Growth modelling for planning sustainable wood production

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Abstract

This paper provides a brief overview of appropriate growth modelling design, utility and *modus operandi* for sustainable wood production planning and management. Emphasis is given to outlining integrated inventory, modelling, monitoring and auditing systems that are appropriate for overall planning, controlling and reporting of operational performance and also associated resource outcomes.

A relevant philosophy that is applicable to New Zealand forests which come under Part III A of the 1949 Forests Act as amended in 1993 and which conforms with international agreements and protocols as well as the RMA, is outlined. This philosophy is supported by a few wide-ranging examples that are typical of what might be envisaged. The principal aims are: (i) to indicate the place of growth modelling within the overall management process, (ii) to explain relevant and recommended forms of growth modelling, (iii) to suggest how model predictions can be monitored and controlled and (iv) to provide for ecosystem accountability. Knowledge on how to proceed in principle has been widely known for quite some time within the forestry profession, but the process is not well understood by managers and researchers who have no tertiary qualifications in forestry, nor among most politicians, media journalists and the public at large.

This paper is aimed at professional foresters, however, in the hope that the rationale outlined here can be used by them to help inform stakeholders how wood production forestry in an ecosystem can be made sustainable in their particular situations.

Keywords: *sustainable forest management, inventory, modelling, planning, monitoring, controlling, auditing systems.*

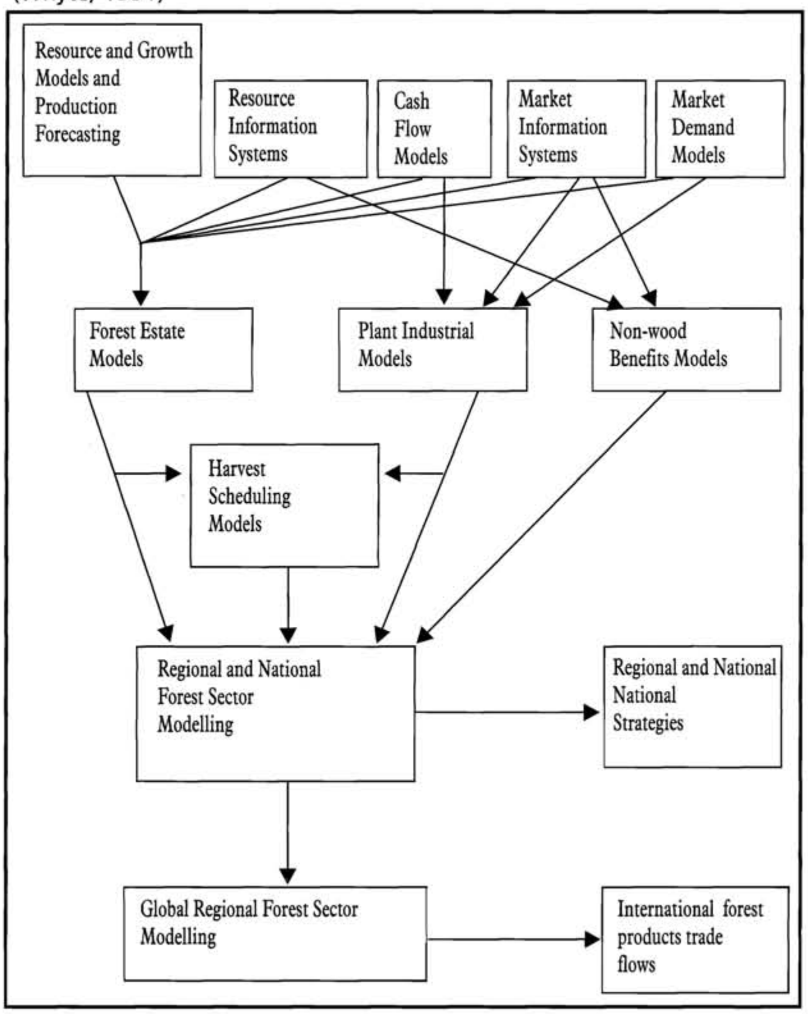
Introduction

This article reflects a personal view on the role of growth modelling for planning and managing forest resources for a range of purposes. It refers to several standard texts and publications which are reasonably well known to professional foresters. In a summary review such as this, however, it is inappropriate to go into details that are already well documented elsewhere; thus, the article simply refers to a few major sources of knowledge and some of my own publications to support the philosophy argued here. Readers interested in greater detail should consult further (e.g. Clutter *et al.*, 1983, Vanclay, 1994)

