Factors affecting the establishment of natural regeneration of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) in Ireland

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Summary

In Ireland, natural regeneration of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) is becoming common on reforestation sites, especially in the eastern part of the country. The management of this phenomenon is relatively new to many foresters here, as its occurrence is often sporadic and difficult to predict accurately. Due to this novelty, its management can often be difficult. The main objective of this study was to examine the influence of various site factors on the establishment of natural regeneration, in order to make it more predictable for forest managers. It was also intended to examine the extent of natural regeneration in the study area, which was confined to State owned forests in Counties Wicklow and Dublin. Results showed extensive regeneration on sites with a previous crop of Sitka spruce. Over 50% of planted sites had an adequate cover of natural regeneration. It was found that poor soils, especially those with a peat layer which only sustain a thin cover of ground vegetation, regenerated more readily than richer soils such as brown earths or gleys. Good seed years were also shown to have a significant impact on the establishment of natural regeneration, especially on sites which are recolonized quickly by very dense vegetation. Some shade appears to favour the development of natural regeneration, probably by protecting seedlings from environmental extremes. An examination of ground cover types showed that Sitka spruce regenerates most readily on low moss and litter and that regeneration generally does not occur in areas with dense grass, rush or brash. The main conclusion of this study is that, while there are many factors which influence the establishment of natural regeneration, it can be predicted with a fair degree of accuracy if all important variables are taken into account.

Introduction

Natural regeneration of Sitka spruce in Ireland

Forest and wooded areas now occupy 8% of the total land area of Ireland. The dominant species is Sitka spruce, occupying 57% of State owned plantations (Anon., 1995). This figure is rising, with Sitka spruce currently representing almost 80% of the species planted by the State.

As clearfelling usually occurs after 40 years, only a comparatively small percentage of the total forest area has now reached the reforestation stage during which natural regeneration might be expected. This is thought to be the main reason why large scale natural regeneration was almost unknown in commercial forestry in Britain and Ireland until the last decade. Several other climatic and biological reasons for the limited extent of natural regeneration have also been suggested. These include cool and humid summers, late spring frosts, strong winds, and the 'temperateness' of the Irish climate, which often sustains populations of seed predators and favours weed growth (Brown and Neustein, 1974).

In the past 10 years, as an increasing number of Sitka spruce stands in Ireland are reaching maturity and are being harvested, the phenomenon of natural regeneration has begun to occur sporadically. While it often appears in localized areas where there are small breaks in the canopy, whole stands up to several hectares in area have regenerated naturally after clearfelling. This has been reported especially in Co. Wicklow (Murphy *et al.*, 1991).

Natural regeneration usually occurs irregularly, often making it necessary to replant sites upon which it is the main form of crop establishment. Another disadvantage of natural regeneration is its frequent high density, with densities of up to 120,000 seedlings/ha recorded in Co. Wicklow (Moore, 1991). Research has shown the importance of reducing stocking levels by selective respacing to the currently recommended planting density of 2,500 plants/ha, in order to produce useful volume assortments at the end of the normal rotation. The current standard procedure of respacing is, however, quite laborious, resulting in costs as high as £1,000/ha. It involves thinning the dense pockets of natural regeneration when the trees are at a height of two to three metres, using a combination of a modified harvesting/cleaning head and a clearing saw. Work is also currently being carried out on the potential management of Sitka spruce regeneration using herbicides (Ward, 1994).

Because of these problems, forest managers prefer artificial methods of crop establishment. However, as an increasing number of Sitka spruce stands are being felled, natural regeneration will inevitably become more common. This should not necessarily be seen as a threat to present silvicultural practice in Ireland, but as a possible opportunity to make crop establishment more attractive, in both an economic and environmental sense.

Natural regeneration and its use in forestry

Natural regeneration is defined as the reproduction of a stand by means of the seed from the original trees, standing, felled or residual (McNeill and Thompson, 1982). The most important factors to be considered when pursuing a natural regeneration programme include the following.

Cost: Natural regeneration is not without cost. The level of these costs depends on whether preparatory management of the site or previous crop is required to achieve adequate regeneration, or, subsequently, whether respacing is required to manage overly dense crops.

