Regeneration of red and silver beech: How important is the size of harvested area?

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Abstract

Successful regeneration is a critical part of sustainable management of indigenous forest. Although current legislation allows a range of cut sizes within a management plan, in practice, managers tend to gravitate to a narrow span of harvest areas and use a particular extraction method. Here, we analyse 8 years of data from experimental coupe and group-selection harvesting trials in mixed red-silver beech forest to compare and contrast the effect of harvest area on light availability, soil conditions and beech regeneration. Coupe and group selection subplots differed initially in that group selections tended to be on higher landform positions (more on ridges and spurs, less in gullies) and have higher potential solar radiation than coupes. After harvesting coupe subplots had higher maximum water fern frequency, soil Ca, soil pH, soil mineralisable N, mean litter depth, and exotic plant species occurrence than group-selection subplots. All of these variables appear to be directly related to the size of the harvested area. Coupes appear to provide the best conditions for regeneration of red beech, whereas group selection harvests provide the best conditions for silver beech. This follows expectations about how a shade-intolerant (red beech) versus a shade-tolerant (silver beech) tree species would be expected to respond to different sizes of canopy gap openings. Our results imply that, all else being equal, a range of sizes of harvested areas will promote a more mixed-species forest, whereas uniform sizes of harvested areas are likely to favour one species over the other.

Introduction

Successful regeneration is a critical part of sustainable forest management. The 1993 indigenous forestry provisions amending the Forests Act 1949 require harvested areas in beech forest to be no greater than 0.5 ha. Further, *regeneration must have reached a predominant height of 4 m and a stocking of the harvested species equal to or greater than pre-harvest levels before further adjacent harvesting can occur* (Benchmark 2.2.1.13; MAF 2002). Although current legislation allows a range of cut sizes within a management plan, in practice, managers tend to gravitate to a narrow span of harvest areas and use a particular extraction method.

Current harvesting in beech forests tends to be from either group selections, small coupes of less than 0.1 ha, patch cuts of ~0.5 ha, or shelterwood systems. Although such systems have been in use for more than 10 years and have generated considerable controversy (see Mason 2000), few data exist on how each affects the regeneration of harvested species.

It is well known that in natural forests canopy gap size influences light and soil parameters that in turn influence sapling growth and hence sapling density (e.g. Denslow 1980; Runkle *et al*. 1995). Wardle (1984) describes red beech as a light-demanding species that tends to form even-aged structures initiated by stand-scale disturbance, whereas the more shade-tolerant silver beech tends to form mixed-aged stands and does not require the stand to be extensively opened to regenerate. In natural mixed red-silver beech forests, red beech saplings only become more numerous than silver beech saplings in the very largest natural gaps (>0.04 ha; Stewart *et al*. 1991). It follows that different sized harvest areas in mixed beech forest will be expected to result in different compositional trajectories.

Here, we analyse 8 years of data from experimental coupe and group-selection harvesting trials in mixed red-silver beech forest. Previously we have presented the consequences of small coupe harvesting for the growth and mortality of residual trees (Wiser *et al*. 2005). The maintenance of forest structure and composition, however, also depends upon contrasting regeneration patterns among species. In this article we compare and contrast the effect of harvest area on light availability, soil conditions and beech regeneration.

Trial sites and measurements

From 1994 to 1998, a series of silvicultural trials were established in mixed red-silver beech forest near Maruia, Westland. One goal was to compare the impacts of three treatments on beech forest: unharvested forest, harvesting with small coupe (<0.2 ha) and group-selection (~4 large trees removed) silviculture. Permanent transects were established across the harvested area and periodically remeasured to assess the impacts of harvesting on a range of ecological values. A contiguous series of 0.5 m × 1 m subplots (used to determine plant composition and seedling density by species) and 10 m × 10 m subplots (used to determine sapling density by species) were centred along the transect lines. Near Station Creek, transects were established on six coupes (ranging from 60 to 80 m long) and three controls in unharvested forest (50 m long). Three kilometres away near Coal Creek, nine paired sets of 40-m transects (one crossing a group-selection harvest and one in nearby unharvested forest) were established. Transects have been recensused annually or bi-annually since establishment.

