Integrated sampling strategies – application at the regional and continental levels for monitoring sustainable forest management

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Abstract

Adaptive management has been accepted as a core principle underpinning sustainable forest management throughout the world. Monitoring, assessment and reporting is fundamental to the process of adaptive management. Information provided through monitoring assists with forest industry development, raises community awareness of forest issues, and improves the responsiveness and relevance of programs on sustainable forest and environmental management. Utilisation of Montreal Process Criteria and Indicators (C&I) for sustainable forest management related monitoring and performance assessment within Australia, and worldwide, is increasing. Presently many indicators can only be reported as narratives, making quantification and comparison of trends through time difficult. Even those indicators for which quantitative reporting is possible, trends are at best indicative only due to the extent of spatial and temporal inconsistencies in measurement methods. These limitations led the Australian National Forest Inventory (NFI) to commit to develop the Continental Forest Monitoring Framework (CFMF) using integrated sampling strategies as a way to substantially improve Australia's capacity to meet its monitoring and reporting obligations. The development process has been strongly influenced by a regional study undertaken in 2000 to test the feasibility of systematic sampling schemes combining field and remotely sensed data. This study was carried out in central Queensland and demonstrated that combining ground based and remotely sensed data within an integrated sampling strategy greatly improves the efficiency and operational reporting and monitoring of a range of C&I for sustainable forest management.

Keywords: Criteria and Indicators, monitoring plots, remote sensing, integrated sampling strategy

Introduction

Sustainable Forest Management (SFM) has been a central scientific, social and political goal for many years. While governments and the community are critically interested in assessing progress towards SFM, the concept and definitions of SFM continue to evolve. C&I such as those of the Montreal Process have been developed to provide tools to identify trends in the forest estate arsing from a wide range of forest management practices (Commonwealth of Australia 1998). These tools contribute to enhanced understanding on what SFM is and provide a common framework for describing, monitoring and evaluating progress towards SFM. The C&I framework is not the only mechanism for SFM assessment, but it has been widely accepted nonetheless (Yokohama Meeting, 2001). While there is general acceptance that C&I tools are useful and desirable for SFM, actual implementation can take longer to achieve. In Australia, C&I reporting on forests is used to inform public debate, to support policy development, to inform industry investment, and to meet national and international reporting obligations. C&I frameworks therefore are being used as a tool to monitor progress towards addressing issues regarding the sustainable management of the present forest resource. Such issues include balancing biodiversity and harvesting requirements, dealing with the impacts of introduced plants and animals, investigation of biomass/carbon sequestration and emissions, dealing with water use and salinity, and assessment of various policy responses (such as creating conservation reserves and landholder extension programs). Addressing these

issues will have a major bearing on the future health and prosperity of Australians and the Australian environment, and requires information on the baseline and trends in condition of forest resources (Commonwealth of Australia (in press)).

Prior to the establishment of the National Forest Inventory (NFI) in 1989, capacity to report nationally on Australia's forests was limited. In the 13 years since its establishment the NFI has compiled a complete and relatively consistent baseline snapshot of Australia's forests – their extent and basic characteristics. The NFI had to rely on a compilation approach for national reporting due to limited resources, demands for immediate reporting, the system of government, and resource management responsibilities. This meant that data was compiled from a variety of pre-existing sources and collected to a variety of standards. This approach has been largely successful in meeting the immediate need for a snapshot of Australia's 163 million hectares of native forest and just over 1.5 million hectares of plantations (National Forest Inventory 2002). However, its limitations have been evident in attempts to report comprehensively against condition or trends (eg *Australia's First Approximation Report for the Montreal Process* (Commonwealth of Australia 1997) and *Australia's State of the Forests Report* (SOFR) (National Forest Inventory 1998)). Also it is unlikely that the time, staffing and financial resources available to States and Territories will continue to be available to continue to undertake mapping at the required detail.

In completing each snapshot and the associated national statistics on Australia's forests major gaps were identified in Australia's capacity to report nationally, in particular for areas of forest other than those most intensively managed for timber production (Commonwealth of Australia (in press)). For C&I reporting for instance, many of the indicators could only be reported in a narrative fashion, making assessments of trends through time only subjective and qualitative. Even for those indicators for which quantitative information was available, trends are at best indicative due to the extent of spatial and temporal inconsistencies in measurement methods and the sampling base. Therefore, as the demand for forest information and reporting of trends has continued it is evident that the compilation approach presently used by the NFI is unable to provide the required detail needed for trend analysis.

