Developing management systems for the production of beech timber

Rob Allen1, Jenny Hurst1,2, Susan Wiser3 and Tomás Easdale4

Background

The extraction of timber has been the most controversial issue for beech forest management over the last half century (e.g., Benecke 1996; Mason 2000). The issue largely revolves around whether it is possible to extract timber from beech forests while maintaining or enhancing the non-extractive benefits from these forests. In 1993, Part 3A of the Forests Act 1949 came into force with provisions that require harvested areas in beech forest to be no greater than 0.5 ha, unless specific approval has been obtained for a larger area (up to 20 ha; Ministry of Agriculture and Forestry 2007). 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 adjacent harvesting can occur. The Forests Act also aims to achieve an appropriate balance between productive use and maintenance of the forests’ natural values (e.g., native versus exotic dominance). This article summarises nearly 20 years of experience in implementing the types of beech management systems allowed by Forests Act provisions. We consider what is known about their direct influence on tree recruitment, growth and mortality, and, where studied, on other natural values such as biodiversity, nutrient cycling and carbon storage.

There are approximately 1.0 million ha of indigenous forest where beeches (Nothofagus) dominate the canopy and 3.6 million ha where beeches co-dominate with other hardwoods or conifers (e.g., Wiser et al. 2011). One estimate is that there are 166 000 ha of beech forest types in private ownership that are suitable for commercial harvest, of which one-quarter has MAF-approved allowable harvest (Indigena 2011). Beech accounts for 88% of the annual allowable harvest from all indigenous forests under Forests Act requirements (Hurst et al. 2007; Richardson et al. 2011). These harvest volumes are from second-growth forest, resulting from historical land clearance and logging, as well as from old-growth forest. In practice, harvest operations tend to be from either selective, group-selection, small-coupes (0.1 to 0.2 ha), or coupes of ~0.5 ha, and typically slight silvicultural tending of developing stands is undertaken.

Size-class system in a Canterbury black beech forest

The first sustainable management plan approved under the Forests Act was for 83 ha (390 - 610 m elevation) of black beech forest near Oxford, Canterbury, owned and managed by J. and R. Wardle. This forest is second-growth following earlier logging and fire (1860-1910). Total basal area is rather low and averages 23 m²/ha (for trees ≥ 10 cm in diameter) across the forested area, 91% of which is black beech (Allen et al. 2000). Across the forest there are dense, high basal area stands on infertile ridge sites and low-density, low basal area stands on fertile sheltered sites (Allen et al. 2000). About 80% of trees have a diameter ≥ 10 cm, but < 30 cm and many of the dense stands are undergoing self-thinning. Black beech is considered a light demanding species although it is difficult to distinguish growth responses due to increased light availability from those resulting from reduced root competition, particularly on infertile soils (Platt et al. 2004). There is a low density of marbleleaf and broadleaf in the subcanopy, and the understorey is dominated by small-leaved Coprosma spp., with wineberry common on sheltered sites and crown fern common on many sites.

This black beech forest has been subjected to a range of management approaches as knowledge has developed. Initially timber harvesting utilised small-coupes (30 - 50 m across) established throughout the forest. In an attempt to maximise the stability of adjacent stands the specific coupe areas were determined based on existing stand structures. Subsequently a shift was made towards a size-class selection system in which trees ≥ 45 cm were selected for harvest including those recently dead. Log removal has been by conventional skidder or a tracked mini-skidder. With time it became increasingly apparent that there was high turnover (tree mortality and recruitment) in this beech forest, often unrelated to management activities. Tree mortality events on exposed sites are often driven by wind storms and on sheltered sites by snow storms, as well as subsequent pinhole beetle damage. At the same time, progressive thinning and pruning has been undertaken in many of the second-growth stands and in some of the early coupes. This thinning serves to increase the stability of dense stands in the face of wind and snow storms. The Wardle property now represents the beech forest where Forests Act requirements have been applied over the greatest proportion of a managed indigenous forest.

There was usually prolific black beech

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1 Landcare Research, Lincoln, New Zealand
2 School of Forestry, University of Canterbury, New Zealand
regeneration soon after black beech forest coupe creation, except where crown fern was dense. Poor germination by beech, when the forest floor is densely covered by ferns, grasses and sedges, is well known (e.g., Wardle 1984), although an interesting observation in this black beech forest was that warm dry years, which promote beech tree seeding, can sometimes cause crown fern dieback and allow seedlings to establish (John Wardle pers. obs.).

