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Design and Implementation of a State-of-the-art Inventory Reporting and Yield Forecasting System for Indigenous Forests

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Abstract

Inventory for forest management cannot be divorced from area estimation and yield forecasting. An integrated area-inventory-forecasting system is essential for efficient and effective forest management. Such a system implemented by the Queensland Department of Forestry has proved versatile and useful.

The forest estate is divided into management units for administrative and management convenience. Each management unit is further stratified into homogenous subunits, for which both gross and nett areas are determined. The area information sub-system is implemented on desk-top computers in regional offices, and local staff familiar with the area provide and update the area data.

Inventory ensures at least two plots per subunit enabling computation of sampling errors. Additional plots are established in subunits with high sampling errors to minimize overall sampling errors. Inventory data is stored on a central computer network in an hierarchical file structure with one plot per file. This approach is efficient and flexible, and facilitates the retrieval of selected data. Software for validating, editing and reporting simplifies management of the data.

Yield forecasting employs heuristic simulation to predict the logging schedule, grows each individual plot to the scheduled year of logging, and estimates yields and standard errors for each management unit. The information so provided enables both strategic and tactical planning. Users may specify minimum and marginal stem sizes and yields per hectare, as well as economic and operational criteria which influence the simulation of the logging schedule and the predicted yields. An interactive user interface enables users to investigate silvicultural alternatives for individual forest stands.

The system has been favourably received by users. Printed and on-line documentation and on-line help assist both new and experienced users.

Introduction

One often neglected component of inventory systems is the analysis and reporting of data. Too many agencies suffer "information constipation", having vast amounts of data and no efficient means to analyse and report meaningful information in the form required.

The Queensland Department of Forestry has recently re-appraised its inventory requirements in indigenous forests (Vanclay *et al* 1987), and a new state-of-the-art system has been implemented. In this paper, I shall not dwell upon field procedures, but shall concentrate on that the analysis and reporting of data. The system is designed to provide analysis and reporting at the regional and provincial level, although the output can be further aggregated as necessary. The primary use of the system is for analysis and reporting of timber and other commercial aspects of the natural forests in Queensland, but provision has also been made to accommodate non-commercial aspects.

Information concerning the present resource is generally derived from inventory plots which indicate units per hectare. To obtain the full picture, areas corresponding to each plot must also be provided. Thus two essential components of an inventory reporting system are area and plot subsystems. The future nature of the forest and availability of forest products is also a major information requirement, and this requires an integrated growth prediction system.

Area Information

Several methods may be used to compile and reconcile area data. However, one of the most flexible and useful approaches is to identify unique parcels of land, and record relevant attributes for each. The lands under the control of the Queensland Department of Forestry have been divided into Management Units (MUs), defined for administrative and management convenience. Each MU is further stratified into subunits, each of which is relatively homogeneous with regard to accessibility, forest type, site quality, stocking and logging history. There is no prescribed size for MUs. The appropriate size depends largely on the nature of the forest and the intensity of management. Thus in the productive coastal forests, MUs may be as small as 10 hectares, whereas in the sparse forests of the arid inland, MUs may exceed 10 000 hectares. Subunits may be any size necessary to achieve reasonable homogeneity.

Attribute data is compiled for each subunit, providing a place oriented geographic information system (GIS). Contrast this with the more common factor oriented GIS where information is stored in layers, and details for any particular place are provided by overlaying the relevant layers. The factor oriented approach is widely used and most appropriate for well mapped areas, but may be cumbersome where mapping is inadequate or where data are absent for substantial areas. An advantage of the place oriented approach is that missing values can easily be accommodate. It also facilitates checking and updating of information for any subunit, and enables yield predictions to be checked against realizations.

For the present application, there are several advantages of the place oriented approach. Attributes can be collated on those subunits for which details are available, and missing values can be accommodate within the system, to be completed as data become available. MUs and subunits are have not yet been digitized into a GIS, but are maintained as paper maps, which can easily be reproduced on a photocopier. Attribute information is stored on computer for efficient interrogation. This approach is upwardly compatible with a GIS approach. Avoiding the complexity of digital graphics enables this system to be implemented with less expense and fewer computer resources.

The area subsystem is implemented in regional offices on desk top computers (IBM PCs) in Nantucket Clipper, a compiled look-alike of dBaseIII. The design philosophy was to ensure that the system was easy to use, and useful for field staff, thus ensuring that it would be used. I am sure you have experienced the "black hole" syndrome, where some distant Head Office requests lots of complex and seemingly unnecessary information, never provides any feedback, and gets no enthusiasm or cooperation. To avoid this syndrome, we created a system which was owned by regional staff and was useful for them in their day to day work. Regional staff are asked to provide copies of their system after any changes, both for security and to provide the information desired by Head Office. This procedure has worked very well, but it does mean that the system is bigger than it would have been had it been designed to service Head Office needs only.