To address these issues the Continental Forest Monitoring Framework (CFMF) is being developed by the NFI as an alternative approach. The approach has drawn on expert panel discussions and commissioned research (Vanclay unpub), to produce Terms of Reference, which include:
- Provide authoritative data to meet national reporting and monitoring requirements for criteria and indicators of sustainable forest management.
- Establish a cost efficient, permanent site-based sampling framework utilising the relative strengths of field derived and remotely sensed data that samples forests at fine scales, while continuing to map forest type and extent at coarser scales.
- Measure a specified list of agreed metrics (including - forest extent and structure (height, cover), forest type (genus, species), growth stage, tenure (including private individual, industrial, institutional), reserve status (including reserves on private land), intended land use (areas zoned or intended to be managed for various objectives), disturbance, and forest health.
- Utilise existing data where possible and report all estimates of change for metrics at 5 yearly intervals.
- Implement the CFMF in stages.
   - First stage - develop the concept and rationale.
   - Second stage - develop a CFMF sampling design at a continental scale that will be piloted at a regional scale and reviewed.
   - Third stage - progressively implement the CFMF across the nation.
   - Final stage - a 5 year report and review.

This paper addresses some of the reporting requirements of C&I for SFM and discusses how a CFMF utilising integrated sampling strategies is being developed. In order to do this, two main questions need to be addressed:
- Do these strategies provide the best way forward for SFM monitoring, assessment and reporting?
- How would these strategies be applied, and what are the major issues with implementing these strategies under a CFMF?

Integrated Sampling Strategies – the approach

With increasing demands for more accurate and timely information to meet C&I reporting requirements, the need to develop and implement integrated and comprehensive sampling and mapping strategies is recognised. Technically, field survey is capable of meeting many of the information needs for SFM. However they cannot provide information at the required intensity, precision and timeliness of survey in a cost effective manner, especially when remote sensing can offer a more efficient alternative for many attributes. Therefore key components of an integrated sampling strategy should include the development of efficient mechanisms for scaling-up field data to the landscape through the use of remote sensing, the ability to routinely evaluate and update estimates of key forest/woodland attributes, and to undertake this task in a cost effective and efficient manner (Tickle *et al.*, 2001). In developing these strategies it is crucial for natural resource scientists, managers, and policy-makers to recognise that:
- The value of remotely sensed data for operational vegetation assessment depends on the ability to accurately, efficiently and cost-effectively retrieve key biophysical attributes, such as vegetation extent, density, height, species composition, biomass and health.
- Few attributes can be currently mapped wall-to-wall cost-effectively and at the scale required for various monitoring, strategic planning or policy purposes. Many attributes may therefore need to be sampled using, for example fine spatial resolution airborne or spaceborne sensors and/or field survey.
- A combination of remote sensing systems at a range of scales may be required to meet forest assessment and monitoring demands, for attributes that are suited to assessment by remotely sensed data.
- Many attributes (e.g. merchantable timber products) cannot be estimated to an acceptable level of accuracy using remotely sensed data and sampling in the field is therefore the only option.
- Remote sensing cannot operate in isolation from field data, which is an essential component of calibration and validation methodologies. These methodologies can also help to reduce operator bias through automation.
- The identification and quantification of change in structural attributes will be dependent upon the temporal frequency of observation. For example, to detect changes in land use, observations on a more frequent basis (monthly to annually) are required whereas changes in forest/woodland health or species/community composition may require comparison of data over longer time periods. Observations at different spatial scales will also become important and dependent upon the size of the object of interest in relation to the spatial resolution of the observing sensor.
- Due to issues with spatial and temporal variability of many attributes, reporting requirements are only likely to be fulfilled through development and implementation of an integrated and comprehensive sampling and mapping framework.