Coupe edge-tree stability has been variable, and it remains unclear the level to which edge-tree mortality is elevated above that found in forest stands more distant from harvested coupes. Implementation of the size-class system, where one or a few individual trees are harvested, should promote growth of residual trees that are partly released from competition (Table 1). While short-term seedling growth responses to canopy opening have been observed, their success is ultimately determined by the rate of lateral canopy closure by remaining trees.

Based upon 40 random plots sampling the forest area, Allen et al. (2000) did not detect a separate influence of current management on the structure and plant species composition of individual stands. This suggests harvesting impacts on biodiversity are not marked. A central message from managing this black beech forest is that forest structure is changing continuously, and management on any particular site may need to be constantly adjusted in response to various forms of natural disturbance, that may or may not be repeated in time or space.

0.5 ha coupes in a Southland silver beech forest

Silver beech forests found on the lower slopes (< 200 m elevation) of the Longwood Range and Woodlaw Forest are currently managed by Lindsay and Dixon Limited for the Waitutu Incorporation. Much of the managed forest area was clear-cut under various cutting licences more than 80 years ago. The resulting second-growth forests are dominated by silver beech, with some kamahi and southern rata and the occasional podocarp, and have an understory dominated by the small trees broadleaf and lancewood and the shrubs weeping matipo, Coprosma spp. and crown fern and tree ferns (Wardle 1984). Plots located systematically in part of the forest have shown that regrowth, in combination with occasional older trees, resulted in silver beech having an reverse-J diameter-size-class structure (TACCRA Ltd 2004). Seventy-five percent of trees have a diameter < 30 cm and stand level basal area averages > 60 m² per ha.

Figure 1. 0.5 ha coupes harvested in Woodlaw Forest silver beech forests.
with adjacent unharvested forest, although a few coupes are as yet poorly stocked (Figure 2). Some of the seedlings and saplings will likely represent individuals that were present before harvesting, while others will have established subsequently (see TACCRA Ltd 2004). The reason for poorly stocked coupes has not been determined although Southland is an area where fern removal was historically used to ensure beech regeneration (Wardle 1984). The mean diameter of silver beech trees in logged coupes was 3.9 cm, with only 10% > 5.3 cm diameter, and in unharvested forest the mean diameter was 23.9 cm, with 10% > 48.8 cm diameter. Most of the saplings and trees in the coupes have reached a height of 4 m which would allow harvesting access to adjacent stands. Observations suggest that coupe boundaries have been stable with little mortality of residual trees since harvesting, although some crowns have partially died back.

Small-coupe (0.1-0.2 ha) trial in north Westland red-silver beech forest

From 1994 to 1996, a harvesting trial was established in a mixed red-silver beech forest at Station Creek, north Westland. The forest has not been previously logged and is found on gentle slopes and terraces near the valley floor between 450 and 600 m elevation. Red beech accounts for 80% of the basal area and 44% of the trees whereas silver beech accounts for 19% of the basal area and 52% of the trees (Wiser et al. 2005). Thirty-five percent of the red beech trees were < 30 cm DBH and trees were found over a wide range of diameters up to 132 cm, but 80% of the silver beech trees were < 30 cm diameter. The existing forest structure indicates regeneration happened following canopy disturbance with canopy gaps ranging from 126 to 443 m² (Stewart et al. 1991). The light-demanding red beech seedlings exhibit rapid height growth following gap creation while silver beech is more shade tolerant and is thus more abundant in the intact forest understory (Wardle 1984). The forest contains a sparse understory of crown fern.

The forest was previously managed by Timberlands West Coast but is now administered by the Department of Conservation. In the red-silver beech forest, six approximately circular small-coupes were harvested over a 20-ha area and they ranged in size from 400 to 2000 m² (Wiser et al. 2005). Some of the small-coupes were helicopter harvested while others had logs extracted by low-impact skidders. There has been no tending in the small-coupe areas.