It should be noted first of all that, although growth models are an important tool in managing forest ecosystems, they are only one of several modelling tools needed in any holistic forest management system. Such systems and associated management modelling generally conform in many countries to the structure shown in Fig. 1. (Whyte,1991)

For many years, responsible forest resource managers have held to the concept of sustained yield of timber harvests in both quantity and quality, and have assumed that, if sustained yield were achieved, the whole forest ecosystem would be in good heart in all respects. But sustained yield was not always practised and even when it was, it was rarely documented in formal reports available to the public. Consequently, concerned people, including

Fig 1 Major Components of Regional and National Forest Sector Modelling (Whyte, 1991)



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forest managers themselves, have been unable to refer to and evaluate verifiable evidence about the ongoing state of ecosystems. A well known consequence is that the general public has mostly taken the view that unacceptable adverse impacts on ecosystems and associated environments occur all the time in managed forests, an attitude which is often reinforced by various media commentators. In short, wood harvesting and forestry have had a bad press in many parts of the world. To some extent, such views have not been adequately countered by either the forestry profession or the timber industry, mainly because of a lack of clear objective evidence about the ongoing state of forests and whether or not the forests are in fact being managed sustainably. Allison (1992) developed measures of determining and reporting wood supply and financial states to assist directors of an integrated wood-processing company, particularly accountants, to appraise company resource capability and performance. Similar sorts of simple measures may well be helpful today in order to provide full ecosystem accountability.

Principles arising out of the 1992 UNCED summit in Rio, together with subsequent associated initiatives and developments world-wide, have helped to restore a more balanced perspective on the true nature of forestry. The same concepts have been around for a long time, however. For example, Hartig enunciated a set of basic principles and criteria for sustainable timber harvesting and holistic management of resources as long ago as 1820. So too did MacIntosh Ellis in his 1920 forest policy statement for New Zealand. Implications of this renewed interest in monitoring, controlling and auditing forest condition have been taken on board by the international community. It is important therefore, that forest resource managers take the opportunity offered in various international protocols (e.g. the Montreal and Helsinki Processes) to document in acceptable and standard ways what impacts their operations are actually having on specific forest ecosystems. There is a particular need for harvesting personnel to be fully aware of responsibilities applicable over a broader perspective than hitherto, because they are the ones receiving the most adverse publicity.

New Zealand forest managers are required to comply with the Resource Management Act (1991) and the Forests Act of 1949. Management of New Zealand's indigenous forests is required to conform to the 1993 Forests Amendment Act, which forms Part IIIA of the 1949 Forests Act. There are four exceptions to this last requirement, forests under the stewardship of (1) Department of Conservation (DoC), (2) Timberlands West Coast (TWC), (3) SILNA owners and (4) owners of planted indigenous forests. TWC's intention to manage its forests sustainably, despite not being required to do so by New Zealand law, and to demonstrate how it proposed to achieve this worthy aim, has been thwarted by the Labour-led minority coalition government's forcing TWC in early December 1999, to withdraw its application for a Resource Consent hearing. Central to the debate on this decision has been concern about the model dealing with a combination of growth and harvesting rates used by both TWC and its opponents.

Meaning of sustainability

Sustainability is a term which is now generally understood to refer to flora, fauna and physical attributes within ecosystems, in terms of their associated biodiversity, soil and water qualities, scenic, recreational and amenity values, usufruct rights and other such system elements, in addition to harvest yields. There is general acceptance of this perspective, but sustainability still appears to mean different things to different people. There was agreement at the Rio Summit that management and use of a forest should not destroy the potential of a forest ecosystem to offer the same or even enhanced quantity and quality of goods and services in perpetuity. This had to be evaluated in terms of ecological, socio-economic and cultural considerations. Conservation of resources and their so-called intrinsic values cannot be conducted in a vacuum when there are competing pressures on their legitimate uses. Management should be directed at eliciting trade-offs so as to assist resolution of the inevitable conflict arising from competing uses for resources, but this approach can be successful only if all interested parties are willing to compromise. I have examined this issue broadly in two earlier publications, Whyte (1994a and 1996) and in relation specifically to harvesting in Whyte (1999). In each of these, there was an attempt to distil the views of many international commentators. Readers should consult such literature given in the references to these three publications for further detail.