Until the advent of widespread aerial photography and subsequent satellite remote sensing in the 1980's, forest inventories were exclusively based on ground plots and transects. Changes through time (or trends) have been estimated either through comparison of successive aggregate values from single-measure temporary plots, through aggregation of compared successive measures of individual permanent plots, or through a hybrid (sampling with partial replacement). Permanent

sample plots are the most direct measure of change, providing the most effective assessment of trends (provided they are representative) (Scott 1998) and are widely utilised throughout the world to, for instance, measure forest and tree growth. Similar permanent site remeasure systems are also widely applied to monitor a range of other environmental attributes such as environmental pollution and soil condition (Bureau of Rural Sciences, unpub).

Systems such as this are not new to forestry and a number of countries comparable to Australia approach to forest management (most notably Canada, New Zealand and the USA) have faced similar issues and have implementing similar permanent plot-based inventory approaches. All three countries have extensive areas of relatively undisturbed natural forests over which the level of management intervention is relatively limited. Additionally the natural forests include a high proportion of poorly accessible areas and the level of existing knowledge is limited. The inventory systems are based on a systematic grid using permanent plots with limited if any pre-stratification. Sampling is based on simple and flexible (but less efficient) systematic grids, and are commonly two-stage (or phase) incorporating Air Photo Interpretation (API) (as in the case of the USA) or satellite based remote sensing (as in the case of New Zealand and Canada). However sample density, plot dimensions, shape and orientation all vary considerably between countries with no apparent rationale other than history (Bureau of Rural Sciences, unpub).

Some Australian institutions are already committing effort to monitoring trends. These systems are either national inventories directed at a subset of the questions similar to those being addressed by the CFMF, or they are addressing these issues for only a subset of the geographic area. Examples include the monitoring of biomass as part of the National Carbon Accounting System (Furby, 2001), State of the Environment reporting (Hamblin, 1998), the Australian Collaborative Rangeland Monitoring Information System (Commonwealth of Australia, 2000), the pilot Private Native Forest Inventory in south east Queensland (Ryan, *et al*, 2002), and as part of the Natural Resource Management National Monitoring and Evaluation Framework. Significant potential exists between these systems and the CFMF for economies of scale in measuring attributes at common sites.

Experience in Australia and elsewhere highlights factors such as a clear statement of purpose, engagement of users and other programs with common interests, scientific rigour to ensure that the design is sound, defensible and appropriate, long term secure resources and budget, and continuous improvement, are all critical to the success of a project such as the CFMF. With these factors in mind, the aim of the CFMF is for a representative sample of permanent sites across Australia at which a common set of attributes is measured, to consistent standards, at regular intervals. Comparison between successive measurements will give an unambiguous measure of change and eventually, over a sufficient period of time, of trends in these attributes.

A regional case study in central Queensland

Study Area

The following case study was designed to assess the likely issues that would arise from implementing the CFMF. The case study uses an integrated sampling framework for estimating and scaling-up key forests and woodland attributes (e.g., height, cover and therefore extent) as required for C&I reporting and monitoring. The study area (Figure 1) is located in proximity to the township of Injune within the Southern Brigalow Belt (SBB) biogeographic region, and has an area of 221,120 hectares (~ 2.5 % of the SBB). Diverse multi-aged and mixed species forests and woodlands cover 192,153 hectares (87%) of the study area, in comparison to the SBB which only has approximately 41% of the area covered in forest and woodlands (Commonwealth of Australia, 2002).

Sampling design

The study focused on the integration of field-based measurements, airborne lidar, large scale (1:4000) aerial photography and Landsat Thematic Mapper (TM) data. The sampling framework was designed to provide robust and repeatable measures for attributes such as species composition, stand height and cover, and included assessments of forest health, condition, and habitat availability. Existing data were to be enhanced through calibration and validation with finer scale data.