What does the area subsystem record?

For each management unit: Its name, administrative details (Region, Parish, Tenure, etc.) and a remarks field for regional staff to use as they wish.

For each subunit:

- MU and subunit identifiers,
- Gross and nett areas, and an indication of their reliability,
- Management intent and accessibility for logging,
- Forest and soil types using the standard classifications,
- Australian Map Grid (AMG) reference,
- Year of last logging and silvicultural treatment,

- Presence of any special timber products (telegraph poles, etc.),
- Standing and loggable volumes, and an indication of reliability,
- The unique identifiers of any inventory plots within the subunit,
- Date of any modification to any entry for this subunit.

The system includes rigorous validation to ensure that all entries are valid and reasonable. The estimates of area and volume require an indication of the reliability to be given. This is an important concept, and enables the system to be initiated with subjective and possibly unreliable information, and to be progressively improved as time and resources permit. The reliability is given as a code in the range 1 to 5, where 1 indicates perfect information (e.g.. areas derived analytically from surveyed boundaries clearly visible in field; volumes derived from several plots within the subunit for which the sampling error does not exceed 5 percent) and 5 indicates approximate information only (e.g.. areas derived from coarse dot grid count on poorly defined subunit; volumes guessed without field inspection).

This incremental approach to implementing the system was particularly useful at the time it was introduced. The Department then had many field staff who were approaching retirement and had served much of their careers within the one region, accumulating an intimate but subjective knowledge of the area. It was desirable not to lose this information when these staff retired. These staff could have recorded their recollections on paper, but usually such reports gradually become buried by other papers on file, and cannot readily be interrogated. The area subsystem provided a focus for the recording of information, and ensured complete details, for all subunits and for all attributes.

There are few standard reports from the area subsystem. Reporting most frequently takes the form of user defined reports. The area subsystem is set up so that users can easily select only those MUs or subunits satisfying specified criteria, and report only those attributes they require, in the order they specify. They may also specify which numeric fields they wish to have summed or averaged. Typically, a manager may request a report indicating the identifiers of MUs containing *Eucalyptus cloeziana* of sufficient number and form to provide a viable harvest of telegraph poles.

"The proof of the pudding is in the eating", and the area subsystem has proved itself in this regard. It is now being regularly used by field staff with no previous exposure to computers and has received ready acceptance with minimal training.

Selecting Inventory Data

The inventory subsystem and database have been designed to simplify the selection and reporting of inventory data. They are implemented on a Unix computer system, but the design concepts would be applicable to most computer systems.

A hierarchy is used for both identifying and storing inventory plots. Each inventory plot is stored in its own file, the name of which is identical to the plot identifier which is a 10 character reference indicating Region, Year of measure and Plot number: RR/YY/NNNN (e.g. 01/89/0123). This provides an efficient, meaningful and unique identifier for each of the 20000 plots presently in the database.

Inventory data is stored in a form as near as possible to the way it was recorded on the field form at the point of collection. This facilitates detection and correction of errors in data entry. The format is also sufficiently flexible to enable different amounts of detail to be accommodated. The first several lines of the file comprise the plot header, and identify the plot, its location, size and layout. Plot attributes such as site quality, forest type, soil type and so on are also recorded here. The header is followed by the individual tree data, stored with one tree per line, and recording species, diameter and other attributes. As varying line lengths are permitted, trailing blanks are, not stored, providing a compact means of storing the data. Historical data which recorded only species and diameter, can be processed in the same way, with the same software, as more recent data which recorded additional data such as straightness and thinning codes, log lengths and crown quality. This system allows expansion to accommodate any additional attributes which may be required in the future.

A design feature of the the entire system which is particularly conspicuous in the inventory subsystem was the creation of a suite of simple programs rather than a single large, complex program. This simplicity greatly reduces the time and cost of writing and maintaining the software, and increases portability. Unix facilitates this design by providing "pipes" which enable the output of one program to become the input to another, so that simple programs can be chained together into a "pipeline" to perform complex tasks. The inventory subsystem exploits this facility by providing a standard input/output for all programs, being a list of inventory plots. Some programs create lists of plots, others modify these lists, and a few compile reports on the plots so listed.

The inventory subsystem comprises computer programs which perform several functions, including inserting, modifying and checking data; producing and modifying lists of inventory plots; generating reports; enabling interactive investigative analyses; and providing on-line documentation (Vanclay 1988). Programs to create and modify lists of inventory plots include programs to:

Create lists of inventory plots: **get** lists all the plots within nominated directories (which may be the whole lot, one or two regions, or a few years only) and search lists all plots which match a string specified by the user. The area subsystem can of course, provide these lists directly.