Adaptation to the environment: Natural regeneration, at least initially, is often better adapted to the site than planted stock. Root form may also be better, although the regenerated crop may become unstable after early respacing. It is often felt that naturally regenerated crops are visually attractive due to their lack of uniformity. The opposite, however, may by the case, particularly in very dense stands.

Crop quality: Plantations can be established at desired densities while naturally regenerated crops often require some form of either density control or filling-in to attain the required stocking level. High initial densities reduce the proportion of juvenile wood, promote early self-pruning and reduce knot-size, all of which increase the potential value of the crop.

Management: In Ireland, foresters are used to clearfelling and replanting and generally do not wish to work with natural regeneration unless absolutely necessary. This is largely due to the lack of predictability of natural regeneration, with foresters preferring to retain control by selecting the cut/replant option. Natural regeneration, however, has long been used in commercial forests around the world. It accounts for 52% of reforestation in the original nine countries of the EC, but less than 1% in Britain and Ireland (Kroth *et al.*, 1976), where it has generally been restricted to areas with a low commercial priority. Although the precise figure for Ireland is unknown, natural regeneration has certainly risen substantially since 1976. An area of 600 ha has been noted for Coillte Teo.'s Region 1 alone (Murphy *et al.*, 1991).

Stages in the development of natural regeneration of Sitka spruce

It is generally accepted that the process of natural regeneration passes through several biologically and temporally distinct stages, *viz.* seed production, seed dispersal, seed survival/germination, and seedling survival (Clarke, 1992; Howells, 1966). Stages in the development of natural regeneration of Sitka spruce are detailed in Table 1.

Study trial

Objective

While realizing the limitations involved, the main aim of this project was to examine some of the major factors affecting the establishment of natural regeneration of Sitka spruce on recently clearfelled sites in Counties Wicklow and Dublin.

Table 1. *Stages in the development of natural regeneration of Sitka spruce.*

Stage	*Factors*	*Reference*
Seed production	Sexually mature at 20-25 years, maximum cone production at 35. Heavy seed production periodically (generally every 4-5 years). Amount of seed produced directly related to the mean July temperature of the previous year.	Brown and Neustein, 1974 Harris, 1991 Pfeifer, 1991
Seed dispersal	Seed fall generally between October and May. Numbers of seed released may be very large (up to 20 million/ha under canopy). Dry easterlies often important in seed dispersal. Almost all seed fall within 80 m of parent crop.	Mair, 1973 Ruth and Harris, 1979
Seed survival and germination	Germination survival rate may be as low as 2%. Little storage of seed in the litter after one summer. Good seed bed depends on germination surface, temperature, light, moisture and ground vegetation.	Clarke, 1992 Howells, 1966
Seedling survival	Most losses in first winter. Main causes include predation, green spruce aphid and heat/drought. A three year limit is generally allowed for seedling development.	Murphy *et al.*, 1991 Robertson, 1976

Site selection

For the purpose of this study, site selection concentrated on an area incorporating 13 forests in Counties Wicklow and Dublin, from which most of the reports of natural regeneration originate. Site eligibility was governed by the following criteria.

- Clearfelled during one of the three seed years 1988/89, 1989/90 or 1990/91. A seed year was defined as the period from seed ripening in September, to the end of seed germination during the following June.
- Minimum area of one hectare.
- Previous parent crop made up of a pure stand of mature (at least 35 years old) Sitka spruce.
- Closed canopy status prior to clearfelling.
- Brash left untreated after clearfelling, thereby ensuring that the seed content of the field layer remained undisturbed.
- No herbicides applied to the site after clearfelling.

Only 21 of the sites examined fulfilled the above conditions. These sites were then subjected to a field examination to facilitate further selection.

As it was intended to analyse at least part of the data using Analysis of Variance (ANOVA), a randomized block design was required. Accordingly, equal sized areas varying only in respect to seed year and soil type were selected. It was decided to assign the five different soil types as 'blocks' and the three seed years as 'treatments', in order to comply with the necessary conditions for an ANOVA. It was assumed that the treatments (seed years) were distributed randomly over the blocks (soil types). As one site had to be examined for each soil type and seed year, a total of 15 sites was required. However, only 13 suitable site could be found, with the category 'deep peat' represented in only one of the three seed years (1990/91).

Measurements

Data collection was carried out in two separate phases during November and December, 1992. The following measurements were taken for each $2m^2$ sample plot.