Vegetation sampling was undertaken in stages in order to optimise the accuracy and precision of outputs by recognising the limitations of data, and to allow efficient use of staff and resources. The process was undertaken to assess whether the sampling design was efficient, and to test if the strengths of utilising both field and remotely sensed data for calibration and validation, could be fully realised. There were four main stages (Table 1).
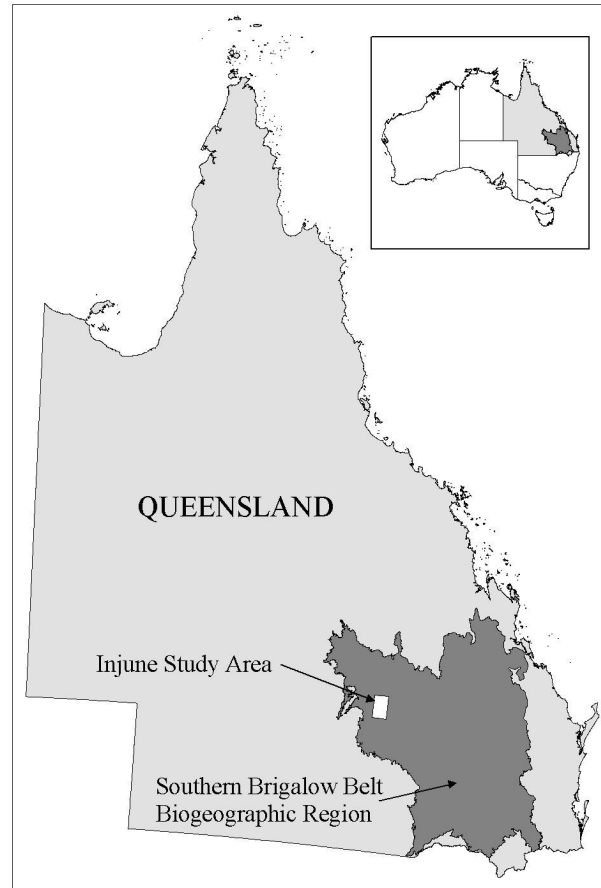

Figure 1. Location of the Injune study area in Queensland, Australia.

Table 1: Main stages involved in the sampling design.

Stage	Task	Purpose
Stage I	Sample design and pre-stratification using large scale photography (LSP)	To select appropriate field sample locations
Stage II	Field and lidar data collection, analysis, and calibration and validation through simple linear regression models	To quantify structural attributes of forests and woodlands.
Stage III	Detailed air photo interpretation at 1:1000 and 1:4000 scales	To establish species/community composition, cover and disturbance.
Stage IV	Calibration/validation of Landsat TM data using field and lidar data, also utilising simple linear regression models	Regional estimation of structural attributes.

Figure 2 illustrates the sampling design used (Schreuder, *et al.,* 1993). Figure 2 (A) represents the study area, where a 37km x 60km grid was used as a basis to systematically sample the area, divided into 15 rows by 10 columns, creating 150 cells of 3.7km x 4km. The two main sampling units were located at the centre point (Figure 2 - B). At the Primary Photo Plot level, LSP was acquired for all 150 cells, over an area of 800m x 800m (64 hectares), which was approximately 4% of the area of a 3.7km x 4km cell (not shown in diagram). Initial rapid stratification of vegetation into broad forest and cover types over the LSP utilised a 7x7 dot grid (nominally 100m spacing), where an assessment was made only at each dot. The Primary Sampling Unit (PSU) was located at the centre of the Primary Photo Plot. The PSU (Figure 2 - C) was 150m wide by 500m long (7.5 hectares) and was made up of 30 secondary sampling units (SSU), each being 50m x 50m (0.25