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To provide a measure of regeneration success of both red and silver beech for each 100-m^2 subplot, we determined the maximum seedling and sapling density (by species) recorded in that subplot since harvesting. Regeneration progresses at different rates in different parts of the areas harvested, and where growth rates are especially rapid, seedling and sapling density is beginning to decline because of onward growth and self-thinning. Use of maximum densities from seedling or sapling subplots prevents self-thinning and onward growth from obscuring patterns in the data. From the seedling subplot data, maximum frequency over the remeasurement period for water fern (*Histiopteris incisa*), crown fern (*Blechnum discolor*) and exotic species (all species grouped) were calculated for each 100-m^2 sapling subplot.

In December 2005, we characterised the environment of each 100-m^2 sapling subplot. To obtain a measure of daily shading, we averaged measurements of the angle from the centre of the subplot to the top of the canopy at three compass bearings representing true north, true west and true east. This produced a high value in small openings and near the edges of larger openings and a low value in the centre of larger openings. For each 100-m^2 subplot we calculated a local terrain shape index (McNab 1989) and a mesoscale topographic index (McNab 1993). High values of these indices represent low topographic positions (e.g. gullies) whereas low values indicate high topographic positions (e.g. ridges). We converted measurements of slope and aspect to an index of potential solar radiation (after Frank and Lee 1996). The top 100 mm of mineral soil was collected on four evenly spaced samples within each subplot and pooled for analyses of mineralisable N, pH, total C, N and P, and exchangeable Ca (all according to Blakemore *et al*. 1987). Litter depth was measured in these same four locations and averaged.

Did Station Creek and Coal Creek subplots differ in site conditions?

There were some differences in average site conditions between the Station Creek (coupe harvest treatment and controls) and Coal Creek (group-selection treatment and controls) sapling subplots (Table 1) that may have influenced differences in regeneration success between the two localities. Station Creek subplots tended to be on lower landform positions (more in gullies, fewer on ridges and spurs,) and have lower potential solar radiation than Coal Creek subplots. This corresponded to higher total P on Station Creek subplots than Coal Creek subplots. Station Creek and Coal Creek sapling subplots showed no differences in terrain shape index, slope, total soil N, or total soil C.

Are harvesting effects different between coupes and group selections?

We inferred a harvesting effect when treatment sapling subplots (coupes or group-selections) were different from their respective controls in a measured variable (Table 1) and examined the magnitude of these effects to determine whether they were different on coupes versus group-selections. The difference in size of the harvested area is shown by the significantly lower angles to the canopy (i.e. decreased daily shading) on coupe than on group-selection subplots. Coupe subplots also had higher soil Ca, soil pH, soil mineralisable N, mean litter depth, maximum water fern frequency, and maximum exotic occurrence than group-selection subplots (Table 1). All of these variables, except mean litter depth, are strongly negatively correlated with the angle to the canopy (Spearman rank correlation ranges from -0.38 to -0.75; all $P < 0.0001$), suggesting that these are direct effects of the size of area harvested. The higher mean litter depth (and high variability in litter depth) on coupes reflects the concentrations of large amounts of residual slash in certain parts of the coupe.

Does beech sapling and seedling density differ between coupes and group selections?

Six years after harvesting, the mean maximum sapling density of red beech was higher on coupe subplots than group-selection subplots (44 saplings/100 m^2 vs 23 saplings/100 m^2; $P = 0.0516$ with a *t*-test). In contrast silver beech sapling density was lower on coupe subplots than on group-selection subplots (4 saplings/100 m^2 vs 12 saplings/100 m^2; $P \leq 0.0001$ with a t-test). At this time, seedling density of both species was lower on coupes than on group selections (Fig. 1), but the ratio of red beech seedlings to silver beech seedlings was similar between coupes and group-selection subplots (32:1 on coupes, 35:1 on groups). By the sapling stage, however, it had shifted markedly (11:1 on coupes, 2:1 on groups) illustrating how red beech is favoured on the coupes compared with the group selections. These differences may reflect both differences in environments between Station Creek and Coal Creek and different effects of harvesting on the environments of coupes versus group selections (Table 1). The coupes did not appear to provide a suitable environment for establishment of new seedlings of either species, although there were masting events during the study period that resulted in new seedling establishment on control plots and group selections (Fig. 1).