Phase 1: Density of natural regeneration, dominant ground cover type, microrelief and shelter status, measured over the entire sample plot.

Phase 2: Seedling age, dominant ground cover type, microrelief and shelter status, carried out on the seedling nearest to the plot centre.

Date analysis

Where ANOVA and f-tests demonstrated significant treatment effects, it was necessary to compare each treatment mean with every other treatment mean to determine which were significantly different from each other. Duncan's Multiple Range Test was adopted during this procedure.

Results

Extent of natural regeneration

The extent of natural regeneration was assessed in terms of seedlings/ha and percentage distribution (Table 2). Adequate distribution of natural regeneration was defined as being the equivalent of at least one seedling present in every second sample plot, corresponding to the standard planting density of 2,500 plants/ha.

The average density was 22,800 seedlings/ha. However, this mean is distorted by the extraordinary high density on the mineral site from 1990/91 (228,500 seedlings/ha). If this figure is excluded, the mean is significantly lower, lying at 5,750 seedlings/ha.

Table 2. *Natural regeneration (seedlings/ha) and its distribution (in brackets) (%) on the 13 sites examined.*

			Soil type		
Seed year	*Mineral*	*Peaty gley*	*Shallow peat*	*Peaty podzol*	*Deep peat*
1988/89	0 (0)	2,500 (36)	300 (8)	9,400 (100)	Site not available
1989/90	300 (8)	1,800 (64)	20,800 (84)	2,700 (68)	Site not available
1990/91	228,500 (100)	1,800 (40)	3,200 (96)	2,200 (52)	18,300 (100)

While only one site had no natural regeneration at all, three of the 13 sites examined had a 100% cover. The average cover was 52%. A comparison of the extent of regeneration in each case shows that the expression of density alone can be quite misleading. For example, the density of natural regeneration on sites clearfelled in 1990/91 is eight times higher than on those felled in 1989/90, while the percentage cover is only 1.4 times higher.

Planting and natural regeneration

Some of the sites examined had already been planted. Planted sites had a percentage cover of natural regeneration ranging from 0 to 100%, and averaged at 52.8%. Natural regeneration on sites left unplanted ranged from 40 to 100%, averaging at 88.6%.

Examination of factors affecting the occurrence of natural regeneration

Each factor is treated individually in the following presentation of results.

Soil type

ANOVA was carried out to examine the effect of the five different soil types included in the survey on total natural regeneration (expressed as percentage cover). The f-test showed no significant difference at the 95% confidence level. Despite the failure of the results to illustrate a significant difference, the means did show an interesting trend, with a general increase in natural regeneration on increasingly poorer soils (Figure 1).

Seed year and seed source

While giving some indication of seed production during those years, the extent of natural regeneration on the sites felled during the three seed years can be

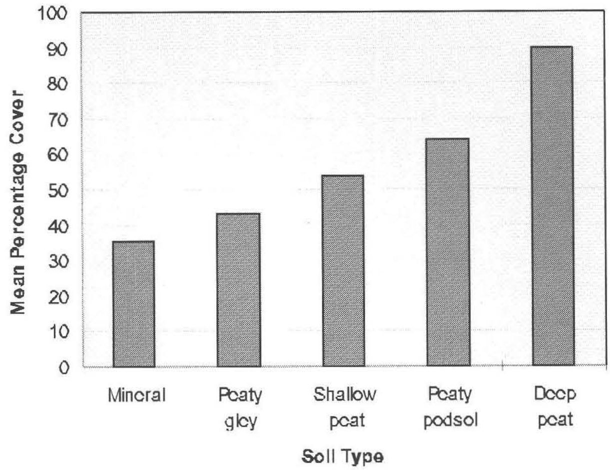

Figure 1. *Mean percentage cover of natural regeneration for each of the five soil types.*

slightly misleading, as natural regeneration does not always date back to the year in which the parent stand was felled. The examination of the age distribution of the total natural regeneration observed emphasizes this point (Table 3).

Table 3. *Age distribution of total natural regeneration.*

Age yr	*Density seedlings/ha*	*% of total*
>4	359	1
4	949	2
3	1,553	4
2	29,691	66
1	12,321	27

Sixty-six percent of all natural regeneration encountered was two years old. This suggests that it was produced in 1990/91, which is known to have been a good seed year. Only four and two percent of the total regeneration, on the other hand, were three and four years old respectively, confirming very poor seed production in 1989/90 and 1988/89.

