Natural regeneration within the Coillte estate

II The occurrence of natural regeneration of lodgepole pine on clearfelled areas

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Abstract

The factors that influence the probability of lodgepole pine (*Pinus contorta* Dougl. var. *contorta*) regenerating naturally were examined in a field survey of clearfelled lodgepole pine sites in the Coillte (Irish Forestry Board) estate. Sixty-six sites with naturally regenerated lodgepole pine and 41 sites without were selected. Logistic regression was used to model the relationship between its occurrence and site and stand factors. Of twenty-five factors examined, four were shown to significantly influence the probability of natural regeneration occurring: site exposure, site drainage status, the percentage of the clearfelled crop comprising lodgepole pine and whether the antecedent stand had been thinned. Lodgepole pine natural regeneration was reduced at increased exposure, whereas improved site drainage increased it. The greater the percentage of lodgepole pine in the antecedent crop, the greater the probability of lodgepole pine regeneration occurring. Thinning also increased the probability of natural regeneration occurring.

Keywords: seed germination, seedling survival, logistic regression, probability model

Introduction

The majority of forests in Ireland consist of even-aged monocultures of exotic species, managed under a clear cutting system. At final harvest the entire crop is felled, followed (usually) by artificial regeneration with nursery-produced plants, often of the same species as the antecedent crop. There is however, increasing national and international pressure to examine and introduce alternatives to the clear cutting system. These alternatives rely largely on natural regeneration as a means of reforestation.

As a result of increased clear cutting levels in Irish forests, spontaneous natural regeneration of a number of species, including lodgepole pine, is occurring more frequently. Lodgepole pine is the second most widely planted coniferous species in the Coillte estate, comprising 15 % of the company's forest area. It is most commonly found on poor sites with low fertility and productivity, where the financial justification of forestry is often questionable (Carey and Hendrick 1986). However, adequately stocked crops arising from natural regeneration could prove to be economically viable, as they avoid the costs associated with planting. In addition, basal sweep, a common defect in planted lodgepole pine, is generally not found in naturally seeded trees (Pfeifer 1982).

A range of factors is known to influence the occurrence of lodgepole pine natural regeneration. Lotan and Critchfield (1990) found the highest germination rates in full sunlight and on bare mineral soil or disturbed duff, free of competing vegetation. Minore (1972) found that the germination rates of lodgepole pine under field conditions ranged from 30 to 88%, depending on the nature of the seedbed and amount of shading. Moderate and heavy shade reduced germination by up to 20%. Another factor influencing natural

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regeneration is the seedbed moisture level. Lotan (1964) found drought the most common cause of mortality among first-year lodgepole pine seedlings. In its natural range, the greatest losses of lodgepole pine seedlings occur on soils with low water-holding capacity, and on seedbeds of duff and litter, with losses declining after the first growing season (Lotan and Critchfield 1990).

Objective

The objective of the work described was to determine the stand and site factors associated with the occurrence of natural regeneration of south coastal lodgepole pine on clearfelled sites in Ireland.

Materials and methods

The later stages of the natural regeneration process, seed germination and survival, were considered and the factors influencing these two stages identified. Stands (subcompartments in the Coillte estate) with natural regeneration of lodgepole pine (referred to hereafter as 'regeneration sites') were examined, as well as sites where it was assumed seed of lodgepole pine was available, but had not germinated ('non-regeneration sites').

Sites were selected using the following criteria:

1. a second rotation crop was present and the antecedent crop had been clearfelled,
2. sites on which crops were clearfelled prior to January 1986 were excluded because data were not available.

Regeneration sites were selected from Coillte's subcompartment database. Up to four tree species were recorded in the database for each subcompartment together with their relative canopy composition (if above 5%). The database also recorded which species were naturally regenerated. Subcompartments in the database which had naturally regenerated stands of lodgepole pine were listed in descending order, according to the percentage of the canopy composed of natural regeneration. The first 66 sites on this list were chosen.

Forty-one non-regeneration sites were identified using GIS, inventory data, and information from Coillte personnel. These were sites which had no evidence of naturally regenerated lodgepole pine but

1. contained lodgepole pine in the antecedent crop or
2. contained no lodgepole pine, but at the time of harvest had at least one adjacent subcompartment containing mature (at potential seed-bearing age) lodgepole pine.

