Evaluation of a model beech forest growing on the West Coast of the South Island of New Zealand

Euan G. Mason

Abstract

A matrix model representing beech forest on the West Coast of the South Island of New Zealand was evaluated. The model was widely distributed and had been used to "attest " that a proposed low-impact harvesting scheme was unsustainable. The evaluation showed that while the mathematics of the model were acceptable, the model's software encouraged a naive user to adopt unrealistic assumptions and to project effects of harvesting over periods of centuries. The matrix model, while adequate for initial planning, was unsuitable for such long projections, and a spatially explicit, individual-tree modelling approach was suggested as an alternative that would suit adaptive management.

Introduction

During 1998 a state-owned enterprise, Timberlands West Coast Ltd. (TWC), released a proposal to harvest, using an innovative reduced-impact approach, 98,513 hectares of beech forest growing on the West Coast of the South Island of New Zealand (Ministry of Agriculture and Forestry 1999). TWC had planned to harvest approximately half of the projected mortality in size classes that did not include the largest size class by identifying and removing some of the trees that were dying. Fifteen trees per hectare would have been harvested every fifteen years. Before it could be implemented, the plan had to comply with provisions in the Resource Management Act (1991) (RMA), especially those dealing with sustainability. Sustainable management is defined in the RMA as:

"Managing the use, development and protection of natural and physical resources in a way, or at a rate which enables people and communities to provide for their social, economic and cultural well-being and for their health and safety while

a) *sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonable foreseeable needs of future generations;*
b) *safeguarding the life-supporting capacity of air, water, soil and ecosystems; and*
c) *avoiding, remedying or mitigating any adverse effects of activities on the environment".*

TWC's proposal was opposed immediately by environmental groups on the grounds that it was not sustainable.

Harvesting of native forest has long been highly politicised in New Zealand. Prior to human habitation the country was about 80 per cent forested. Polynesians arrived during the first millennium, and Europeans began to settle in large numbers during the 19th century. By the time Europeans had arrived, approximately 50 per cent of the land area was still in forest. By 1919 only 25 per cent of the area remained in forest, and a projected wood deficit prompted the government of the day to create a Forest Service charged with ensuring a domestic wood supply in perpetuity (Roche 1990). As areas of exotic plantations began to provide wood, logging of native forests declined markedly. By 1997, only a tiny fraction of total roundwood harvests came from native forests (New Zealand Forest Owners Association 1997), and the area under native forest increased from 6 million hectares to 6.5 million hectares between 1920 and 1999. This history of forest decline has fostered a deep love of native forests among New Zealanders, who are particularly concerned that habitats supporting our unique fauna should not be further reduced.

Introduced exotic fauna, especially possums, deer, goats, rats, stoats and wasps, are changing the nature of native forest ecosystems, however, and low-level wood harvests offer finance for control of these pests as well as access roads that are necessary for control operations. This finance is not currently available in sufficient amounts. Management could not be truly sustainable without adequate pest control. Managed forest might actually provide better habitat for native fauna than in some protected forest where control was inadequate.

A model of forest growth along with projected impacts of low-level harvesting were important elements of TWC's proposal. The model was used to determine a level of harvesting that would retain a habitat for native fauna and to make the case for sustainability in terms of the RMA. Environmental groups were therefore delighted when Dr Murray Efford, a Landcare ecologist, was contracted by the Forest and Bird Protection Society to critique the TWC model and to develop an alternative that purported to show that TWC's proposal was not sustainable. The critique contained some good criticism of the mathematics of TWC's model, and Efford (1999) proposed an alternative model.

Dr Efford distributed his model via the worldwide web on Landcare's website. Until recently it was prominently featured on the front page of the site. It is no longer so prominent, but at time of writing it can still be downloaded from http://www.landcare.cri.nz/information_services/media/1999/beechm.exe.