Suffice it to say here that sustainability can be assumed to mean, from a utilitarian point of view (see Whyte, 1994a):

> *"maintaining the supply of as many benefits, goods and services at as high a joint level of each as can be reasonably supplied in perpetuity, without permanent loss of current resource management options".*

It also needs to be noted that the quality of the resource depends, on the one hand, on leaving a forest more or less intact, while on the other, recognising that some elements of the forest, (e.g. wood, fruits, bark, resins and medicinal plants) involve consumption on- or off-site. This is the kind of conflict that has to be resolved managerially and there needs to be a greater effort by practitioners directed to that end and less towards their own perception of what is needed purely from a selfish narrow viewpoint of interest.

Characterising forest ecosystems

In responding to the above challenge, forest resource managers need to be committed to collecting, processing, storing, analysing, retrieving, summarising and tabulating huge quantities of data pertaining to characteristics both within and outside the forest. All this information has to be available to managers from a regularly updated, comprehensive relational data-base management information system, which can be employed as a means of readily reporting the state of a forest ecosystem and of predicting the ecological, economic, social and cultural consequences of implementing various management activities. Multi-resource data which need to be considered in the evaluation process, might include records of:

1. land on which the forest occurs;
2. composition and structure of vegetative cover;
3. resident animal populations and their dynamics
4. yielding capacity of wood, other tree and plant products, water run-off, sediment load and the like;
5. demand forecasts for forest outputs;
6. production of goods actually realised;
7. protection, recreational and amenity values actually realised;
8. costs and revenues of sustaining a flow of goods and services;
9. labour and equipment capabilities and their productivities; and
10. social, cultural, stakeholder and environmental responsibilities.

This is far too large a topic to cover in just one short paper and so readers interested in more detailed insights should consult the IUFRO guide-lines for designing multi-resource inventory systems drafted by Lund (1996) and related texts such as Davis (1986). Detailed inventory considerations for the management of forests, range, recreation, water, soil, air, wildlife, fish, minerals and land in general are provided by Lund, but one is left wondering to what extent his guide-lines are under consideration of being implemented in current practice. The proposals advocated here are philosophically consistent with the IUFRO guide-lines, particularly with respect to setting objectives at the outset, coordinating component parts, providing reports of the outputs to meet requirements for forestry statistics, national and regional strategic planning, and assisting the implementation of tactical/operational local plans. Lund also emphasises the importance of taking advantage of modern technologies such as GIS, geo-referenced data-bases, together with electronic measurement and data-recording. Management inventory practitioners need to be aware of what is on offer in this regard and take advantage of the improved cost-effectiveness new techniques can provide.

Growth models and other population dynamics models based on historical data are needed to indicate the likely future outcomes from managing forest resources, particularly for categories 2, 3 and 4 listed above. The rest of this paper concentrates, therefore, on the role of growth modelling for production planning.

The role of growth modelling

For centuries, foresters have recognised that no forest resource can be sustained if annual removals through natural mortality and harvests exceed the mean annual increment of the whole forest. But, management today requires something more elaborate than just this simple check. Appropriate forms of model should use state variables that can be reliably and easily determined, produce outputs that are sufficiently comprehensive, accurate and managerially relevant, and which realistically represent biological processes in the forest dynamics relationships contained within the model. A very brief indication of model forms suited to planning and controlling wood harvests is given next before examining what this implies in modelling growth of New Zealand's indigenous forests.