Add details to lists of inventory plots: dist determines the distance from each plot to a reference point specified by the user, and extr extracts information (stocking of specified species, standing and loggable volumes, etc) from the plot. Both append this information to the list in the comment field following the plot identifier.

Modify lists of inventory plots: sort and strat alter the order of plots in the list; strat also inserts controls to initiate the production of stratum reports. Choose and except delete unwanted plots from the list. Choose selects on specified strings for text fields and specified ranges for numeric fields, and can select for location, stocking, site quality, stand composition and many other attributes.

Report information from lists of inventory plots: nodist reports the number of inventory plots by location and year of measure, and spock reports the species occurrence within each region.

The most frequently used reporting programs are rip (report on individual plots), rol (report on one line) and **map,** and are described in more detail below.

Prepare yield forecasts and harvest schedules: sked

Enable interactive investigation of growth and silviculture: whatif

This flexibility in selecting inventory plots from the database has greatly assisted the ability of the Department to respond to information needs. A typical application might be to indicate the species available and stand tables stratified by forest type within 300 kilometres of a proposed woodchip operation. A map (at 1:250000 scale) showing available yields per hectare is also required. This information can be supplied in minutes using these three pipelines:

get $NFI/11 | dist 570800767700 | choose 0 300 | tee file | spock –np
strat +3 <file | rip -b -dN -nc +S n 9 -P CU
map -s250000 +12 10 CU <file

The first pipeline **get**s plots from the Rockhampton region, computes the **dist**ance of each plot from the proposed mill location, **choose**s plots within the range zero to 300 kilometres, keeps a copy of this list on **file**, and reports the **sp**ecies **oc**currence showing both the numbers and products of species encountered in inventory.

The second pipeline **strat**ifies the list from **file** on forest type (field 3), and prepares a stand table report for each stratum, showing numbers of trees of chipwood or useless form, and their common names for the nine most common species. This would of course, give only an approximate indication of the stand table. A more reliable estimate could be prepared by employing the areas for each stratum, provided by the area subsystem.

The third pipeline produces the lineprinter **map** showing the basal areas (field 12) of trees of chipwood or useless form which exceed 10 cm diameter. Basal area rather than volume is reported, as many of these non-commercial species will have no volume equation.

Reporting Inventory Data

Flexibility and ease of use were key design principles in creating the inventory reporting subsystem. Accordingly, the reporting programs are highly flexible, and can readily be tailored to meet almost any user requirement. Most needs are met by three programs, **rol** (which reports each plot on one line), **rip** which prepares a full page report for each individual plot and aggregates these into stratum reports, and **map** which produces map overlays showing plot locations and attributes.

The **extr|rol** pipeline can report on any or all of the following, in any order determined by the user:

- Location (descriptive or AMG reference)
- Logging and treatment history, fire and storm damage, accessibility
- Forest type, soil type and site quality
- Species composition (by number, basal area or by volume)
- Total stocking (number or basal area)
- Merchantable stocking (number, basal area or volume)
- Stocking (number, basal area or volume) expected to be harvested during next logging

Individual plot reports are perhaps the most flexible in the whole system. **Rip** prepares a two-way table for each plot, revealing the number, basal area, volume and/or total log length within each cell. Users can elect the basis for preparing the table, typically species by size (dbhob, dbhub, d-line[1] or log length), size by species or diameter by length. Two tables for each plot are optionally available, one reporting the selected stand fraction, the other reporting the whole stand. Users can define the selected fraction by species, size, potential products or anticipated removals at the next thinning. Stratum reports are also produced.

The output of both **rol** and **rip** is written to a file, which can be printed or reformatted into a form suitable for spreadsheets such as **visicalc** and for further processing by 4GLs.

Maps are another essential form for reporting inventory data, and **map** enables both the location and attributes of inventory plots to be printed as a line-printer map at any scale. Map scales can be determined automatically or specified by the user. The same data can be transferred to a GIS and plotted on transparent film with greater precision, but experience has shown that line-printer maps are a rapid and cost effective alternative more frequently chosen by users. Map can display both qualitative and quantitative data. With quantitative data (site quality, stocking, loggable volume, etc), the minimum, mean or maximum value within any print position (1/10th inch square) can be shown. Users may specify the scaling to be used, or may use the automatic scaling which will scale all values into the range 0 to 9 for display. With qualitative data (forest and soil type, tenure, major species), the user specifies which character of the string is to be plotted. In case of conflict, an asterisk is normally plotted.