The political impact of the model was enormous. The Labour party, then in opposition but soon to be in government, adopted a policy to cease all harvesting in the Crown's native forests in September of 1999. In early December 1999, after Labour was elected into government, TWC was instructed to remove sustainable logging of beech forest from its statement of corporate intent, thereby forcing it to withdraw a resource consent application that was being subjected to a hearing. On the 22nd of December Hon Peter Hodgson, the Minister of Forestry, responded to criticism of this action by saying in parliament:

"The member can laugh and scoff. He can go to the net and play with buttons himself, and what he will find out is this. If one logs the forest, sooner or later—and there is debate about whether it is sooner or later, that much I will concede—the

character of the forest changes for ever." (Hansard B09-3, December 22 1999)

The purpose of this paper is to examine critically both the model built by Efford and the software made available to the public. It should be noted that Efford's model was an amendment to the original, unpublished model created by TWC to act as a guide for the management proposal. The software it was delivered in, however, was a new development.

Efford's model

The model was essentially a stand table projection using an Usher matrix (Usher 1966). This approach projects the movement of trees from one size class to another, beginning with a certain minimum size class, by allowing for growth rates and mortality. Key elements of such a model were:

i) recruitment, the inflow of trees into the smallest size class represented in the model (0-100 mm dbhob);
ii) ingrowth, the flow of trees from one size class to the next largest in any given time period, which is critically dependent on growth rates; and
iii) mortality of trees in any given class during a period.

The Usher technique uses matrices and involves an assumption that ingrowth and mortality are dependent solely on existing tree size. Usher matrices differ from earlier matrix models in that there are non-zero values in the diagonal, thus allowing the retention of some stems in a class during any growth period. There are also assumptions that coefficients do not change over time and that trees do not grow more than one size class in one projection interval (Vanclay 1994).

The model developed by Efford is applied to an inverse J shaped size class distribution first documented by de Liocourt in 1898 (Meyer 1953) for all-aged stands. This shape implies that there are many more small trees than large trees, and that mortality occurs reasonably regularly to maintain a steady state for the structure of the forest. Wardle (1984) found that size class distributions of red, silver and mountain beech exhibited such shapes after pooling of data from a large number of 400 m^2 plots. However, disturbance by physical and biotic factors had led to the development of even-aged stands of light-demanding red and mountain beeches and this local composition tended to persist. Silver beech, a more shade-tolerant species, tended to acquire a locally mixed age-class distribution, even during periods of relative forest stability. The assumption of an all-aged forest might be tenable for red and mountain beech over reasonably large areas, therefore, but not necessarily within local stands subjected to large scale natural disturbances. In a sense, Efford's model is more accurately described as an estate model than as a stand model because it applies to large mosaics better than to stands.

Recruitment in both TWC's and Efford's (1999) model was arbitrarily fixed at 57 stems ha^{-1} an^{-1}. Obviously recruitment would vary with levels of natural or artificial disturbance, unless the disturbance merely replaced or was "subsumed" into background natural mortality, as proposed by TWC. Both TWC and Efford acknowledged that this was an area requiring further research. Wardle (1984) summarised relevant research from a variety of sources. It is clear that New Zealand's beeches have mast years every four to six years (a mast year is defined as one in which more than 4000 nuts/m^2 are produced). Partial mast years may occur more frequently. Although mast years occur over a wide region, they are not necessarily consistent between species nor between sites. Seedlings establish themselves successfully so long as moisture is adequate and competition from ferns is not too severe. Species differ in their tolerances of shading and of soil limitations. The seedlings then become part of an "advance growth pool", in a quiescent state that can last for many years before the death of a tree creates a gap and conditions become favourable for the seedlings to attain high growth rates. With greater amounts of disturbance, a greater proportion of this "advance growth pool" would have the opportunity to grow, and so recruitment would be greater.

For both models, estimates of ingrowth were obtained from measurements of increment cores from beech in the Maruia, Grey and Inangahua districts, but these estimates would have to be adjusted for planning over a range of species and sites. While some permanent sample plots were available (Whyte, 2000), they were not considered sufficiently representative for the TWC model (James, Pers. comm.). Wardle (1984) reported growth rates that varied highly with species, stocking and site conditions. Models capable of providing accurate forecasts of the consequences