The results illustrated in Table 3 indicate that it cannot always be concluded that most of the natural regeneration on a clearfelled site originates from seed shed by the parent stand in the seed year before felling. On sites that did not receive substantial amounts of seed from the parent stand prior to felling, i.e. sites harvested in 1988/89 and 1989/90, but which nevertheless had large amounts of natural regeneration, seed must therefore have been blown in from nearby mature stands of Sitka spruce. In the data analysis, although the 1990/91 seed year had a substantially higher value than either of the other two years, the effect was not significant.

Effect of microrelief, shelter status and ground cover types

To help clarify the effect of microrelief, shelter status and ground cover types on natural regeneration, a regeneration affinity index (RAI) was used. This index was calculated for each of the three variables by dividing its percentage occurrence on the seedbed by its percentage distribution on the site as a whole. For example, the microrelief category 'stump base' was encountered on 15.1% of all seedbeds, but on only 7% of the total area examined, giving a RAI of 2.16 for this category.

A value of one indicates no special affinity for natural regeneration. If the index value is less than one, the distribution of natural regeneration is below average. A RAI greater than one, on the other hand, indicates a greater than average distribution of natural regeneration. These values were then classed as described in Table 4.

Table 4. *Regeneration affinity index (RAI) and corresponding regeneration affinity class.*

RAI	*Regeneration affinity class*
>1.5	NR-friendly
0.5-1.5	NR-indifferent
<0.5	NR-inhibiting

Microrelief: Microrelief was examined for all 13 sites together (treated as a single block). Five categories of microrelief were defined. Table 5 lists these categories, together with their respective distribution and affinity for regeneration. The raised microrelief provided by either mounds or stump bases resulted in natural regeneration-(NR-)friendly classes, while all other categories were indifferent to regeneration.

Table 5. *RAI, regeneration affinity classes and percentage distribution for microrelief, listed in order of increasing RAI.*

Microrelief category	*RAI*	*Regeneration affinity class*	*Percentage distribution*
Flat/gentle slope	0.7	NR-indifferent	59.9
Depression	0.8	NR-indifferent	2.2
Moderate/steep slope	1.1	NR-indifferent	26.9
Mound	2.2	NR-friendly	4.0
Stump base	2.4	NR-friendly	7.0

Shelter status: For the examination of the effect of shelter status on the extent of natural regeneration, all sites were, as with microrelief, treated as a single block, as seed year and soil type do not have a very important impact on most of the seven categories concerned. Results are given in Table 6.

The three main shelter status categories, 'heavy vegetation', 'light brash' and 'heavy brash', together cover nearly 79% of the area examined. Heavy brash and heavy vegetation allow practically no natural regeneration, since they do not allow any light to reach the ground surface. The categories 'light brash', 'stump base', 'open ground' and 'sheltered by boulders and logs', on the other hand, are very receptive to natural regeneration.

Table 6. *RAI, regeneration affinity classes and percentage distribution for shelter status, listed in order of increasing RAI.*

Shelter status category	*RAI*	*Regeneration affinity class*	*Percentage distribution*
Heavy brash	0.0	NR-inhibiting	17.1
Heavy vegetation	0.0	NR-inhibiting	29.8
Light vegetation	0.7	NR-indifferent	12.4
Light brash	1.9	NR-friendly	21.4
Stump base	2.1	NR-friendly	7.3
Open ground	2.8	NR-friendly	7.7
Sheltered by boulders and logs	3.2	NR-friendly	4.3

Dominant ground cover types: Eleven dominant ground cover types were classed (Table 7).

Table 7. *RAI, regeneration affinity classes and percentage distribution for dominant ground cover types, listed in order of increasing RAI.*

Shelter status category	*RAI*	*Regeneration affinity class*	*Percentage distribution*
Other	0.0	NR-inhibiting	1.2
Heavy brash	0.0	NR-inhibiting	19.4
Rush	0.0	NR-inhibiting	4.9
Heavy grass	0.0	NR-inhibiting	28.6
Light grass	0.6	NR-indifferent	10.0
Heather	0.7	NR-indifferent	3.3
High moss	1.5	NR-indifferent	0.6
Bare	1.9	NR-friendly	2.9
Rotten wood	2.1	NR-friendly	1.3
Litter	2.9	NR-friendly	9.6
Low moss	3.0	NR-friendly	18.2

NR-inhibiting dominant ground cover types: NR-inhibiting ground cover types encountered, ranked in decreasing order of percentage distribution, were heavy grass, heavy brash, rush and others.