It was assumed therefore that seeding but not germination had occurred at these sites. In order to ensure that the process that was being examined was germination and survival, rather than seed production *per se*, non-regeneration sites were selected close to those where regeneration had occurred. This approach had the added advantage of ensuring that environmental influences on seed production and its rate would be similar on both site types. Thus, if seed were produced in one stand of lodgepole pine, it was likely that seed was also produced in the neighbouring stand, provided it had reached seed production stage (about 20 years) as both would have been subject to similar (seed producing) climatic conditions. Selecting crops in the manner described did not fully ensure that they had produced seed and it did not germinate. However, it was the only available means to identify non-regeneration sites.

Data collection

Site (Table 1) and crop (Table 2) data were recorded for each subcompartment. Sites which were clearfelled some time before they were visited contained little evidence of the understorey vegetation type and weight that was present under the antecedent crop. In those instances the vegetation type and weight of similar clearfelled sites were used. The antecedent crop history was obtained from local forest records. Some historical data proved difficult to obtain due to lack of long-term records.

Table 1. *Site variables recorded.*

Variable	*Category*	*Source*
Aspect	N, NE, E, SE. S, SW, W NW, flat	Survey
Slope	Gentle (0-5°), moderate (6-11°), steep (12-17°)	Survey
Elevation category	1 (<100 m), 2 (100-199 m), 3 (200-300 m), 4 (>300 m)	Ordnance Survey
Exposure	Sheltered, moderate, high	Coillte records[1]
Soil type	Brown earth, blanket peat, etc.	Coillte records[1]
Drainage status	Good, moderate, poor, very poor	Coillte records[1]
Germination surface	Organic, mineral	Survey
Site fertility	High, intermediate, low, variable	Coillte records
Animal trespass?	Yes, no	Survey

[1] Updated during field survey if necessary

Table 2. *Antecedent crop variables recorded.*

Variable	*Category*
Proportion of antecedent crop comprised of lodgepole pine (%)	0, 1-50, > 50
Stocking at clearfell	
level (%)	0-32, 33-66, > 66
volume	m^3ha^{-1}
Initial crop spacing (m)	≤ 2, > 2
Crop thinned?	Yes, no
Yield class ($m^3ha^{-1}an^{-1}$)	< 10, 12-14, > 14
Windthrow	
presence	Yes, no
% of crop area affected	0-32, 33-66, > 66
Age of antecedent crop at time of clearfell	Years
Year of clearfell	
Time of clearfell	1 (February-April), 2 (May-July), 3 (August-October), 4 (November-January)
Harvesting method	Harvester, motor-manual, combination

Table 2. *continued*

Variable	*Category*
Time interval between harvesting and reforestation	1 (< 5 months), 2 (5-8 months) 3 (> 8 months)
Reforestation site preparation used?	Yes, no
Vegetation at clearfell	
volume	Heavy, moderate, light, none
type	Predominant plant species
Brash	
mats	Yes, no
windrowed	Yes, no
volume	Heavy, moderate, light

The presence and location (compass bearing) of adjacent, mature lodgepole pine was recorded at each site. Of the sites visited, the crop age at the time of clearfell ranged from 20 to 51 years, yield class ranged from 6 $m^3 ha^{-1} an^{-1}$ to 16 $m^3 ha^{-1} an^{-1}$. The mean time period between clearfelling and reforestation was 12 months (Table 3).

Table 3. *Current and antecedent crop, and site characteristics at the study sites.*

Variable	*Minimum*	*Maximum*	*Mean*
Area of lodgepole pine regeneration (ha)	0.3	13.9	2.2
Age of antecedent crop at time of clearfell (years)	20.0	51.0	31.5
Yield class of antecedent crop ($m^3 ha^{-1} an^{-1}$)	6	16	12
Time interval between harvesting and reforestation (months)	2.0	24.0	12.1
Proportion of antecedent crop comprising lodgepole pine (%)	0	100	95
% of productive stand area stocked	70	100	90
Initial spacing of antecedent crop (m)	1.5	3.0	1.8
Extent of antecedent crop affected by windthrow (% of area)	0.0	50.0	7.1

Data analysis

Stepwise logistic regression (using GENSTAT™) was used to model the probability of lodgepole pine regenerating naturally (the dependent variable) based on the antecedent crop and site (including treatment) factors (independent variables). Each level of the categorical variables, for example exposure, was represented by a score.