Figure 1A

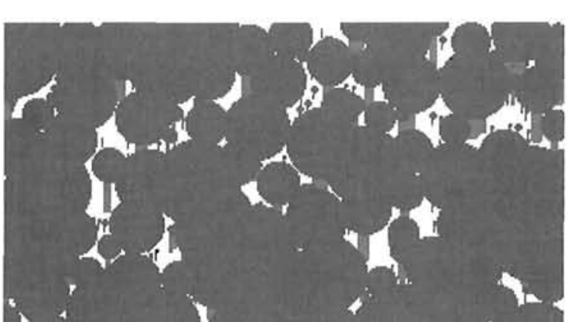
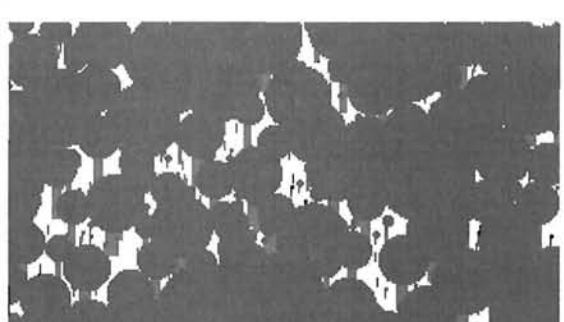


Figure 1B



Graphical representation of forest from Efford's software before (a) and after (b) 400 years without harvesting.

Figure 2A

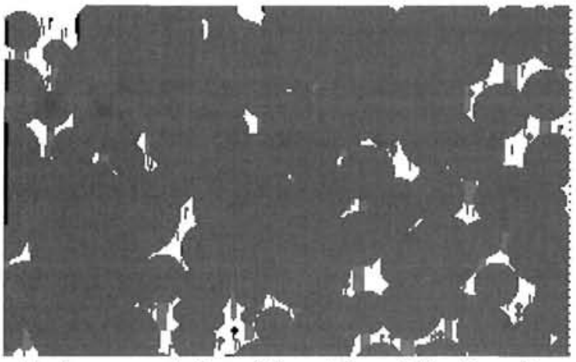
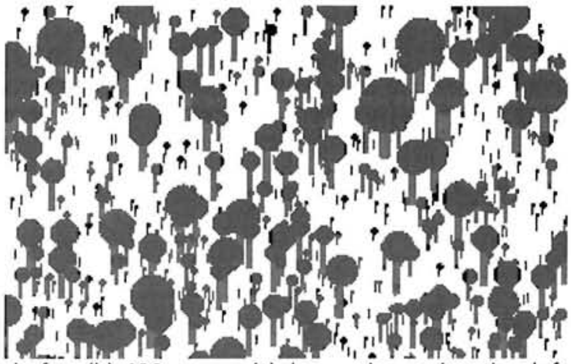


Figure 2B



Graphical representation of forest from Efford's software before (a) and after (b) 400 years with harvesting, using the default values that most naive users would adopt.

of variation in these factors would be required, as soon as the data became available, for adaptive management.

Mortality estimates were set so that the forest was in a steady state, with losses of trees throughout the distribution maintaining the decline in numbers with size. This could be realistic only on very large scales, as was the case with TWC's use of the TWC model. Mortality appears to be episodic. Hosking & Kershaw (1985), for instance, reported mortality of red beech in Maruia from scale following a period of drought. Wardle (1984) provides ample evidence for the importance of periodic episodes of mortality caused by disturbances, and Whyte (2000) confirms this from analysis of PSP data.

TWC determined an individual mortality rate for each size class by an iterative process to maintain constant original numbers in that class (James, pers. comm.). Efford (1999) refined this technique, but both authors acknowledged that the forests were unlikely to maintain a steady state, and the nature of mortality is clearly a topic requiring further research. With control of pests, and no harvesting, the forest would not naturally maintain its current structure. It is obviously more important to ensure that the ecosystem maintains its life supporting capacity, as required by the RMA, than to ensure that management does not change the forest structure. Clearly, the nature of mortality in the forest needs to be measured rather than simply inferred, and structural changes need to be monitored.

Evaluation of model software

While matrix models were useful for the purposes of initial project planning, the way Efford's model was presented in software was misleading.

Recruitment, mortality and ingrowth estimates are clearly shown on the main screen, but there are default values that allow a naive user to run the model without making any changes to these values.