1. Heavy grass: Heavy grass, occurring on 28.6% of the total area surveyed, was the most abundant ground cover type. It normally completely covered these areas with a dense grass sward, leaving little or no likelihood for possible Sitka spruce seedlings to compete. The main species encountered on nearly all sites were velvet bent (*Agrostis canina*) and common bent (*A. tenuis*), with wavy hair (*Deschampsia flexuosa*), Yorkshire fog (*Holcus lanatus*) and purple moor grass (*Molinia caerulea*) occurring on some sites only.
2. Heavy brash: Slightly less than 20% of all sites examined were covered by heavy brash, which was defined as being a cover of lop-and-top heavy enough to prevent light from penetrating to the ground surface. No natural regeneration was observed on this ground cover type.
3. Rush: The species encountered were mostly soft rush (*Juncus effusus*), with smaller species such as jointed rush (*J. articulatus*) and sharp-flowered rush (*J.*

acutiflorus) occurring occasionally. It generally formed thick tufts, thereby suppressing any possible natural regeneration.

4. Others: This category represents the very small percentage of the total area covered by bracken (*Pteridium aquilinum*) and gorse (*Ulex gallii* and *U. europaeus*). While no natural regeneration was observed on these plots, they were considered too few to indicate the affinity of these ground cover types for natural regeneration.

NR-indifferent dominant ground cover types: NR-indifferent ground cover types encountered, ranked in decreasing order of percentage distribution, were light grass, heather and high moss.

1. Light grasses: Ten percent of the total area was covered by light grass, defined as having only a sparse cover and which did not classify as a sward. The species encountered were the same as for heavy grass. With a RAI of 0.6, light grass is described as being NR-indifferent. It generally occurred in more or less similar quantities on all sites which had not already been colonized by heavier vegetation.
2. Heather: Although only 3.3% of the total area examined had heather (*Calluna vulgaris*) as the dominant ground cover type, the percentage distribution on all 13 sites shows an increase with time as well as a strong presence of heather on the more peaty sites. Bilberry (*Vaccinium myrtillus*), which has similar site requirements to heather, was frequently associated with the latter. The RAI of heather (0.7) indicates only a slight inhibiting effect on the extent of natural regeneration.
3. High moss: Since other authors, having examined the effect of vegetation on natural regeneration of Sitka spruce, mention varying regeneration success on moss surfaces, depending on thickness, it was decided to differentiate between high and low moss. *Polytrichum commune*, *Sphagnum* species and *Mnium hornum* were encountered, all of which are high mosses. Since these only cover 0.6% of the total area surveyed, their RAI of 0.5 must be treated with some caution. The considerable difference between the regeneration success on low and high moss does, however, indicate that the latter grouping is less suitable as a seedbed for Sitka spruce germinants.

NR-friendly dominant ground cover types: NR-friendly ground cover types encountered, ranked in decreasing order of percentage distribution, were low moss, litter, bare and rotten wood.

1. Low moss: Slightly less than 20% of the areas surveyed had a ground cover of low moss. The main species encountered were *Pleurozium schreberi*, *Hylocomium splendens*, *Plagiothecium undulatum* and *Hypnum cupressiforme*. Low moss has a RAI of 3.0, the highest of all ground cover types examined.

2. Litter: Nearly 10% of the areas surveyed had litter as a ground cover. A litter site was defined as having a surface ground layer consisting mainly of undecomposed Sitka spruce needles. The RAI of this ground cover type (2.9) is nearly as high as that of low moss. The depth of the litter surfaces encountered ranged from 1 cm to 20 cm, with the best regeneration found on litter depths of 1 cm to 7 cm.
3. Bare ground: Only 3% of the total area examined had no ground cover at all. Peaty soil types (peaty gley, peaty podzol and deep peat) show the highest incidence of bare ground.
4. Rotten wood: The category 'rotten wood', which was represented by only 1.3% of the total area, was included in the survey mainly because of its importance as a seedbed in the natural regeneration of Sitka spruce within its natural range. The high RAI of 2.1 confirms its suitability as a seedbed for natural regeneration.