The first step identified individual variables which significantly ($p \leq 0.05$) influenced lodgepole pine natural regeneration. A second logistic model was then fitted to a subset of these factors, arrived at by deleting them one by one until only significant factors were included in the overall model. The final model had the form:

$$p_i = \frac{e^{\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots \beta_n x_n}}{1 + e^{\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots \beta_n x_n}}$$

where:

p_i: probability of lodgepole pine regenerating naturally in subcompartment i,
$\beta^0_{,1\dots n}$: parameters fitted by regression,
$x_1, x_2, \dots x_n$: level of independent variable x_n in subcompartment i.

Results

The second regression model included four factors and an intercept (Table 4). The four factors were: site exposure, drainage status, the percentage of the antecedent crop comprising lodgepole pine and whether or not the antecedent crop had been thinned (Table 5). The residual element of the model was not significant, indicating no significant lack of fit.

Table 4. *Analysis of variance of fitted logistic regression model.*

Dependent variable	*Probability of natural regeneration occurrence*			
Fitted terms	*Constant, exposure, drainage, % of antecedent crop comprising lodgepole pine and whether or antecedent crop thinned*			
Summary of analysis				
	Degrees of freedom	*deviance*	*mean deviance*	*deviance ratio*
Regression	8	76.26	9.5321	9.53
Residual	96	63.29	0.6593	
Total	104	139.55	1.3418	

Table 5. *Parameter estimates for the variables in the natural regeneration probability model.*

Variable	*Parameter estimate*	*Standard error*	*t-value*	*Probability > t*
Intercept	3.43	1.71	2.00	0.045
Exposure				
1. Sheltered	0.00			
2. Moderately exposed	-2.97	1.18	-2.51	0.012
3. Highly exposed	-3.03	1.32	-2.30	0.022
Drainage				
1. Good	0.00			
2. Moderate	-3.14	0.92	-3.43	≤0.001
3. Poor	-5.32	1.20	-4.43	≤0.001
4. Very poor	-4.64	1.36	-3.42	≤0.001

Table 5. continued

Variable	*Parameter estimate*	*Standard error*	*t-value*	*Probability > t*
Proportion of lodgepole pine in antecedent crop				
1. None	0.00			
2. < 50%	1.22	1.66	0.74	0.461
3. > 50%	2.46	1.29	1.91	0.056
Thinned				
1. No	0.00			
2.Yes	1.73	1.05	1.65	0.099

The model showed that thinning increased the probability of natural regeneration after clearfelling (Figure 1). Thinning the antecedent crop almost doubled the probability of natural regeneration occurring on both highly and moderately exposed sites, with moderate drainage and an antecedent crop of 100% lodgepole pine. On sheltered sites with similar

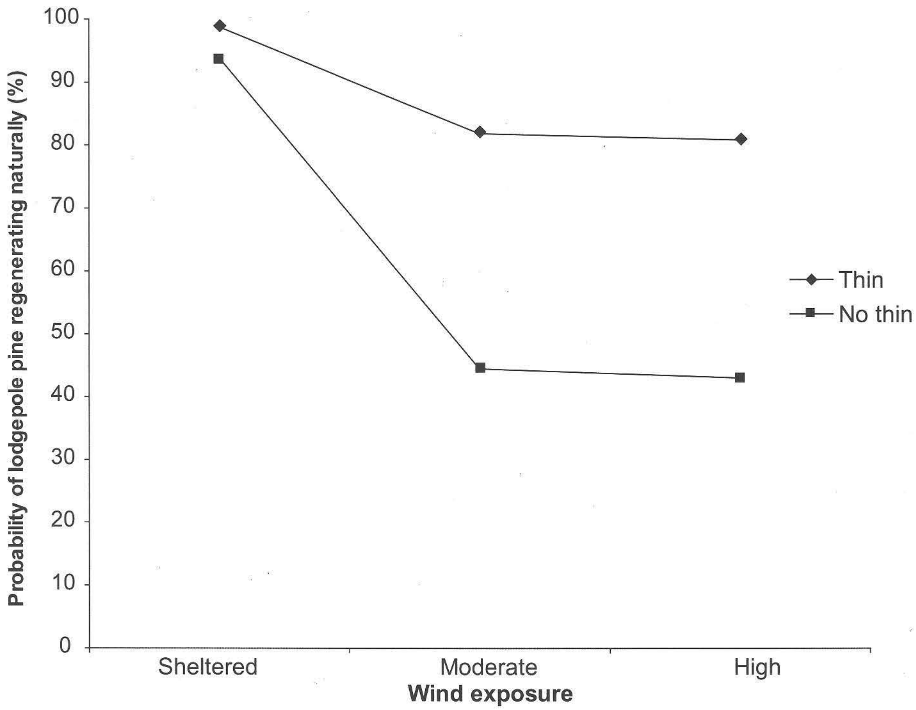

Figure 1. *Combined effect of thinning and wind exposure on the probability of lodgepole pine regenerating naturally (assumes site is moderately drained and antecedent crop comprised 100% lodgepole pine).*