The graphical interface is very nice, and the output is clearly meant for public consumption. Figure 1 shows a graphical display of the stand before and after 400 years without harvesting. This presentation gives the illusion that the model represents trees explicitly in space and that all size classes would be represented in a small area, but there is in fact no spatial component in the model, and reports suggest that local patches would often be even-aged apart from the advance growth pool.

While the presentation of output is a bit misleading, this is nothing compared to what happens when a user selects a logging option from a menu on the right hand corner. Selection of "GI Logging", for instance causes a series of removal estimates to be placed under some of the diameter class columns. These removals are set at 100 per

Figure 3A

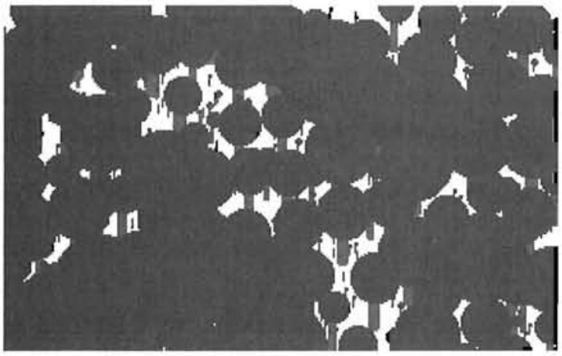
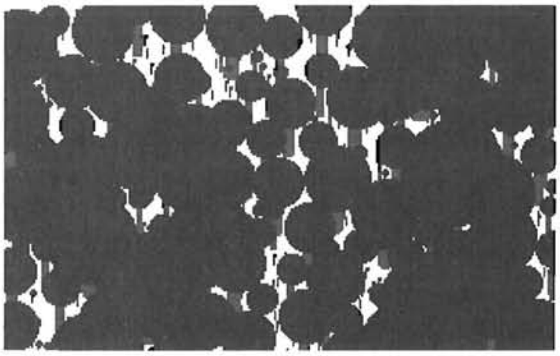


Figure 3B



Graphical representation of forest from Efford's software before (a) and after (b) 45 years with harvesting, assuming that harvest had been reduced to half the increment and that identification of dying trees was wrong 25 percent of the time. Mortality of remaining trees was assumed unaffected by harvesting of competitors, and no extra recruitment was allowed in the new gaps in the canopy.

Figure 4A

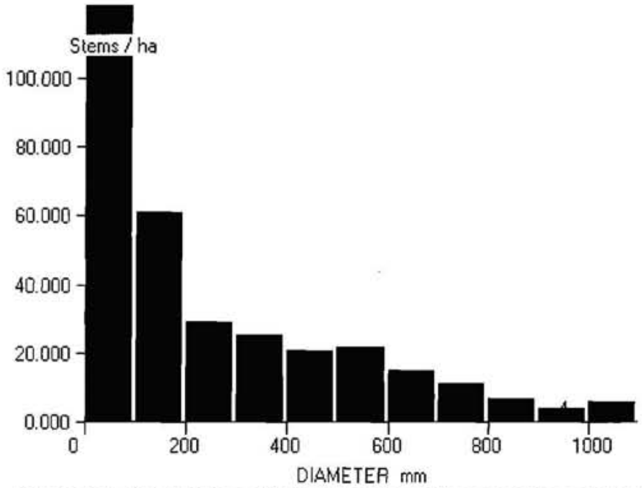
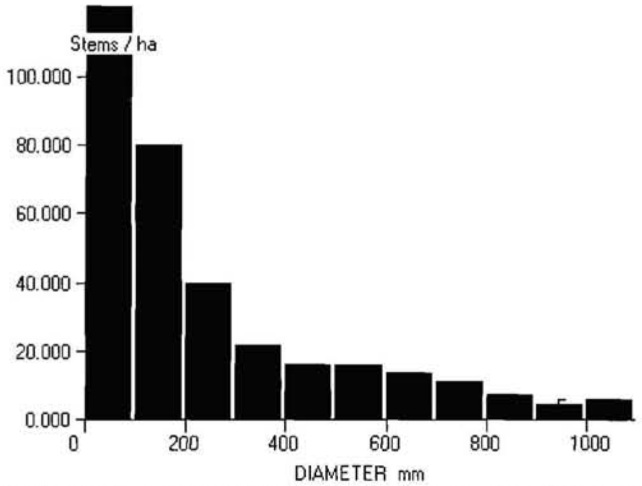