Ten years ago the level of residual tree growth and mortality following small-coupe harvesting was a controversial issue (Mason 2000), and the Station Creek small-coupes have contributed to a resolution of that issue. The diameter growth of small trees was elevated along the small-coupe edges relative to intact forest, whereas the growth of the largest silver beech trees and intermediate sized red beech trees was not (Figure 3; Wiser et al. 2005). Note that the growth of the largest red beech trees appeared to be lower on coupe edges (Figure 3). Edge trees were more likely to die if infested with Platypus beetle, but overall tree mortality was unrelated to an edge versus intact forest. Eight years after small-coupe harvest red beech and silver beech saplings averaged about 5000 and 400 stems per ha respectively (Wiser et al. 2007). As expected, based upon light requirements, red beech sapling density declined, and silver beech sapling density increased, with edge tree shading over the small-coupe area (Wiser et al. 2007). The diversity and cover of herbaceous native plant species increased following harvesting, particularly of water fern. Creation of the small-coupe did not affect the diversity of ectomycorrhizal fungi, but had a significant effect on the species composition in the soil organic horizons (Dickie et al. 2009). A range of exotic species established post-harvest (e.g., Himalayan honeysuckle, blackberry), but none were common (Wiser et al. 2000).
Group-selection (<0.05 ha) trial in north Westland red-silver beech forest

In 1998, a second trial was established in the red-silver beech forest described above at Station Creek (Figure 4). Nine group-selections (~ 4 large trees removed) were harvested within a 10-ha area. These group selection harvests were < 500 m² and in this way were of a similar size to the natural canopy gaps found in these forests. These group-selections were helicopter harvested and there was minimal ground disturbance, although there was considerable slash concentrated in the harvested area. These group selections continue to be monitored with sample transects but no further manipulations have been undertaken.

The creation of this group-selection trial allowed a comparison of harvest effects on light availability, soil properties, and beech regeneration with the small-coupes in the same red-silver beech forest. Post-harvest, small-coupes had less shading, greater soil available nutrients (e.g., N and Ca) and pH, water fern frequency, and exotic plant species occurrence than group-selection areas (Wiser et al. 2007). As expected, small-coupes provided the best conditions for red beech regeneration, whereas group-selection provided better conditions for silver beech regeneration. It is of note that red beech regeneration appears to be

Small-coupes (0.2 ha) trial in north Westland hard beech forest

A harvesting trial was established in a hard beech forest in the Grey Valley in 1994. This forest is found on dissected topography at 100 - 300 m elevation. Hard beech dominates the less fertile hill-slopes and ridge crests with scattered red beech restricted to the more fertile sheltered gullies. Before harvesting, hard beech comprised 72% of the basal area and 36% of the stems in the study area. About 60% of the hard beech trees were < 30 cm in diameter and trees were found with diameters up to 90 cm and attained heights of 27 m (Wiser et al. 2005). Quintinia and kamahi, both hardwoods, were common subcanopy species. Hard beech typically regenerates in small canopy gaps, although even-aged stands have developed after larger-scale mortality resulting from windthrow and following gold mining activities in the 19th century (e.g., Smale et al. 1987). The soils are strongly leached, acidic (mineral soil pH of 3.9), and have low available P when compared with Station Creek red-silver beech forest soils (Wiser 2000).

Nine approximately circular cuts were made in the hard beech forest in 1994. These small-coupes ranged in size from 800 to 2000 m² and were distributed over

Figure 3. Relationship between mean diameter growth (mm/yr) and initial diameter (DBH; cm) for small-coupe edge trees and trees found in adjacent unharvested red-silver beech forest.

Figure 4. Group-selection 10 years after harvest in Station Creek red-silver beech forest in 1998
a 50-ha area. After felling the logs were removed by helicopter. There has been no further silvicultural treatment of these small-coupes. A similar small-coupe trial was established in a hard beech forest at Glenhope, Nelson.

Diameter growth of small hard beech trees was elevated along the small coupe edges relative to intact forest, as in the red-silver beech Station Creek trial, whereas the growth of the largest hard beech trees did not differ from the intact forest (Wiser et al. 2005). Seven years after small-coupe harvest hard beech saplings averaged about 4500 per ha, with quintinia and kamahi saplings also abundant (Brignall-Theyer et al. 2001). The diversity and frequency of native plant species also increased following harvesting, again particularly water fern. The lower richness and frequency of exotic plants in the hard beech small-coupes, relative to the red-silver beech small-coupes, has been attributed to their lower soil fertility (Wiser 2000). Small-coupes again affected ectomycorrhizal fungal species composition in the soil organic horizons (Dickie et al. 2009).