hectares). Airborne scanning laser (lidar) data was acquired over every PSU. PSU's were classed into broad forest and cover type according the initial LSP stratification. Field plots (35) were randomly selected from within PSU's based on proportional allocation of area of each broad forest type, with final plot selection based on practical constraints of accessibility and travel time. Core attributes collected with the various methods were species composition, forest structure, condition, biomass, disturbance, land use and broad land cover change over the last 10 years.
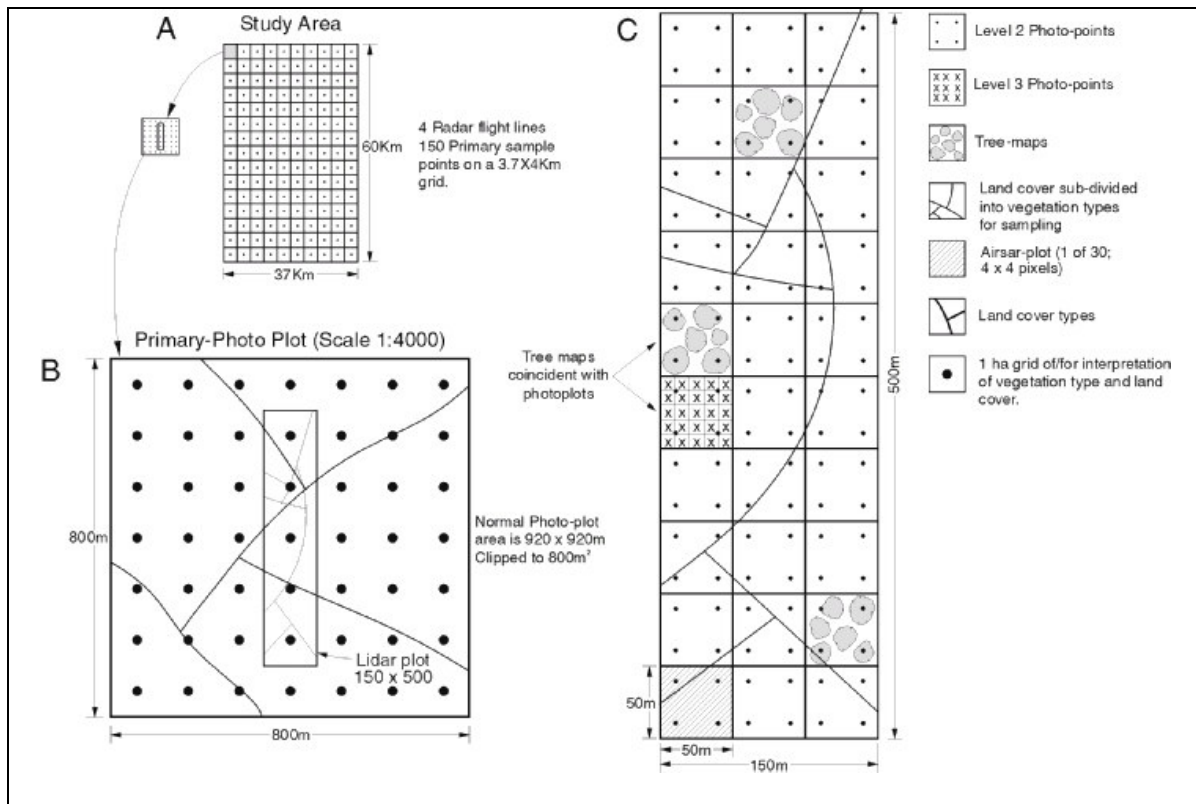

Figure 2. Integrated field based and remote sensing multi-phase sampling design implemented across the study area.

Simple linear regression models were used to calibrate and validate coarser scale data using finer resolution data. For example, Foliage Projective Cover (FPC) estimates for field plots were regressed against lidar estimates of cover for the same SSU, and a linear relationship between field FPC and lidar cover established. This calibration model was then applied to the lidar data on SSU basis, resulting in FPC estimates for all SSU's. FPC estimates across the study area used Landsat NDVI and band 5 values (Kuhnell *et al* 1998) calibrated and validated with lidar FPC. Two calibrations were tested, using the 0.25 hectare SSU, and mean lidar FPC across the 7.5 hectare PSU (Tickle, *et al*, (in review)). The Landsat FPC estimates were then divided into broad reporting classes as presented in Table 2.

Case Study Results

Tickle, *et al*, (in review) provides results on the wide range of forest attributes that were collected and analysed, including biomass, but this paper only reports the forest area results. Table 2 compares FPC estimates, aggregated to broad NFI cover classes. Both lidar, Landsat calibrated with lidar, and the Queensland Statewide Land and Trees Study (SLATS) data for 2000 indicate that the dominant cover in the study area is open forest (which is categorised as 30-70% FPC). These results agree with those from State of the Forests Report (SOFR) data, even though it was compiled with much coarser NOAA AVHRR data. Conversely the current NFI 2000 data, National Vegetation Information System (NVIS), and Landsat calibrated with field plots indicated woodland

(categorised as 10-30% FPC) as the dominant cover class. Estimates for non-forest (categorised as 0-10% FPC) are with 10% of all data sources. Standard Error (SE) values are presented for lidar and Landsat FPC estimates. Using tabulated values, a non-parametric test (Kolmogorov statistic) was used to approximate 95 % confidence intervals on the proportions since the data were not normally distributed (Conover, 1971). Values with a smaller SE have more certainty in the mean area value, and therefore there is more confidence in identification of any real change when measurements are subsequently repeated. It should be noted that none of the existing data sources give estimates of potential error and this makes comparisons difficult, as well as reducing confidence in the numbers currently presented.

