjacent to mature native trees, which acted as a seed source. Mean regeneration densities of native tree species on clearcut sites were typically greater than 1000 stems/ha, exceeding minimum recommended planting densities for the establishment of new native woodland. Whilst 10 native woody tree species were recorded, the regeneration was dominated by birch species. Regeneration densities were significantly higher on clearcut sites than on adjacent areas of unplanted moorland, probably due to the lack of a dense ground flora following the clearfelling operations. Our results indicate that where local native seed sources exist, clearfelling upland conifer plantation sites to allow natural regeneration has the potential to be an effective method of establishing native woodland.



## 1. Introduction

Timber plantations have been widely established across Northern Hemisphere mid-latitudes (Zerbe, 2002; Yamagawa et al., 2010) with plantation forests now making up 14% of total forest area in western European countries (Forest Europe, 2011) and about 70% of total forest area in Britain (Brockerhoff et al., 2008). These plantation forests usually consist of fast-growing, non-native conifer species located on marginal agricultural land in the uplands (Humphrey et al., 2006). They are typically intensively managed for timber production with substantial site preparation before planting (e.g., ploughing, drainage, and occasional use of fertiliser) and harvesting of timber occurring by clearfelling after a relatively short rotation. Whilst plantation forests can provide habitat for a range of species (Humphrey et al., 2000; Quine and Humphrey, 2010; Bremer and Farley, 2010; Coote et al., 2012), semi-natural woodlands typically contain greater biological diversity (Brockerhoff et al., 2008; Bremer and Farley, 2010). Furthermore, plantation forests can result in soil and stream acidification (Carling et al., 2001) as well as potential negative impacts on water resources. Recently, a greater interest in woodlands for their ecological and recreational value means that semi-natural and mixed forests consisting of native species are becoming increasingly valued (Felton et al., 2010). As many plantations are now reaching the end of their rotations, there is considerable potential for establishment of semi-natural woodland on former plantation forest sites (Spiecker et al., 2004; Dedrick et al., 2007).

The restoration of plantation forests to semi-natural woodland can be carried out through a range of methods. The conifer crop can either be clearfelled or the trees can be removed more gradually through multiple thinning operations. There are also a range of methods for establishing native trees including planting, direct seeding or natural regeneration. Natural regeneration is the establishment of trees from seeds produced in situ (Harmer and Kerr, 1995) and is the preferred means of achieving native woodland expansion in Great Britain (Forestry Commission, 1994). Potential advantages of natural regeneration include the preservation of local genotypes and greater structural diversity of the resulting woodland (Peterken, 1996), high seedling density (Holgén and Hånell, 2000) as well as increased cost-effectiveness (Tarp et al.,



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2000; Jonásová et al., 2006). Natural regeneration has been studied in a range of environments including degraded lowland tropical pasture (Parrotta et al., 1997), tropical mountain forests (Holl et al., 2000), boreal forest (Peltzer et al., 2000; Holgén and Hånell, 2000; Hanssen, 2003; Man et al., 2008; Man et al., 2009), lowland European forests (Madsen and Larsen, 1997; Emborg, 1998; Olesen and Madsen, 2008; Modrý et al., 2004; Swagrzyk et al., 2001; Harmer and Morgan, 2009; Wagner et al., 2010; Smit et al., 2012) and European mountain forests (Jonásová et al., 2010; Bace et al., 2012). However, the regeneration of native species on clearfelled conifer plantations is still poorly understood (Zerbe, 2002) with Wallace (1998)'s study of birch regeneration in clearfelled spruce plantations the only previous study in upland Britain.

Here we report the first extensive study of natural regeneration of native hardwood species on clearfelled upland conifer plantations in Britain. We addressed the following questions: (i) How well do native tree species regenerate on clearfelled upland conifer plantations? (ii) How does regeneration on clearfelled conifer plantations compare to regeneration on improved farmland and open moorland? (iii) What are the dominant factors controlling regeneration? (iv) How does the ground flora develop in the years following clearfelling and how does this impact tree regeneration?

## 2. Materials and methods

### 2.1. Experimental sites

We surveyed a total of 21 sites at 4 different upland locations: Hardknott forest and Rainsbarrow wood in the Lake District, northwest England and Clashindarroch forest and Bin forest in Aberdeenshire, north-east Scotland. All forests surveyed were managed by the Forestry Commission. The soil type, obtained from Forestry Commission soil maps, was used to predict the natural woodland community that would be expected to develop (Rodwell and Patterson, 1994). Details of the sites selected are given in Table 1 and locations are shown in Fig. 1. Hardknott forest was planted on upland moorland between 1940 and 1955 (N. Williams 2008, Forestry Commission, personal communication). There are several broadleaf woodland fragments of *Quercus spp.* (oak spp.), *Betula spp.* (birch), *Sorbus aucuparia* (rowan), *Ilex aquifolium* (holly) and *Salix spp.* (willow). Nearby Rainsbarrow woodland was planted with conifers between 1959 and 1962 and is designated as a Planted Ancient Woodland Site (PAWS) (Thompson et al., 2003). PAWS are sites with a long history of forest cover, with the original semi-natural woodland cleared and replaced by a plantation, a practice that was widespread in the UK before around 1980 (Thompson et al., 2003). Clashindarroch forest was established from 1930 onwards (Forestry Commission, 1964). Prior to afforestation, the land was mostly upland moorland with a dense flora of *Calluna vulgaris* (ling heather) and *Vaccinium myrtillus* (bilberry) with limited areas of *Pteridium aquilinium* (bracken) on the lower elevations (Forestry Commission, 1952). Bin forest was established from 1926 onwards when most of the land was upland moorland with dense ling heather vegetation (Forestry Commission, 1964). Both Clashindarroch and Bin forests retained small fragments of semi-natural woodland consisting largely of birch and rowan as well as *Alnus glutinosa* (common alder) and willow on the wetter ground.