Does sapling density vary according to position within the area harvested?

Red beech saplings were more dense on those coupe or group-selection sapling subplots having the lowest angle to the canopy in the northern direction (Spearman rank correlation between maximum sapling density 6 years after harvesting and angle to the canopy = -0.55, $P < 0.0001$); Fig 2). These will be those parts of the harvested areas that got the most sunlight over the course of a day. Again, such a pattern is expected for a shade-intolerant species such as red beech and echoes findings that red beech saplings also grow fastest in the centre of canopy gaps (Runkle *et al*. 1995). In contrast, silver beech showed the opposite pattern (Spearman rank correlation between maximum sapling density 6 years after harvesting and angle to the canopy = 0.52, $P < 0.0001$); Fig. 2).

Discussion

The patterns observed here follow expectations about how a shade-intolerant (red beech) versus a shade-tolerant (silver beech) tree species would be expected to respond to different sizes of canopy gap openings (see review by Runkle 1985). Recent natural canopy gaps in South Island mixed beech forest tend to be smaller than the coupes; expanded gap sizes at four sites range from 0.01 to 0.09 ha (median range 0.026-0.035 ha; Stewart *et al*. 1991) whereas the coupes in this study ranged from 0.08 to 0.20 ha. In natural canopy gaps red beech saplings become more numerous than silver beech saplings in only the largest gaps where gap diameter is greater than the height of adjacent trees (Stewart *et al*. 1991). Accordingly, in our study, the subplots in the centre of the opening in both coupes and group selections (i.e. those with the lowest angle to the canopy) had the highest density of red beech saplings. That smaller openings in our study had the highest density of silver beech corresponds to the behaviour of 'small-gap specialists' (cf. Denslow 1980; Barton 1984) and observations on natural canopy gaps in the size range of openings created by the group-selection harvest (Stewart *et al*. 1991).

In our study, red beech may also be responding to the increased soil Ca, mineralisable N and pH on coupes. Even-aged mountain beech stands recovering from recent disturbance have the highest soil Ca and available N during stand development, presumably because Ca and N are released from decaying wood faster than saplings can uptake these nutrients (Allen *et al*. 1997; Clinton *et al*. 2002). Increased soil Ca and mineralisable N in coupes also could be a result of a lower proportion of the harvested wood being removed from coupes resulting in more woody debris, increased decomposition rates due to different micro-environmental conditions on coupes, and more uptake in the group-selection subplots from adjacent trees.

Our results imply that, all else being equal, a range of sizes of harvested areas will promote a more mixed-species forest, whereas uniform sizes of harvested areas are likely to favour one species over the other. This is likely to be the case in most New Zealand mixed-species forests where tree species vary in their degree of shade tolerance. A range of size of harvested areas parallels what happens naturally where disturbances produce openings of different sizes (Stewart *et al*. 1991; Allen *et al*. 1999).

Table 1: Environmental properties of 100-m² subplots at Station Creek (coupe harvesting treatement) and Coal Creek (group-selection harvesting treatment). Significance in differences in average conditions among the two localities and harvested versus control subplots was assessed using a one-way ANOVA. Within results categories (in bold) variables are ordered from those that differ the most dramatically to those that differ the least. Tukey's test was used to contrast differences between means. Significant differences are indicated by different letters in the superscript.