Collective analysis of the dominant ground cover types

From the above, it is evident that the effect of the 11 individual dominant ground cover types on natural regeneration can vary considerably across a site. When examining their collective effect on the natural regeneration of an individual site, it would be useful if the site could be classed as a whole using only one figure. For this study, this was carried out by expressing the sum of the regeneration affinities of the individual ground cover types multiplied by their fractional representation on the site as an average regeneration index.

All soil types show a decrease in regeneration affinity over the three year period, although the rate of this decrease varies considerably on the different substrates. The richer soil types, mineral, shallow peat and peaty gley, tend to lose their affinity for natural regeneration more quickly with time than the poorer peaty podzols, which are still highly conducive to natural regeneration, even after the fourth growing season following clearfell.

Discussion

It must be borne in mind that the results of this study relate specifically to conditions in the Wicklow Mountains and therefore must be applied circumspectly to other areas where the pattern of climate may be different. Admittedly, the forester has little or no direct control over many of the factors studied. Nevertheless, the effects of such factors permit tentative conclusions to be reached regarding the possibility of naturally regenerating Sitka spruce.

Soil type

The main finding with respect to soil type was that natural regeneration seemed to be more prolific on the poorer soils, especially those with a distinct layer of peat. This tendency can most probably be attributed to the vegetation which recolonized the various soil types. Both Lees (1969) and Brown and Neustein (1974) confirm this, stating that poorer soils, especially peats, are recolonized by vegetation more slowly than fertile brown earths and surface water gleys (mineral soils), permitting at least two year germinants to become established. In the case of deep peats, regeneration will be more successful where purple moor grass does not colonize first.

Seed year, seed source and seed viability

Of the three seed years examined, 1990/91 was exceptionally good, while 1988/89 and 1989/90 were quite poor. This was a fortunate coincidence, since it not only allowed a comparison between regeneration success on sites felled during poor and very good seed years, but also allowed an examination into the effect of a good seed year on sites clearfelled up to two years previously. Since seedling age and distance to the nearest mature stands of Sitka spruce had been recorded, certain conclusions could be drawn concerning seed dissemination and seed viability.

An examination of seedling age in this survey showed that a surprisingly high proportion (27%) of the total natural regeneration encountered was one year old. While one would normally expect it to have germinated from seed produced in 1991/92, this is practically impossible, given the period's status as an extremely poor seed year. The only remaining possibility is that some of the large quantities of seed produced in 1990/91 retained their viability into the second growing season following clearfell. This would contradict the currently accepted view that Sitka spruce seed normally loses its viability after the first growing season following seed fall.

Since most of the one year old seedlings were found on sites felled in 1990/91 (the good seed year), it seems plausible that cones still hanging on the brash after the felling operation may have provided a protected environment for large quantities of seed, and, in this way, increased the chances of seed retaining viability into the following growing season. In conclusion, it must be said that, while results strongly indicate that seed can retain its viability into the second growing season following clearfell, the whole area of seed viability requires further research.

Microrelief

Results of this survey indicate that only the categories 'stump base' and 'mound' are receptive to natural regeneration. The affinity of the former might be explained by their moisture conserving microrelief (between old tree roots), as well as their shading effect which provides protection from dessication during dry spells. The suitability of mounds is of an entirely different kind, since they expose seedlings to climatic extremes rather than protecting them. It seems that this category favours seedlings by providing them with a raised seedbed which is less susceptible to quick colonization by vegetation, while at the same time allowing better soil aeration and warmth.

Shelter status

Results of this survey showed that all categories providing some shelter, with the exception of 'light vegetation', were very receptive to natural regeneration. 'Light vegetation' showed a slightly less than average distribution of regeneration. Surprisingly, 'open ground' proved quite suitable as a seedbed. This can possibly be explained by the absence of competing ground cover on areas belonging to this category. In other words, in the case of 'bare ground', the effect of ground cover seems to override shelter status. Not surprisingly, the categories 'heavy vegetation' and 'heavy brash' show practically no regeneration, due to the total shade imposed on the ground surface.

Ground cover types

The comparative germination success and seedling growth of Sitka spruce on the various ground cover types examined in this investigation generally agree with results of previous works. The main ground cover types are discussed below, on an individual basis generally in order of decreasing regeneration affinity.