Figure 4B



Diameter distributions from Efford's software of forests unharvested (a) and harvested (b) after 45 years, assuming that harvdest had been reduced to half the increment and that identification of dying trees was wrong 25 percent of the time. Mortality of remaining trees was assumed unaffected by harvesting of competitors, and no extra recruitment was allowed in the new gaps in the canopy.

cent of the projected growth, while TWC had planned to harvest approximately half the growth. When one inspects the recruitment and mortality boxes, it is clear that these are assumed to be unchanged following harvests. This misrepresents what would have happened in reality, for two reasons:

i) recruitment is vigorous in gaps created in the canopy of beech forests (Wardle 1984); and
ii) TWC planned to identify and harvest only dying trees.

One cannot have it both ways. Either harvesting is successfully planned to remove dying trees, in which case mortality rates of remaining trees should decrease accordingly, or more recruitment from the "advance growth pool" should occur in the extra gaps created by harvesting. Even with mistakes in identification of dying trees, harvesting would decrease mortality to the extent that mortality is influenced by competition between trees.

Figure 2 shows the graphical representation of the stand before and after 400 years (the default) of low-level harvesting, using the default values of the software. While the model could apply plausibly only to a large area, the graphical output suggests that all events affecting size class distributions would occur within a small area. Moreover, making harvests additional to mortality, while not changing recruitment, inevitably leads to a graphical display that resembled a savanna more than a forest. Furthermore, assuming that managers would use the same model and harvest calculation over a 400 year period is unrealistic. It is no wonder the Minister of Forestry was so strident in his denunciation of the scheme.

A user educated in forest ecology and management would be likely to change estimates of harvesting level, recruitment and/or mortality. Fortunately the software allows some changes, and the results suggest that sustainable management is feasible. Successful identification of dying trees would result in stands identical in structure to an unharvested forest, according to Efford's model. Even if identification of dying trees was wrong 25 per cent of the time and one allows for no compensatory survival and no increase in recruitment in the extra gaps, Efford's model shows very few differences between structures of harvested and unharvested forests after 45 years (Figures 3 and 4).

Efford (1999) claims that identification of dying trees would be impossible on a 15-year harvest cycle, as deaths would be due to weather, geomorphology and pathogens. Representative estimates of these factors cannot be anticipated. But, he acknowledges that local tree density may moderate mortality from these agencies, and there is a wealth of research that supports the relationship between density and mortality in these (Wardle 1984) and other forest ecosystems (eg: Reineke 1933, Zeide 1987). Given the patchwork nature of many beech landscapes and the tendency for stands to be more uniformly aged on local scales, the inverse J frequency distribution obtained after data are amalgamated at larger scales (Wardle 1984) implies that mortality is strongly related to density. Efford's model begins with this distribution shape, and the shape implies that size and local density should be indicators of the likelihood of mortality within any 15-year harvesting cycle. Moreover, harvesting one tree could change the fate of another tree locally, contrary to Efford's assertion that removals would have no impact on mortality of remaining trees.

Prof. Vanclay (*pers. comm.*) has suggested that TWC would be able to refine criteria for identification of dying trees by marking and monitoring the proportion of trees judged to be dying that was not harvested. External and visual criteria for detecting dying trees have been successfully developed elsewhere (Seydack 1995, Seydack *et al.* 1995).

Alternative modelling approaches

Extrapolating from a model of a natural forest to a model of a harvest production forest requires a higher level of structural resolution than can normally be obtained with a simple matrix approach. To successfully use a matrix approach for estimating effects of employing different harvesting strategies, one would have to develop a set of matrix coefficients for each different strategy and these would have to be estimated using data from stands where the strategies had already been tried.

Using data from permanent sample plots and studies of gaps in the canopy, a spatially explicit, individual-tree model could be built that would allow managers to explore the consequences of alternative logging strategies. It would be important for the model to allow for variation in future states of any given tree, otherwise variances would be underestimated and the stand table could not be represented in a realistic manner. Stage (1973) developed a deterministic solution to this problem that involved splitting each tree's growth into three paths; one low, one average and one high. Stage's solution was appropriate when computing power was limited. An alternative solution to the problem that involves separate parametric distributions for each diameter class was recently demonstrated for juvenile radiata pine (Mason, in prep), and such a solution could be tried in a beech model.