Variable	Harvested		Control areas			
	Coupe	Group	Coupe	Group	*F*	*P*
Environmental features that differed between Station Creek and Coal Creek						
Mesoscale topographic index	$^{a}16\pm3$	$^{b}9\pm4$	$^{c}12\pm3.6$	$^{b}8\pm3.4$	25.49	<0.0001
Potential solar radiation index	$^{a}0.40\pm0.04$	$^{b}0.48\pm0.05$	$^{a}0.42\pm0.04$	$^{b}0.47\pm0.05$	16.75	<0.0001
Total P (mg/kg)	$^{a}530\pm297$	$^{bc}327\pm204$	$^{ac}510\pm189$	$^{b}309\pm222$	6.25	0.0006
Environmental features where magnitude of harvesting effect differs between coupes and group-selections						
Angle to the canopy (°)	$^{a}57\pm14$	$^{b}82\pm8$	$^{c}90\pm0$	$^{c}89\pm2.9$	77.72	<0.0001
Maximum water fern frequency (%)	$^{a}62\pm33$	$^{b}15\pm27$	$^{bc}0\pm0$	$^{c}0.8\pm4.0$	39.85	<0.0001
Mean litter depth (mm)	$^{a}65\pm61$	$^{b}14\pm6$	$^{b}20\pm7$	$^{b}15\pm5$	17.85	<0.0001
Exchangeable Ca (cmol+/kg)	$^{a}0.93\pm0.85$	$^{b}0.45\pm0.50$	$^{b}0.32\pm0.44$	$^{b}0.22\pm0.15$	9.07	<0.0001
pH	$^{a}4.20\pm0.22$	$^{ab}4.06\pm0.23$	$^{c}3.9\pm0.22$	$^{bc}4.0\pm0.18$	7.3	0.0002
Maximum exotic occurrence (%)	$^{a}3.1\pm4.1$	$^{ab}1.7\pm4.6$	$^{b}0\pm0$	$^{b}0.06\pm0.33$	4.87	0.0033
Mineralisable N (mg/kg)	$^{a}35.1\pm18.9$	$^{ab}26.1\pm26.3$	$^{ab}21.6\pm7.36$	$^{b}18.6\pm13.3$	3.45	0.0194
Environmental features that were the same at Station Creek and Coal Creek before and after harvesting						
Mottling (%)	$^{ab}0.5\pm0.8$	$^{a}1.0\pm1.3$	$^{b}0\pm0$	$^{ab}0.7\pm1.3$	2.74	0.0472
Terrain shape index	1.6 ± 2.4	2.5 ± 3.2	0.28 ± 2.5	1.1 ± 2.7	2.64	0.0537
Mean organic matter depth (mm)	70 ± 45	68 ± 30	88 ± 47	87 ± 40	2.14	0.0994
Total N (%)	0.19 ± 0.03	0.19 ± 0.07	0.21 ± 0.06	0.18 ± 0.06	1.08	0.3593
Maximum crown fern frequency (%)	33 ± 29	16 ± 27	19 ± 34	19 ± 30	1.4	0.2463
Total C (%)	4.40 ± 0.46	5.04 ± 1.71	5.02 ± 1.43	4.81 ± 1.52	0.97	0.4094
Slope (°)	13 ± 6	12 ± 6	12 ± 2.6	12 ± 7.9	0.22	0.8795