Table 2. Forest area estimates (FPC) as a percentage of the 220,000ha study region using lidar, lidar and field calibrated Landsat, and existing regional scale mapping.

Data Source	Date	Non-forest (% of area)	Woodland (% of area)	Open forest (% of area)
SLATS	1991	6	16	79
SOFR	1997	11	30	60
NVIS	1999	11	70	19
NFI (Montreal reporting)	2000	13	67	20
Field plot (30) calibrated Landsat	2000	11 ±6	49 ±6	39 ±6
Lidar SSU (4500) calibrated Landsat	2000	5 ±7	19 ±7	77 ±7
Lidar PSU (150) calibrated Landsat	2000	6 ±5	26 ±5	68 ±5
Lidar PSU's (150- 0.5% of study area)	2000	10 ±2	19 ±2	71 ±2

Case Study Discussion

There are a number of issues arsing from the forest area results. Differences between the datasets indicating the dominant cover class could be linked to the data source, data scale, calibration method, representativeness of source data, and the interpretation of cover classification. While Landsat covers the whole study area, the pixels are actually a combination of actual tree cover, with varying influences of regrowth, shrubs and grass, soils, and shadow. Lidar provides a more accurate assessment of the actual cover above 2 metres, but it is still only a sample of the landscape. With the systematic scheme the sample is assumed to be representative, but there may be instances where a 4km distance could be too great for identifying the representative cover in a highly variable environment. Field plots provide an accurate assessment of actual foliage cover, but there are few field plots compared to the study area, and the measurements within the plots are also a sample, as it was derived from observations at 1 metre intervals along 3 50m transects. Therefore transect location could be critical to FPC estimates derived from field plots. As the lidar data was also at 1 metre resolution, the representativeness of the field plot transects could be tested, and in a few cases there were significant differences in the FPC estimate for the field plot area. This bias can then be scaled up to coarser datasets, as evident in different results obtained between the landsat calibrated with just field plot estimates, vs landsat calibrated using lidar. This has implications for sampling schemes relying solely on field plots to calibrate coarser scale data like Landsat, especially if cost and access issues result in relatively few plots for a particular area. Existing datasets have been compiled from both field plot and Landsat data, so it is not surprising that they also have similar results to the case study specific data.

Discussion

The regional case study has shown that integrated sampling strategies can be successfully implemented in a number of ways. There has been improved estimation of a range of forest attributes, and significantly error estimates can now be provided. An efficient sampling design allows more of the landscape variability to be quantified and so enhance the understanding of different vegetation patterns. The regional case study also showed that both field and remotely

sensed data from a range of scales and sources could be integrated. Current methods for aggregating species level information mean that monitoring change in forest composition and cover is problematic. Interpretation methods employed in the case study allow various forest attributes to be reported in a number of ways, so avoiding the problem some existing datasets have where the data cannot be used for monitoring due to different interpretation and sources. LSP and lidar data also provide a permanent record and can be re-interpreted for any new attributes that may be required in the future.

Issues with field plot selection and access

While this regional case study was successful in meeting the objectives, there were a number of issues that arose, which need to be considered for the pilot CFMF project. A major issue was that of plot access on private land. While an efficient and robust sampling design can be developed beforehand, contingencies need to be allowed for if the required ground plots could not be used. In the case study this presented itself in a number of ways. Landowners can refuse permission if they are currently working with stock in the area, for example, or if there are other hazards present such as fire or recently burnt areas. In other cases, landowners may not be contactable meaning that access cannot legally be undertaken on private land. Additionally there were cases of rapid land clearance occurring, such that while potential plots may have been candidates based on the LSP, when field reconnaissance was undertaken it was found that the areas had since been cleared of vegetation. There are also issues with access, particularly where roads may be evident on LSP or even Landsat, however discussions with landowners indicated that the access that was planned was not possible. Decisions have to be made on the travel times to plots, both in vehicles, and if necessary, on foot, as this could have significant cost and safety issues if plots are too far away from the base location. If these decisions have to be made when travel to the field plot location has already been undertaken, then costs can increase significantly.