Yield Forecasting

There are typically three key questions asked by the forest manager regarding yield forecasts:

- What is the maximum sustainable yield;
- If the present cut exceeds this, for how long can it be sustained (without detriment to the forest); and
- What is the nature (average stem size, species composition, yield per hectare) of future harvests?

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[1] d-line is diameter under bark at 2 metres above stump, and is the basis for grading and selling telegraph poles

The yield forecasting subsystem is designed to provide all this information. Standard reports indicate the average stocking (basal area and volume) for the entire resource, and detail the characteristics of the harvest from each MU as it is scheduled for harvesting. Details provided include

- Identity of MU
- Years since last logged
- Area logged
- Average stem volume of harvest
- Average yield per hectare
- Standard error associated with yield estimate
- Proportion of harvested volume from nominated species
- Size (dbh) distribution of harvest
- Species composition (Species and proportion for 3 major species) of harvest

The user may specify if these details are to be reported for each plot, for each subunit, or if details are to be aggregated by MU before reporting.

Yield estimates are prepared by heuristic simulation, and the user may specify a number of constraints. The user may specify minimum average stem volumes and yields to be obtained from MUs and subunits to be included in logging. Users may also specify minimum acceptable running averages for a given number of consecutive MUs, and limits on the acceptable species composition. The minimum interval between successive harvests on any MU may also be specified. MUs may be grouped, and simulation constrained to complete harvesting within any group before a new group is commenced.

Typically the user will nominate a target cut which the manager wishes to sustain within the nominated region. The user may specify the strategy for scheduling MUs for harvesting. Normally the MU with the highest loggable yield per hectare is chosen, but the user may specify longest time since last logging or highest standing basal area. In addition, the user may specify a logging sequence for some or all MUs, which will precede other constraints.

Vanclay and Preston (1989) provide an illustration of this methodology and reporting. These provisions satisfy most timber forecasting requirements.

Interactive Simulation

Another important role of resource information systems is to enable interactive analysis of silvicultural alternatives. Whatif enables interactive use of growth models to study of the growth of real or hypothetical stands under different regimes to investigate silvicultural alternatives and resolve "what if ..." questions. Several simulation options are provided, principal among which are:

Grow the stand a specified number of years, until the stocking (stand basal area or standing volume), or the merchantable volume or stem size reaches a specified level.

Log the stand, using the standard logging simulation model (e.g. Vanclay 1989), removing all merchantable stems exceeding a specified size, or soliciting the user's intention for each species and size class specified by the user.

Treat the stand, applying standard treatment rules, reducing the stocking of specified species and sizes to a specified residual, or soliciting user's intention for each species and size class.

Undo the last (grow, log or treat) command.

Save the present situation for future reference. This is useful for examining different logging or treatment options for a stand which can be logged, treated and grown several times, using different strategies.

Restore stand as at last save.

Display current stand as a stand table, using size classes specified by the user.

This interactive system has been used extensively in developing silvicultural guidelines and in investigating management alternatives. It has been implemented on PC and made available in regional offices, and is extensively used by field management staff.

Feedback

The Department's marketing system will provide details of yields realized from MUs, and these can be compared with earlier predictions. It is unrealistic to expect that predictions for any single MU should be exact, but the average for several MUs should be unbiassed.

An integrated inventory and marketing system enables differences between predictions and realizations to be monitored. Any bias may generally be attributed to area netting factors, growth and harvesting predictions (if made), and volume equations (our procedure is to use volume equations for yield prediction, but actual log measure during sales). Excessive variance may indicate poorly defined MUs or subunits, or inadequate inventory.

The definition of MUs and the integration of these systems provide early warning of any faults in yield predictions.

Discussion

I hope that I have given you some ideas as to what you might find useful in an inventory reporting system. Although I've presented a few specific examples, my intention has been to convey ideas and concepts. Don't simply copy what we've done in Queensland, but develop these ideas to your own requirements. I cannot overstress the importance of identifying your own information needs, and how you wish to have this information reported. Similarly, the design of the system is vital; careful consideration of the design and operation needs of your system will pay dividends.

The hardware and software are of little importance (Area subsystem on IBM PCs with MS-DOS, rest on MIPS 2000 with Unix V), but Unix facilities have greatly facilitated the simplicity and flexibility of the system. Sophisticated computer languages are not necessary: the entire system is written in ANSI standard Fortran-77, except the area subsystem which is implemented in Nantucket Clipper, a dBaseIII clone.

The system is successful because it satisfies user needs, it is easy to learn and to use, and is well documented. A key feature is that the several components follow the same design concepts, and that information can be easily passed from one subsystem to any other.

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