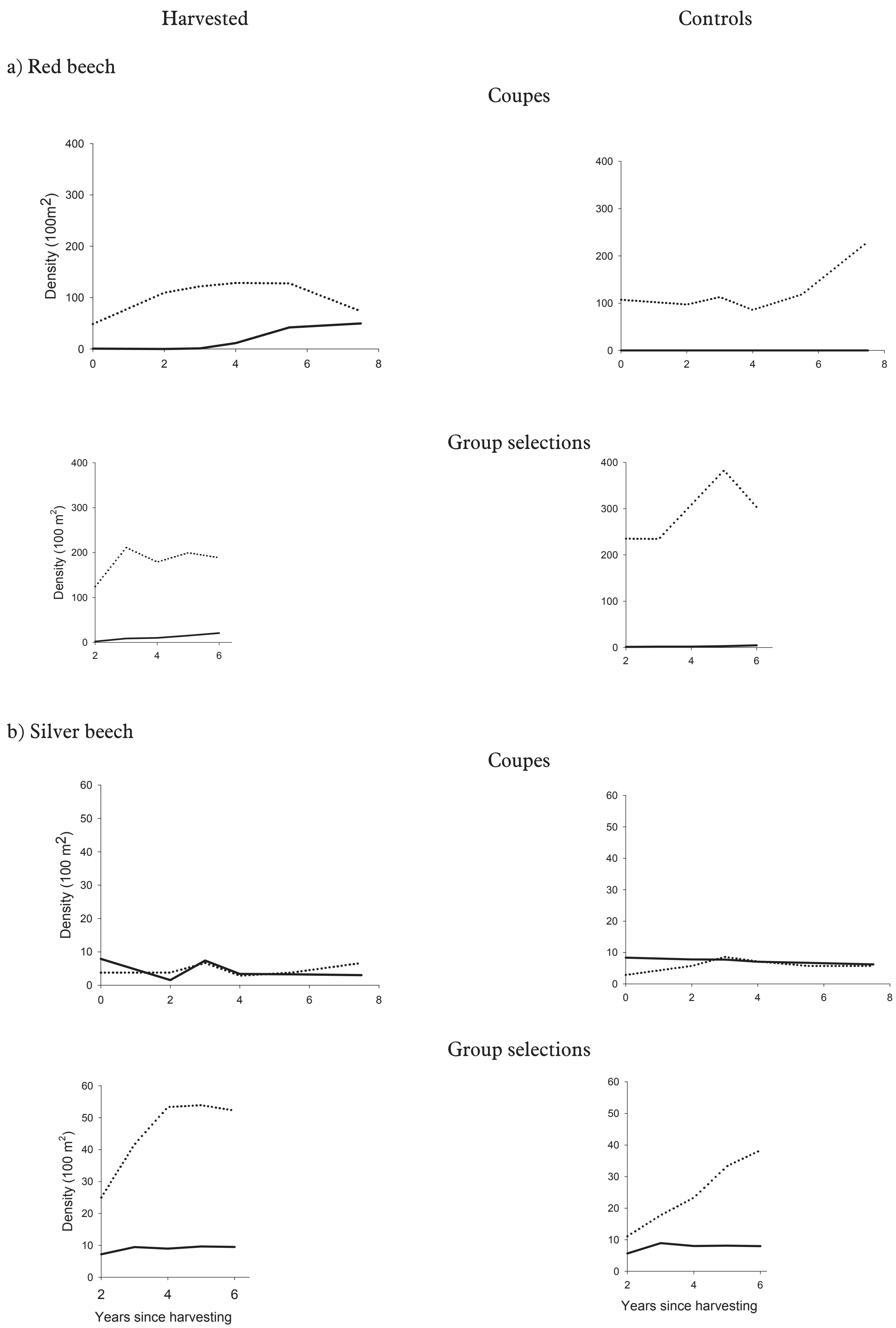

Figure 1. Temporal changes in mean red beech and silver beech seedling and sapling density on 100-m² subplots after harvesting in coupes and group selections and their respective controls in adjacent unharvested forest.