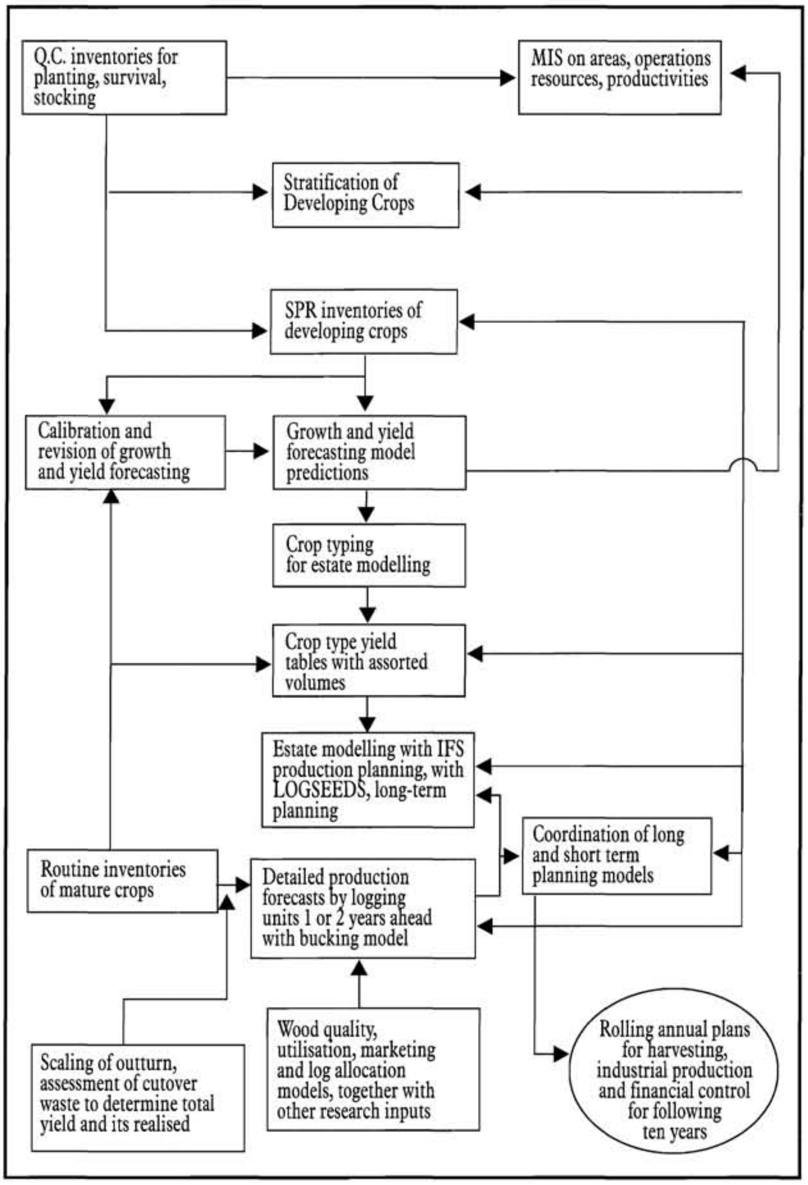
Growth models can be classified in several ways as indicated in, for example, Vanclay (1994). The focus here is on production planning models and not on process nor on ecosystem succession models. The latter two groups are unnecessarily complicated initially for routine wood procurement. Work in New Zealand on developing ecological succession and vegetation dynamics models is proceeding (e.g. Allen,1992; Coomes and Allen,1999). This type of contribution may well be useful later in the management process when understanding of growth processes becomes more important for refining wood production models. But most importantly, the type of model chosen should be consistent with the type of management envisaged. When adaptive management is practised, as TWC had been intending, then growth record updates should coincide with the planned cycles in harvesting, inventory, monitoring and auditing. The growth model should, moreover, be driven by input variables that are easily and reliably obtained through inventory and monitoring procedures. Age, for example, is a variable that is neither easily nor reliably determined when conducting extensive inventories of uneven-aged, mixed species forests. If single tree or small group selection harvests are planned, the choice of practical options for wood production managers narrows down to size-class or distance-independent individual tree models.

The state variables needed to predict future tree or stand values should, moreover, be consistent with intended management, silvicultural and wood removal systems and they need to be easily and reliably obtained through routine data collection. Garcia (1979), for example, adopted a state space approach for plantation forests in which predictions of future states reflected (i) their current state, (ii) existing site and other prevailing environmental characteristics, and (iii) silvicultural or managerial inputs to the system. Thus, future basal area per hectare might be successfully predicted from (i) present basal area per hectare, (ii) soil type, altitude, aspect, average rainfall and (iii) residual stocking/ha after thinning, addition of fertiliser, control of damaging agents and so on. Re-measured data provide the means for deriving regression relationships to describe growth over elapsed time. The same underlying principles applicable to the stand-level models envisaged by Garcia, can be applied to uneven-aged mixed species forests, but the detailed procedures need to be a little modified.

Clutter (1963) explained why growth and yield models should possess several basic, general properties: compatible growth and yield estimation; an inflection point and upper asymptote; numerical consistency; and path invariance. These terms mean, in turn, that the area under the growth curve should equal the yield, that its functional form should be sigmoidal, that the same output should be achieved irrespective of length of period of elapsed time used, and that the same output at a given time should be obtained no matter when the projections commence. Again, these basic requirements apply to all types of forest, but with adaptations to suit individual circumstances, as is discussed later.