A spatially explicit model would allow an accurate representation of the consequences of mortality and harvesting. Given the episodic nature of mortality in beech forests, it is likely that trees of similar sizes are clumped. A completely spatially random model would therefore be misleading. Careful global positioning system measurements of the extent of clumping in a range of stands would provide starting points for the model, and then both mortality and harvesting could be represented stochastically.

The effects of site variation should be taken into account when estimating coefficients. This would allow management to be more site-specific.

Finally, data from permanent sample plots would provide much more reliable estimates of model coefficients than those obtained using increment core data, and the growth rates of different species could be differentiated. Increment cores provide data relating to only surviving trees.

Implications

Clearly, Efford's model could not be used to show that the beech scheme was unsustainable. His model suggests that if all harvest removals were of dying trees, then harvesting would not change forest structure. Furthermore, allowing for 75 per cent of harvest subsumed into mortality, his model suggests that the proposed harvest would have minimal impact on forest structure within a reasonable planning period, even if recruitment is unchanged and harvesting does not affect survival of remaining trees. Moreover, evidence suggests that these latter two assumptions are unduly conservative.

The RMA does not require that forest structure remains unchanged, however. Instead it states that resources can be used while *"safeguarding the life-supporting capacity of air, water, soil and ecosystems"*. Episodic mortality implies that the forest estate structure varies naturally, so it is more important to identify the range of forest structures that would safeguard the life-supporting capacity of the ecosystem and ensure that harvesting does not create structures outside that range than to try to maintain an existing forest structure that would change naturally anyway.

There are some important questions that lie beyond the scope of this paper. The extent and nature of mortality events need further study, and the criteria for identifying dying trees need to be tested. It is very likely that these questions could be addressed and the scheme refined long before any significant damage would be done to the forest if the proposed scheme required change. Larger questions about funding of pest control deserve a separate evaluation and all facts need to be placed before the public so that all the implications of a decision to allow harvesting or not are considered. The RMA consent hearing that began and stopped prematurely would have reviewed the entire evidence and allowed this kind of consideration.

A further question that the issue raises is, "what do we mean when we say that we wish to live sustainably?". The intention of the RMA is to allow resource use while ensuring that ecosystems are protected. The question cannot be completely covered here, but this evaluation of Efford's model will contribute to the debate.

Conclusions

The model constructed by Efford appears to be computationally acceptable, but the model's software implied that a matrix representation would be adequate for estimating the effects of harvesting in beech forests over long periods. Coefficients distinguished neither species, variations in stand structure, nor variations in site quality.

The software used to represent the model encouraged a naive user to assume that harvesting would be completely additional to mortality, despite a clear intention on the part of TWC to harvest dying trees. Moreover, the programme made projections over several centuries without provision for extra recruitment in additional gaps that would have been created if harvesting was not subsumed into mortality. Finally, the software's graphics gave the impression that the model was spatially explicit, when in fact it was a simple Usher matrix.

The size-class distribution adopted by Efford in his model implies that mortality is strongly related to local stand density, and this could be used to predict the likelihood of mortality. It is therefore likely that harvesting of healthy trees would reduce the likelihood of mortality of remaining trees in the local vicinity, but the model's software failed to account for this effect.

An alternative, spatially explicit, individual-tree modelling approach has been proposed here, that would allow managers to project the effects of harvesting with greater confidence.

Acknowledgements

Many thanks are due to colleagues at the School of Forestry and New Zealand Forest Research who have discussed this issue with the author. Particular thanks are due to the three referees who all made very helpful suggestions.