drainage and composition of the antecedent crop, thinning increased the probability of natural regeneration to 99% (with a standard error of ±2%). If the antecedent crop had not been thinned the probability dropped to 93% (with a standard error of ±6%).

In general, better site drainage substantially increased the probability of lodgepole pine regenerating naturally (Figure 2). On well-drained sites the probability of lodgepole pine regenerating naturally was high, irrespective of site exposure.

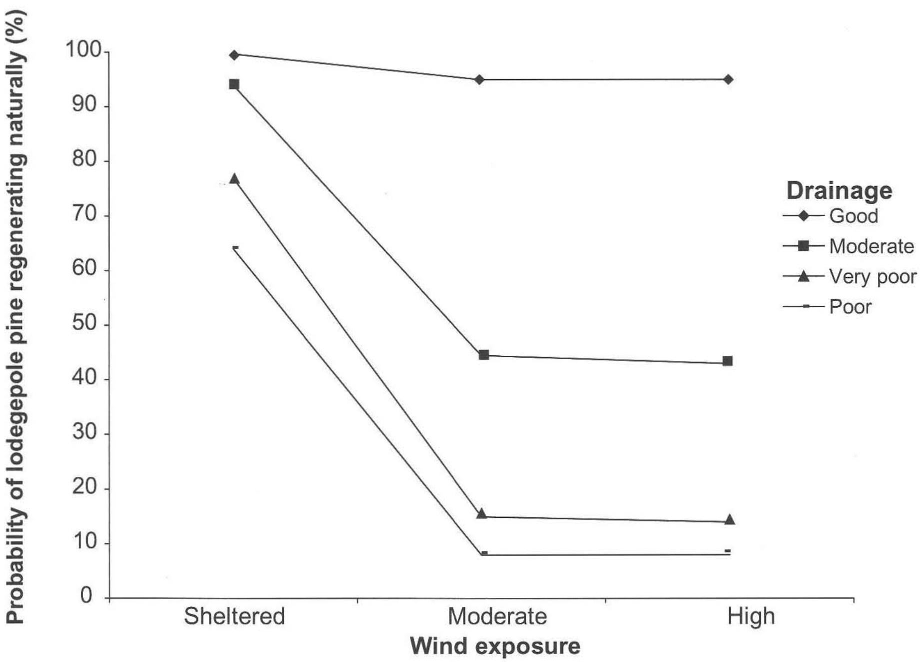

Figure 2. *Combined effects of drainage and wind exposure on the probability of lodgepole pine regenerating naturally (assumes antecedent crop unthinned and comprised 100% lodgepole pine).*

Discussion

Selection of variables in the model

Lodgepole pine was significantly less likely to regenerate on sites that were moderately or highly exposed than on sheltered sites. Stuart et al. (1989) also found that harsh micro-climatic conditions were responsible for limiting the natural regeneration of lodgepole pine. Similarly, Dagg (1998) found that exposure negatively influenced natural regeneration of Sitka spruce. Exposure to wind affects seed germination by influencing both the temperature at the soil surface and the moisture content of the soil. Indeed, Lotan and Perry (1983) found that germination of lodgepole pine seed was significantly affected by climatic conditions. For example, temperature fluctuations between 8°C to 26°C favoured germination. However, greater extremes of temperature are likely on exposed sites. Seedling survival is also influenced by exposure. For example, heat girdling, freezing, frost heaving and moisture deficits all negatively affect survival (Aldhous and Mason 1994) and all are influenced by exposure. Indeed, one advantage of retaining a light slash cover on a clearfelled site is that exposure is reduced. Consequently, environmental conditions for seed germination and seedling survival are likely to be more favourable, with less variation in temperature and soil moisture (Lotan and Perry 1983).