Current forms of growth and yield model generally consist of equations for projecting stand or tree variables, relationships for converting these variables into outputs

Figure 2 Overall timber production planning system and its components (Whyte, 1987)



needed to help in making management decisions, allowances for the rate of natural mortality and recruitment into measurable size, and potential recovery of assorted wood realisations. The application of harvest rules and yield control (see Whyte, 1992) are usually catered for in separate forms of model, a typical example of which is shown in Fig. 2.

For mixed species forest, there might well be equations for projecting individual tree diameters, forecasting rates of natural mortality, predicting recruitment into measurable dimensions, using either one-dimensional volume functions or combined height/diameter and two dimensional volume functions to estimate product volumes, functionalising stem taper and tree bucking practices to dis-aggregate total volumes into log assortments, cull factors (i.e. allowances for defect, stem breakage in felling and other unmerchantable proportions).

These sub-models may need to be separately identified and run for sub-populations such as: forest and soil type; prevailing site conditions like position on slope, altitudinal class and aspect; silvicultural history (e.g degree of tending, control of levels of debilitating agencies and application of fertiliser); and administrative unit (e.g. cutting section and felling series).

In plantation forestry, these aggregations are called crop types, but for mixed species, uneven-aged forest managed under continuous cover, this term is inappropriate and forest type should be used instead. All of these and possibly other categories may need to be considered when using growth and yield models routinely for planning, monitoring, controlling, auditing and reporting operational performance (see Whyte, 1999).

These sub-models also need to be coherently integrated, as there is little point in refining any one component when others may be so less precise and inaccurate that they obliterate the sensitivities in refining just one component. Inventory and monitoring, for example, should output reliable estimates of the state variables to input to the growth model. An appropriate balance in refining growth model predictions, therefore, must be struck for all contributing components simultaneously, not just for one at a time. That is, the inventory design and conduct should include monitoring of all the functions, as explained in Whyte (1979, 1992 and 1994b) and shown in Fig 2.

Development of suitable growth models is best based on data from long term permanent sample plots (PSP's). The use of increment cores is not ideal when applied to management inventory data, unless mortality and recruitment rates are separately determined in ways consistent with the overall measuring and sampling procedures. For example, data collected for TWC's beech harvest model were based on increment core sampling at PSP sites, and then a moving average determined for broad diameter classes. The size of sample in this case was relatively small, given field observations about major influences on tree growth such as altitude, stocking rate, species composition and stand structure. No stratification into these classes was carried out.

Moreover, data using increment cores cannot provide information on mortality and seedling and sapling recruitment rates. Mortality functions are often the weakest component of any growth model, because the patterns are rarely consistent and not clearly defined. Evidence from PSP's in West Coast beech and Westland podocarp forests confirm that mortality is episodic and localised and probably related to the occurrence of earthquakes and cyclones and to the impacts of animal pests. Recruitment patterns are similarly affected. What has occurred in the past may have no bearing in the future.

In another context for example, historical evidence suggested that the probability of experiencing high intensity cyclones in Fiji was predicted to be 1 in 100 years, but in the 1980s there were three which exceeded that high intensity in the space of four years (see Whyte, 1994b).

Growth models for indigenous species

FRI has produced growth models for most plantation species in various regions of New Zealand, but none for indigenous species. Researchers such as Beveridge, Franklin, Halkett, Herbert, Smale and Wardle (see Wardle, 1984 and Hammond, 1995) have set up numerous trials in indigenous forests being managed for timber production, but they have not attempted to report anything more than average rates of growth in tree diameter and periodic mean annual increment of volume per hectare.

Matrix models (see Vanclay, 1994) assume a steady state approach, which is inappropriate for a system of adaptive management and unrealistic irrespective of whether or not any wood harvesting is envisaged. Forest ecosystems are dynamic, not static entities.

TWC planned to set up permanent sample plots to monitor growth, mortality and recruitment trends over periods of five to 15 years. The claims that TWC's beech management plans were "unsustainable" is unjustified, given the inappropriateness and the incompleteness of the available modelling those critics relied on. TWC's proposed level of wood harvest would have been far below the well documented mean annual increment level found in beech forests (see e.g. Wardle, 1984) and so the future forest composition and structure would likely have been more or less maintained. Sufficient time was available, without compromising the resource, to rely on continuous monitoring of the ecosystems to provide verification of sustainable outcomes.