References

Efford, M., 1999, Analysis of a model currently used for assessing sustainable yield in indigenous forests, *Journal of the Royal Society of New Zealand* 2 (29): 175-184

Hosking, G.P. & Kershaw, D.J. 1985. Red beech death in the Maruia Valley, South Island, New Zealand. *New Zealand Journal of Botany 23:* 201-211

Mason, E.G., in prep, A model of the juvenile growth and survival of *Pinus radiata* D.Don: adding the effects of seedling quality, *New Forests*

Ministry of Agriculture and Forestry, 1999, Proposed beech management plan, http://www.maf.govt.nz/Forestry/susman/wcsusmn/httoc.htm

Meyer, J.W., 1953, Continuous inventory management and growth studies, *Journal of Forestry* 51: 410-414

New Zealand Forest Owners Association, 1997, Forestry Facts and Figures 1997, 22 pp

Reineke, L.H., 1933, Perfecting a stand density index for even-aged forests, *Journal of Agricultural Research* 46; 627-638

Roche,1990, History of New Zealand Forestry, Government Printer, Wellington, 466 pp

Stage, A.R., 1973, Prognosis model, United States Department of Agriculture Forest Service Research Paper INT-164, 32 pp

Seydack, A.H.W., 1995. An unconventional approach to timber regulation for multi-aged, multispecies forests. I. Fundamental considerations. Forest Ecology and Management 77, 139-168.

Seydack, A.W.H., Vermeulen, W.J., Heyns, H., Durheim, G., Vermeulen,B., Willems, D., Fergusson, M., Huisamen, J. & Roth, J. 1995. An unconventional approach to timber yield regulation for multi-aged, multispecies forests. II. Applications to a South African forest. Forest ecology & Management 77, 155-168

Usher, M.B., 1966, A matrix approach to the management of renewable resources, with special reference to selection forests, *Journal of Applied Ecology* 3: 355-367

Vanclay, J.K., 1994, Modelling Forest Growth and Yield: Applications to mixed tropical forests, CAB International, 312 pp

Wardle, J.A., 1984, The New Zealand Beeches: ecology, ultilisation, and management, Christchurch, New Zealand Forest Service, 447 pp

Whyte, A.G.D., 2000, Growth modelling for planning sustainable wood production, New Zealand Journal of Forestry (this issue)

Zeide, B., 1987, Analysis of the -3/2 power law of self-thinning, *Forest Science* 33 (2); 517-537

Euan G. Mason

Editoral Contributions

Editorial contributions to the New Zealand Journal of Forestry should be sent to:

The Editor, Dr. Hugh Bigsby,
Commerce Division, PO Box 84,
Lincoln University, Canterbury, New Zealand.
Email: bigsbyh@lincoln.ac.nz

The Editor welcomes material for all sections of the journal, and especially professional and peer reviewed articles, critical reviews and shorter technical notes. Authors should clearly indicate in a covering letter whether they are submitting an article for peer review.

1. Articles should deal with subjects of relevance to forestry in New Zealand and the South Pacific.
2. Two copies of the manuscript should be submitted, along with a computer disk or the copy emailed. Shorter articles, letters and reviews may also be submitted by email.
3. The hard copies of the manuscript must be typed double-spaced on one side only of A4 paper, leaving a 2.5 cm margin at the left, top and bottom. The use of headings, capitals, lower case and italics should be used as in recent Journals. References should be listed at the end of the paper, in alphabetical order of authors' names following the practices used in the Journal. In the text all references should be cited by authors' names and year [e.g. Jones and Smith (1985) or Jones (1975)]. With three or more authors, use the first author's name followed by *et al.*.
4. The electronic version of the manuscript should be saved in a Word for Windows 95 format for ease of conversion by typesetters and printers.
5. Authors should also submit head and shoulders (passport) photographs of themselves to accompany the article.
6. Figures should not be embedded in the text but appear at the end of the manuscript.
7. Peer reviewed articles may be sent to suitable people for comment prior being submitted. When this has been done, the names of the referees and their comments should be included with the manuscript.
8. Papers should normally not exceed four printed pages including tables, diagrams, photographs and references. A full page of text is about 1100 words.
9. No article should be submitted which is being offered to any other journal for prior or simultaneous publication.
10. Five copies of the Journal will be supplied free to the authors of articles (but not reviews, letters, comments etc). Additional offprints may be purchased if ordered at the time the manuscript is finally accepted.
11. Photographs to use on covers and in the New Zealand Journal of Forestry are welcome at any time. Electronic versions of photographs and illustrations for use in colour should be sent as .eps files and those used in montone can be sent as .tif files. Colour images should be submitted in CMYK and not RGB format.