There was little difference in the probability of regeneration occurring between moderately and highly exposed sites. Thus, high exposure did not reduce the probability of natural regeneration occurring below that for moderately exposed sites. This finding would suggest that a moderate exposure is the critical level for natural regeneration to occur. However the assessment of exposure was subjective, and it may be that that the exposure classes were not sufficiently differentiated.

Site drainage status was a significant factor in explaining the occurrence of natural regeneration of lodgepole pine. The probability of lodgepole pine regenerating naturally was significantly greater on well-drained sites as opposed to less well-drained sites. Drainage status is indicative of the condition of the germination surface. On well-drained sites the litter layer would not be expected to accumulate to the same extent as on wetter sites. A thinner litter layer would increase the chance of the roots of germinating seedlings reaching the soil surface. Furthermore seed can lose viability before germination if subjected to prolonged waterlogging, particularly when anaerobic conditions persist (Nixon and Worrell 1999). On poorly-drained sites newly emerging seedlings would be at greater risk of attack from damping-off fungi (Leiffers and Rothwell 1986). There may also be a greater diurnal temperature range on poorly-drained sites (Garman 1955). However, very poorly-drained sites were more likely than poorly-drained sites to support natural regeneration. While this contradicts the overall trend, it may be explained by the fact that most very poorly-drained sites were peat sites. Peat sites readily support natural regeneration, because of the relatively slow rate at which competing vegetation recolonises them (Brown and Neustein 1974).

Thinning prior to harvest also significantly influenced the likelihood of natural regeneration of lodgepole pine occurring after the stand was clearfelled. There is strong evidence that the development of large tree crowns following thinning promotes seed production (Wenger 1954, Allen and Trousdell 1961). Thinning also increases the amount of light reaching the forest floor, which increases soil temperature, which in turn increases the rate of germination (Nixon and Worrell 1999).

Natural regeneration of lodgepole pine was also significantly affected by the proportion of lodgepole pine in the antecedent crop. Where lodgepole pine comprised at least 50 % of the antecedent crop, natural regeneration was more likely to occur than on sites with less than 50 % lodgepole pine. This is most likely attributable to a higher overall lodgepole pine seed production rate in antecedent crops with higher proportions of the species.

A number of site factors which were hypothesised to influence the occurrence of natural regeneration of lodgepole pine were not significant. Soil type was one. It is likely that the effects of soil type were masked by the other factors such as exposure and drainage. Soil type is closely associated with both of these factors. Crop age does determine the occurrence of seed production. However, as this study focused on seed germination and survival, only those clearfelled crops which had reached the age of seed production were included. Thus it may be that once seed production had begun in these crops there was little further increase with age.

Application and limitations of the model

The model answers some questions about spontaneous natural regeneration of lodgepole pine. Combined with local knowledge it should allow forest managers to predict with greater certainty the occurrence of natural regeneration following the clearfelling of lodgepole pine crops. For example, on poorly-drained (non peat), highly-exposed sites, natural regeneration of lodgepole pine has only a 10% chance of occurring (even if seed were available). On the other hand, natural regeneration is highly likely on sheltered and well-drained sites (assuming that seed is available). The model also provides information as to how to increase the likelihood of lodgepole pine regenerating naturally. For example, thinning not only increases the probability of seed production but also the probability of successful germination and survival. Improving drainage will also increase the chance of natural regeneration occurring.

The model is based on a limited number of sites. The standard error of prediction for some categories of the variables reflect this. It is also important to note that a limited number of silvicultural activities were recorded, and some of these, such as the level of brash remaining on the site, were shown in other studies to significantly influence the occurrence of natural regeneration of lodgepole pine (Cochran 1973). No long-term record of silvicultural or harvesting activities, such as the method and time of harvesting had been maintained for the sites in the study. Similarly, the treatment of slash was not recorded. Thus, it was necessary to rely on records that some foresters retained or on their recollection of these activities. As a result, in some instances information on these site activities was not available.

Conclusions

The increased emphasis on alternative silvicultural systems to clear cutting has increased interest in reforestation using natural regeneration. Recent studies have increased the available information on factors which influence its occurrence (Nixon and Worrell 1999, O'Leary 2000). Increased knowledge and the ability to more accurately predict the occurrence of natural regeneration should encourage foresters to seriously consider using natural regeneration as an alternative to planting on certain sites. Further study is required however, to more fully understand the factors favouring the occurrence of natural regeneration.

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