The removal of nutrients in logs has the potential to impact on the soil’s productive capacity, particularly on infertile soils such as those found in hard beech forest. In natural forests there is, in part, a reciprocal oscillation of carbon and nutrients between the soil and live trees and between live trees and the soil through dead trees (Allen et al. 1997). Harvesting trees breaks this cycle. Harvestable hard beech tree stems contain 4 and 10% of the ecosystem total pools of N and P respectively (Clinton et al. 2005). Small-coupe harvesting has been shown to increase foliar N and P concentrations in the harvested area which have been attributed to increased rates of mineralisation and decreased nutrient demand (Smaill et al. 2009). A critical question is whether inputs from natural processes can balance nutrient loss from harvesting stem wood pools in small coupes? Clinton et al. (2005) concluded that the sources of nutrient inputs, with the major exception of P, would be adequate to replace removals following small-coupe harvesting. It remains important to increase our knowledge of nutrient inputs through the weathering of mineral particles in soil (and associated P availability) and uptake by mycorrhiza.

Selective harvest in a Southland silver beech forest

A selective harvest system has recently been initiated in the Southland silver beech forest described above for 0.5 ha coupes. Silver beech stems have been selected across the diameter range to remove about 20% of the basal area over an operational area. The logs are removed by a small bulldozer or skidder. Post harvest, the general form of the forests diameter size-structure is retained (Figure 5). There is considerable soil disturbance caused by the ground based harvest, although this has been observed to enhance seedling establishment in the face of fern competition. It is early days for this system, but central questions that can be answered over the next decade by existing trials include: Is the canopy opening from harvesting silver beech sufficient to allow regeneration?; Does lateral expansion of existing tree crowns into canopy openings limit sapling growth, and over what time period?; Does the selective system lead to less weed invasion than the 0.5 ha coupes?; and, How is carbon storage impacted by stem removal and how does that influence carbon sequestration rates?

Conclusion

Some general conclusions can be made about the management systems allowed for under Part 3A of the Forests Act provisions. Assessments show harvesting operations, with the exception of coupes harvested in black beech, have not so far impacted on mortality rates of remaining trees (e.g., Wiser et al. 2005). Harvest systems applied previously in beech forests (see Wardle 1984), and intended low-impact systems applied elsewhere (Thorpe et al. 2008), have sometimes dramatically elevated tree mortality. Growth responses by residual beech trees...
are variable and depend upon species, tree size, and site conditions (e.g., Franklin & Beveridge 1977; Wiser et al. 2005). Natural beech regeneration has typically been prolific following group or coupe harvesting, at a range of locations, and the > 4 m height requirement for adjacent harvesting will often be achieved in ~ 10 years. Prolific regeneration in homogeneous patches favours the development of long clean straight trunks by natural competition but, eventually, it can lead to stagnant growth of individual trees and compromise stand stability (Franklin and Beveridge 1977). Thus there is some interest in improving tree growth and product quality through thinning and pruning the dense regenerating stands (Easdale et al. 2010). Marked biodiversity responses have been measured in under-storey plant (Wiser 2000), and below-ground ecto-mycorrhizal (Dickie et al. 2009) communities.

So far these management systems outlined have only been assessed over a small part of the beech management cycle, and further issues will emerge through time. For example, whether the group-selection system in red-silver beech forest, or the selective harvest in silver beech forest, will provide adequate canopy openings for a regenerative response to reach the canopy, in the face of lateral expansion of the residual tree crowns, remains unresolved. This could have important consequences for coexistence of canopy tree species in red-silver beech forests (Stewart et al. 1991). Superimposing small-coupe and group management systems on relatively even-aged second-growth beech forest may well lead to some attributes of old-growth forest such as structural complexity, presence of several cohorts of trees, and variation in tree size (Bauhus et al. 2009). However, there is also some evidence that these systems create opportunities for short-lived early successional species (e.g., tree fuchsia and wineberry) rather than the late successional, shade-tolerant species often associated with old-growth forest (e.g., Bauhus et al. 2009).

To some degree, the varying responses to different types of management reflect the context within which the management was applied, rather than the management itself. For example, trees found on fertile soils, where canopies intercept much of the light, exhibit strong competition with neighbouring trees when compared with trees found on infertile soils (e.g., Baribault & Kobe 2011). Such mechanisms may explain why individual tree growth varies in the strength of its relationship to among versus within stand factors (Table 1). Such knowledge explains spatial variation in responses to management but we also need to determine long-term temporal responses to different management systems. Recent advances in the computational power and design of individual-based simulation models provide one option for evaluating long-term effects of forest management (Kunstler et al. 2007).

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