The Indigenous Forest Unit (IFU) within MAF commissioned an independent study on growth models for indigenous species to assist with sustainable and adaptive forest management planning. The first was for Southland (Whyte and Zhao, 1999a), and used by MAF Policy to help in determining sustainable forest management valuations for SILNA forests, then a second series for beech and podocarp species in Westland, the West Coast and Southland. Accordingly, re-measured tree data from more than 150 PSP's in beech and podocarp forests were retrieved from FRI archives in November, 1999. Tree diameters at breast height were modelled first and showed that growth varied enormously, but could be related to species composition, inter-tree competition indices and possibly soil type. Predictions using these draft models of diameter growth (Whyte & Zhao, 1999b,c,d), need to be checked through routine monitoring inventories, and are available to forest management planners from the IFU. As mentioned previously, mortality in these PSP's is so irregular that functionalising the average rate of mortality is not yet practicable. The same holds for recruitment by forest type. But suitable monitoring and other inventory routines necessary for running an adaptive management system will provide better indications for all three main growth model components, as time goes by.

Monitoring, controlling and auditing

Proof of sustainable management can never be guaranteed: it needs the passage of time and evaluation of reported system outputs and operational performance over 20 or 30 years. But evidence from Scandanavian and Central European forests has shown that traditional and desirable forests have been sustained with intensive harvesting for centuries. The greatest threat to their forests at present is probably acid rain and other industrial pollution. In New Zealand it is likely to be depredation by pests and diseases. But, the long production cycles in forestry provide ample time for checking outcomes over 30 or so years.

The three managerial functions, monitoring, controlling and auditing, should be addressed and conducted within organisations and designed to suit individual circumstances. External auditors have an important role to play in reviewing the nature of internal management systems and reports, and in making a few random checks here and there, but there is a limit to how much they can do on their own if working to a limited budget.

For example, would these external auditors be expected to calibrate tree volume, taper and growth functions and merchantable recoveries for every forest ecosystem, or monitor the quality of water, stream sedimentation and soil stability throughout the forest, or check that harvesting operations have not had adverse impacts on all birdlife in general, and so on. Dykstra and Heinrich (1995) have produced a model code of safe forest harvesting practice on behalf of FAO, and New Zealand's own version of a code of practice (Viser & Smith, 1993) would need only a little revision to meet internationally acceptable standards.

But the major concern remains, that, if full monitoring is done by outsiders, their procedures are unlikely to be compatible with the multi-resource inventory and modelling systems employed by the forest organisation being audited. The disadvantages and inefficiencies of duplicating the whole monitoring process (one for certification and the other for management purposes) is undesirable, particularly when costs of monitoring in the present and future environments are very much greater than has hitherto been practised. Fuller discussion of such issues is also covered in Lund (1996), Palo & Uusivuori (1999) and Whyte (1999).

Conclusions

This brief review suggests that providing objective evidence to demonstrate that forest ecosystems are being sustainably managed requires more than just growth models and harvest rules. It indicates where growth modelling fits within the management system and the need to:

- design integrated multi-resource inventory, monitoring and modelling systems that reflect variation in forest composition and structure and the system of management being employed;
- set clear coherent objectives for all parts of the

management process;

- provide management information systems from which evidence about the dynamics of forest ecosystems can be unequivocally deduced and reported;
- develop and utilise growth models which are in balance with overall system sensitivities; and
- focus on internal monitoring and reporting of operational performance and the state of ecosystems, in addition to auditing and certification by independent outsiders.

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Forestry Software use in New Zealand

Hugh Bigsby

In order to get an idea of what software people are using in the forestry sector, a survey was sent out with the November issue of the Journal. There were only 27 respondents to this inaugural survey so the results will have to be viewed accordingly. Nonetheless, the surveys that were returned provide some interesting observations.

Respondents were asked to indicate the major types of forestry analysis that they were involved with. As can be seen in Table 1, most were involved in some sort of financial analysis or forest valuation activity. In many cases this also meant that they were also involved in plantation establishment and management, or involved in wood supply analysis.

Respondents were asked to identify the software that

Table 1 Major types of forestry analysis

Financial Analysis and Forest Valuation	22
Plantation Establishment and Management	17
Wood Supply Analysis	12
Forest Engineering	0
Forest Health	1
Market Forecasting	1
Logistics	1
Harvesting Documentation	1