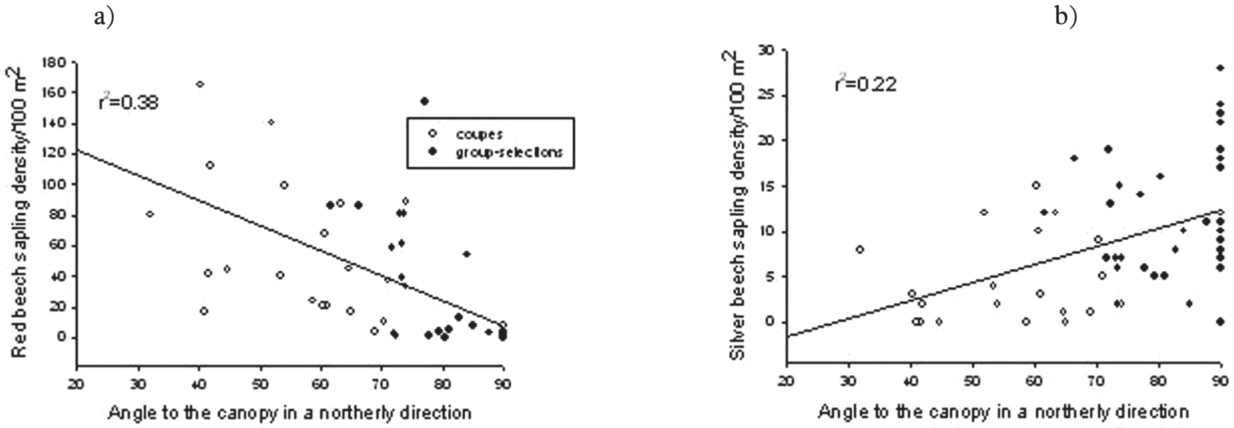

Figure 2. Relationship between angle to the canopy and maximum sapling density (within 6 years after harvesting) of a) red beech and b) silver beech on coupe and group-selection subplots.

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References

Allen, R.B.; Clinton, P.W.; Davis, M.R. 1997: Cation storage and availability along a *Nothofagus* forest development sequence in New Zealand. *Canadian Journal of Forest Research* 27: 323-330.

Allen, R.B.; Bellingham, P.J.; Wiser, S.K. 1999: Immediate damage by an earthquake to a temperate montane forest. *Ecology* 80: 708-714.

Barton, A.M. 1984: Neotropical pioneer and shade-tolerant tree species: do they partition treefall gaps? *Tropical Ecology* 25: 196-202.

Blakemore, L.C.; Searle, P.L.; Daly, B.K. 1987: Methods for chemical analysis of soils. NZ Soil Bureau Science Report 80. DSIR, Wellington.

Clinton, P.W.; Allen, R.B.; Davis, M.R. 2002: Nitrogen storage and availability during stand development in a New Zealand *Nothofagus* forest. *Canadian Journal of Forest Research* 32: 344-352.

Denslow, J.S. 1980: Gap partitioning among tropical rainforest trees. *Biotropica* 12 (Supplement): 165-179.

Frank, E.C.; Lee, R. 1966: Potential solar beam irradiation on slopes: Tables for 30° to 50° latitude. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station Research Paper RM-18. Fort Collins, Colorado, USA.

MAF (Ministry of Agriculture and Forestry) 2002: Standards and guidelines for sustainable management of indigenous forests. Part IIIA Forest Act 1949. 2nd Edition. MAF, Wellington. 134 p.

Mason, E.G. 2000: Evaluation of a model beech forest growing on the West Coast of the South Island of New Zealand. *New Zealand Journal of Forestry* 44: 26-31.

McNab, W.H. 1989: Terrain shape index: quantifying effect of minor landforms on tree height. *Forest Science* 35: 91-104.

McNab, W.H. 1993. A topographic index to quantify the effect of mesoscale landform on site productivity. *Canadian Journal of Forest Research* 23: 1100-1107.

Runkle, J.R. 1985. Disturbance regimes in temperate forests. Chapter 2 in Pickett, S.T.A.; White, P.S. (eds) *The ecology of natural disturbance and patch dynamics*. Academic Press, Orlando, FL, USA.

Runkle, J.R.; Stewart, G.H.; Veblen, T.T. 1995. Sapling diameter growth in gaps for two *Nothofagus* species in New Zealand. *Ecology* 76: 2107-2117.

Stewart, G.H.; Rose, A.B.; Veblen, T.T. 1991. Forest development in canopy gaps in old-growth beech (*Nothofagus*) forests, New Zealand. *Journal of Vegetation Science* 2: 679-690.

Wardle, J.A. 1984: *The New Zealand Beeches: ecology, utilisation and management.* New Zealand Forest Service, Christchurch.

Wiser, S.K.; Allen, R.B.; Benecke, U.; Baker, G.; Peltzer, D. 2005: Tree growth and mortality after small-group harvesting in New Zealand old-growth *Nothofagus* forests. *Canadian Journal of Forest Research* 35: 2323-2331.