The results of the survey show quite clearly that low moss is very receptive to natural regeneration, confirming findings by Scarratt (1966) and Howells (1966). The advantage of a thin layer of moss seems to lie in its capacity to conserve a high moisture level at the ground surface, while at the same time allowing young germinants to penetrate it without great difficulty. It is interesting to note that areas of high moss seemed to have a lower affinity for natural regeneration, again confirming the results of Howells (1966). This is probably due to difficulties in penetrating the thicker moss layer, especially in dry conditions.

Litter also shows a very high affinity for natural regeneration. This result seems to contradict much of the literature which depicts litter as being a particularly unfavourable seedbed on open sites, mainly due to its poor moisture retention capacity. The wet conditions encountered on the sites examined seemed to neutralize the tendency of litter to drain water quickly. Howells (1966) and Scarratt (1966) report similar results for sites examined in North Wales, concluding that, under wet conditions, litter can be a very suitable germination surface.

While rotten wood only occurred on a small percentage of the total area, it showed a high receptivity to natural regeneration. This has been confirmed by several authors, especially those examining the regeneration of native Sitka spruce stands in the Pacific North West.

Bare ground, which must be distinguished from the shelter status category 'open space' (including open areas covered by a moss or litter layer), also showed a relatively high regeneration affinity. This is expected, as such sites are free of competing vegetation and facilitate quick root penetration. Ruth and Harris (1979) warn, however, that seedbeds consisting of bare ground, especially peats, are prone to drying out very quickly during sunny periods. This danger would seem to confine the suitability of bare ground as a seedbed to wet areas.

The investigation showed a slightly below average distribution of natural regeneration on heather/bilberry surfaces. Clarke (1992) quotes some authors who say that this vegetation type is acceptable for regeneration establishment, while others consider it quite unsuitable.

Only on one sample plot was a naturally regenerated seedling found in a heavy grass sward, suggesting a strong inhibitory effect of heavy grass surfaces on natural regeneration.

Heavy brash and rush allowed no natural regeneration to develop in the areas examined. In the case of heavy brash, Dannatt and Davies (1970) confirmed that, with too much lop-and-top, adequate regeneration cannot be expected. Both of these categories obviously allow insufficient light to facilitate regeneration establishment to reach the ground surface.

The combined effect of ground cover types on the establishment of natural regeneration over a period of time is important when assessing the likelihood of its development on certain sites. This recolonization of sites was shown to vary considerably depending on soil type. Poorer soils such as peaty podsol and probably also deep peat (only examined on one site) were recolonized very slowly, while mineral and gley soils lost their receptivity very quickly. In conclusion, it would seem that the rate of recolonization of reforestation sites by ground vegetation can vary substantially, depending on site conditions, especially soil type and ground cover previous to felling.

Conclusion

It is hoped that this study has given an indication of the complexities of the phenomenon of Sitka spruce natural regeneration. Although the following are given as the most important indicators of future natural regeneration on a given site (listed in order to decreasing importance), they are open to challenge and may be proven incorrect.

- A parent stand of Sitka spruce.
- A poor soil type (especially with a thick layer of peat) which does not seem receptive to heavy vegetation.
- A good seed year at the time of clearfelling.
- Mature Sitka spruce stands nearby.
- Advance regeneration already identified, especially on the site perimeter.
- Moderate/steep north facing slope.

If several of these factors apply to a reforestation site, the likelihood of future natural regeneration is quite high. It should, therefore, be left unplanted for at least one year. Each site must be treated separately and no rigid rule for the length of the regeneration period should be applied.

Foresters should be encouraged to become more observant in the forest and to keep better records of site factors and stand histories, e.g. exact clearfell periods, affecting natural regeneration. Careful observations helps a forester build up a great deal of local information about regenerating stands. Good basic knowledge from their local area can be obtained by foresters observing such things as the nature of regeneration on roadsides/stand edges, the timing following disturbance, and the nature and distance of the seed source. These observations can often be demonstrated or even tested using simple permanent plots. If properly documented, these plots can form an invaluable source of further information both to that forester and to others. This information could prove extremely useful, given the likelihood that the occurrence and management of natural regeneration will become an increasingly important factor in Irish forestry over the coming years.

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