Plot selection can also be problematic where representativeness for a number of different attributes is attempted. In the case study, the two main attributes that drove plot selection were forest species, and cover. Due to multiple objectives for the calibration of different remote sensing datasets, a bias slightly towards the woodland cover type was found with the final field plot locations. This introduced issues for the foliage cover calibration of lidar and Landsat, as evident in the difference between field plot and lidar calibrated Landsat FPC values presented in Table 2. Issues with access to field plots in areas with few roads, and/or steeper and more dissected terrain may have caused additional bias. The upper right corner of the study area has this sort of terrain and consequently has no field plots. The use of lidar and LSP over this area was found to be an effective way to at least identify this issue, and work towards addressing it for most forest attributes. Forest species/genus representativeness between field plots and remotely sensed assessments was found to be robust.

Issues with operational monitoring using a range of data

Given the research nature of the regional case study, there may well be issues with an operational monitoring using all the remotely sensed datasets. This is especially so for laser data, where there are high initial costs to gather the data, as well as the need for significant computing hardware and software to process it. This has implications for the broader application of lidar to forest assessment, and it is unlikely that as much lidar will be collected as was gathered at the study area, for a region of this size unless there is a specific requirement to do so, with funding to match. From a research perspective the abundance of high resolution data did allow very good registration of LSP and calibration of Landsat data, as well as excellent quantification of the variability in height, cover and biomass of the forests and woodlands. It could be argued however that a slightly less accurate result, but still acceptable for operational forest monitoring, could be achieved with less laser data and yet still be more representative and efficient than using field plots alone. Given the

variability in results from the field plots, it is unlikely that less field plots could have been measured, and yet still retain confidence in scaling up estimates of the attributes to the regional level. On the other hand in highly variable terrain, it may be beneficial to fly more lidar, especially if field access is difficult. It is this trade off between access difficulties (and therefore cost) of fieldwork and field equivalent remotely sensed data such as lidar and high resolution imagery (ie 1-5 metre pixel size) that will become a key test of the proposed CFMF pilot study. This pilot aims to further develop the implementation of integrated sampling strategies for forest assessment. Additionally subsequent research at the Queensland study site will investigate optimal amount of lidar that could have been gathered over that study area.

Conclusions

Australia has an increasing need to monitor and report on the sustainable use of forests. The Montreal Process has been adopted by Australia, at a regional, State and national level, as the framework of criteria and indicators to meet this need. Current forest inventory and monitoring programs within Australia are inadequate (for various reasons) to report comprehensively against C&I, and to meet a range of other current needs. A sampling-based forest-monitoring program utilising integrated sampling strategies in the CFMF, would address many of these inadequacies. In seeking to implement a continental forest monitoring framework Australia is in good company, a number of like countries (such as the USA, Canada and New Zealand) are establishing (or have already established) similar programs to address the same issues. While there is a range of other programs being considered, or have already been established within Australia to measure and monitor various aspects of forests, the CFMF is currently the only system that is able to fulfil the majority of C&I reporting requirements. There are opportunities to make significant savings in implementation of the proposed CFMF through collaboration and partnerships with such programs.

The case study results indicate that utilisation of integrated sampling strategies provide detailed baselines about forests, and therefore be useful for monitoring subtle changes resulting from a range of natural resource management issues. By improving the resolution of information gathered it is possible to monitor more subtle changes in species, cover and regrowth. These improvements are leading to investigations of the accuracy and repeatability of vegetation cover estimates, and the change in cover over time, especially in response to changing seasonal and climatic conditions. By improving the integration of a range of forest attributes, such as species, growth stage, cover and seasonal variation, better understanding of dynamic forest processes can be achieved across all vegetation types and land tenures. With improvements in these sorts of assessments, additional SFM indicators could be reported on. The design also allows critical assessment of all the data sources, for example the effectiveness of field plot locations, as well as highlighting the limitations of the existing datasets and methods for C&I reporting. This is essential for continuous improvement of monitoring frameworks, as there are still many issues to resolve before an efficient and cost effective framework can be achieved. The use of such an integrated sampling framework for enhancing operational reporting and monitoring of a range of C&I for sustainable forest/woodland management is advocated. The benefits of monitoring programs such as the CFMF are ultimately long term. Continuation of the project beyond this conceptual stage will require a substantial investment of patience and persistence but if the goals of SFM are to be achieved then it is an investment that must be made.

Acknowledgements

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