At these 4 locations we surveyed 15 sites that had been afforested with conifers, clearfelled and then left to regenerate naturally. Table 1 details the species of the felled conifer crop, which was generally dominated by *Picea sitchensis* (Sitka spruce), matching the dominant conifer species used across Britain (Forestry Commission, 2012). The harvesting residues, known as brash, were

**Table 1**
Location and environmental characteristics of study sites.

| Site label[a] | Site name | Lat. (°N) | Lon. (°W) | Altitude (m) | Area (ha) | Soil type[b] | NVC Type[c] | pH | Former crop spp.[d] | Land-use[e] | Years since clearfell | No. quadrats [no. transects] | Month/year of survey |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Bin forest (Aberdeenshire)* | | | | | | | | | | | | | |
| U5 | Ordiquhill | 57.470 | −2.807 | 160 | 7.4 | 1 | W11 | 4.5 | SS/NS | UM | 5 | 120[6] | 6/10 |
| U6a | Binside B | 57.490 | −2.831 | 170 | 11.1 | 1 | W11 | 4.5 | SS/SP | UM | 6 | 100[6] | 7/10 |
| U10 | Binside A | 57.478 | −2.849 | 190 | 2.9 | 7 | W7 | 4.6 | SS | UM | 10 | 60[4] | 6/10 |
| *Clashindarroch forest (Aberdeenshire)* | | | | | | | | | | | | | |
| U6b | Longbank | 57.379 | −2.908 | 380 | 35.2 | 4 | W18 | 4.0 | SS | UM | 10 | 60[4] | 6/10 |
| U15 | Hareetnich A | 57.379 | −2.941 | 380 | 4.1 | 4 | W18 | 4.2 | LP | UM | 15 | 60[4] | 6/10 |
| F1 | Coynachie | 57.390 | −2.903 | 200 | 0.9 | 1 | W11 | 5.3 | SS | IF | 1 | 60[4] | 7/10 |
| F2 | Raibet B | 57.391 | −2.865 | 230 | 0.4 | 1 | W11 | 5.4 | SS | IF | 2 | 60[4] | 6/10 |
| F4 | Raibet C | 57.392 | −2.860 | 220 | 2.3 | 1 | W11 | 5.4 | SS | IF | 4 | 60[4] | 6/10 |
| Ua | Raibet D | 57.390 | −2.873 | 290 | – | 1 | W11 | 5.4 | – | UM | – | 60[4] | 6/11 |
| Ub | Hareetnich B | 57.381 | −2.911 | 300 | – | 4 | W18 | 4.2 | – | UM | – | 60[4] | 6/11 |
| Fa | Drumfergue A | 57.392 | −2.863 | 230 | – | 1 | W11 | 5.5 | – | IF | – | 60[4] | 6/11 |
| Fb | Drumfergue B | 57.430 | −2.873 | 200 | – | 1 | W11 | 5.5 | – | IF | – | 60[4] | 6/11 |
| Fc | Raibet A | 57.392 | −2.867 | 230 | – | 1 | W11 | 5.3 | – | IF | – | 60[4] | 7/10 |
| *Hardknott forest (Lake District)* | | | | | | | | | | | | | |
| U2L | Hardknott A | 54.309 | −3.182 | 325 | 3.7 | 1 | W11 | 3.3 | SS | UM | 2 | 22[2] | 6/08 |
| U3L | Hardknott B | 54.373 | −3.188 | 240 | 1.5 | 1 | W11 | 3.1 | SS | UM | 3 | 38[3] | 6/08 |
| U4L | Hardknott C | 54.376 | −3.193 | 200 | 1.7 | 1 | W11 | 3.3 | SS | UM | 4 | 37[2] | 6/08 |
| U7L | Hardknott D | 54.373 | −3.185 | 250 | 1.4 | 1 | W11 | 3.4 | SS | UM | 7 | 40[2] | 6/08 |
| U9L | Hardknott E | 54.300 | −3.182 | 275 | 1.7 | 6 | W4 | 3.5 | SS | UM | 9 | 35[3] | 6/08 |
| U10L | Hardknott F | 54.300 | −3.185 | 300 | 1.7 | 6 | W4 | 3.5 | SS | UM | 10 | 37[4] | 6/08 |
| UL | Grassguards | 54.370 | −3.194 | 230 | – | 1 | W11 | 3.5 | – | UM | – | 18[2] | 5/08 |
| *Rainsbarrow forest (Lake District)* | | | | | | | | | | | | | |
| P7L | Rainsbarrow | 54.324 | −3.250 | 120 | 1.7 | 1 | W11 | 3.4 | JL | PAWS | 7 | 38[4] | 5/08 |

[a] Site label indicates former land use (U: upland moor, F: improved farmland, P: PAWS) and number of years since clearfelling (indicated by number). All Lake District sites are distinguished by a label L. Control sites are distinguished by lower case alphabetical labels.
[b] Soil types follow the Forestry Commission classification (Pyatt, 1982). 1: Typical brown earth; 4: Ironpan soil; 6: Peaty gley; 7: Surface-water gley.
[c] National Vegetation Classification: Potential woodland community predicted from soil characteristics (see Rodwell and Patterson (1994)).
[d] Species: HL = Hybrid larch (*Larix x eurolepis*); LP = Lodgepole pine (*Pinus contorta*); NS = Norway spruce (*Picea abies*); SS = Sitka spruce (*Picea sitchensis*); SP = Scots Pine (*Pinus sylvestris*); JL = Japanese Larch (*Larix kaempferi*).
[e] UM: upland moor, IF: improved farmland, PAWS: planted ancient woodland site.