Forest Ecology and Management 367 (2016) 86–96

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

A strategic forest inventory for public land in Victoria, Australia

Andrew Haywood [a,b,c,d,*], Andrew Mellor [c,d], Christine Stone [e]

[a] EU REDD Facility, European Forest Institute, Asia Regional Office, c/o Embassy of Finland 5th Floor, Wisma Chinese Chamber, 258 Jalan Ampang, Kuala Lumpur 50450, Malaysia
[b] Department of Forest Ecosystem Science, The University of Melbourne, 4 Water Street, Creswick, VIC 3363, Australia
[c] School of Mathematical and Geospatial Sciences, RMIT University, GPO Box 2476, Melbourne, VIC 3001, Australia
[d] Victorian Department of Environment, Land, Water and Planning, 8 Nicholson Street, East Melbourne, VIC 3002, Australia
[e] New South Wales Department of Primary Industries, Forest Science, Locked Bag 5123, Parramatta, NSW 2124, Australia

ARTICLE INFO

Article history:
Received 19 February 2016
Accepted 21 February 2016

Keywords:
Large area monitoring
National forest inventory
Sampling design
Operational implementation

ABSTRACT

The aim of this paper is to present a strategic forest inventory approach that has been applied on public land in Victoria, Australia. The Victorian Forest Monitoring System is an integral component of a monitoring and reporting program that enables Victoria to critically assess and evaluate its progress towards achieving its sustainable forest management objectives and targets. The inventory approach utilises field measurements in combination with remote sensing data. The approach is novel in that it utilises a relatively small sample size with a stratification scheme designed to examine questions around tenure and land management options. The small sample was dictated by limited resources (capacity, time and budget). The stratification scheme was designed to explore different land management approaches (e.g. National Parks versus State forest), as a more consistent and balanced approach to the management of public forests is currently being considered by most State Governments in Australia. The resultant accuracy of estimates for management and bioregion strata and associated characteristics, like above ground biomass from this small sample size were found to be sufficient for the regional monitoring goals of this study.

1. Introduction

Increasing public recognition of the environmental, economic, social and cultural significance of forest ecosystems at local, regional and global scales, is driving the need for forest inventories to provide reliable information on trends on the ecologically sustainable development of forest resources. Forest inventories can play a critical role in providing information which is important for national and regional level policy and decision making (Cunia, 1978; Tomppo et al., 2010) and providing decision-makers with the necessary perspective and evidence for implementing effective forest management policies and programmes. Large area (i.e. continental or regional scale)(Schreuder, 2001) forest inventories may be characterised as strategic forest inventories (Falkowski et al., 2009), as distinct from tactical or operational inventories. Strategic forest inventories generally collect observations from a relatively sparse network of field plots dispersed across entire jurisdictions within countries according to fixed sampling designs and commonly measure a large number of forest related variables (Tomppo et al., 2010). The intensity of sampling can vary from one plot per a few hundred hectares to one plot per tens of thousands of hectares. Most strategic inventories also use remotely sensed data to enhance inventory sampling and estimation.

Strategic forest inventories have been implemented in many jurisdictions (e.g. Magnussen et al., 2007; Tomppo et al., 2010; Winter et al., 2008) and historically have been focused on assessing and monitoring the extent, state and sustainable development of forests with special emphasis on forest resources (Puumalainen et al., 2003). In more recent years there has been an increased demand for information and data on the non-resource functions and values of forests (e.g. McRoberts et al., 2010). The increasing importance of strategic inventories can be associated with two issues: firstly, a greater public awareness and understanding of the role forests play in issues of global interest and importance. Forests are a critical resource of biological and genetic diversity. They maintain hydrological cycles, regulate climate, store and maintain carbon cycles, provide important cultural, tourism and amenity values as well as timber, fuel-wood and non-wood products (Boyd and Danson, 2005; Myers, 1996; Wijewardana, 2008). Moreover, growing concern about forest environments and global

* Corresponding author at: EU REDD Facility, European Forest Institute, Asia Regional Office, c/o Embassy of Finland 5th Floor, Wisma Chinese Chamber, 258 Jalan Ampang, Kuala Lumpur 50450, Malaysia.

E-mail addresses: andrew.haywood@efi.int (A. Haywood), andrew.mellor@delwp.vic.gov.au (A. Mellor), christine.stone@dpi.nsw.gov.au (C. Stone).

http://dx.doi.org/10.1016/j.foreco.2016.02.026
0378-1127/

and regional stressors which threaten forest structure and composition requires extensive forest data collection at a range of scales to support national and international forest policy. Secondly, there is an increasing demand for consistent data to allow appropriate comparison between different management regimes and between jurisdictions, such as member states of international organisations, certification schemes or voluntary agreements (e.g. Montréal Process, Australian Regional Forest Agreements).

Field measurements are an essential but significant cost component of strategic forest inventories. Many of the variables within the inventory can only be measured with an acceptable level of accuracy using field methods. Generally the high field costs are due to the large number of field plots that are necessary to meet a desired level of precision in the estimates. Unfortunately, it is the understanding of the authors that there has been limited scientific review in the literature of the extent to which the precision of estimates influences policy and decision making. It has been argued (Klein et al., 2011) that the predefined level of precision (and necessary sample size) of forest inventories is not always based on considerations around the final usefulness and credibility of results. Moreover, it appears that often the sampling design is simply driven by the availability of resources (capacity, time and budget) rather than by any optimisation of design elements for a desired statistical precision target. This is an important consideration, as even large reductions in sample size and associated costs can result in only minor reductions in precision target (Maltamo et al., 2010). Therefore in some situations, where the goal is to cost effectively generate and update information on forests at a known level of precision and at a large scale, a strategic forest inventory may be able to support these objectives through a sampling strategy optimised to the objectives (Fischer et al., 2011; Kleinn et al., 2005; Saket, 2002; Thuresson, 2002).

In addition, remote sensing technology (active and passive airborne and space borne imaging and ranging sensors) can be a cost effective means to acquire information (dependent on the coverage and quality of information required) across a range of spatial and temporal scales in a repeatable and consistent manner. This technology can greatly enhance strategic forest inventories – high and moderate resolution remote sensing data can be applied as a surrogate for field-based observations, as ancillary data to improve statistical estimates and the precision of estimates derived from traditional inventory and for generating spatially explicit forest maps (eg. McRoberts and Tomppo, 2007; Tomppo et al., 2008). Furthermore, extensive archives of freely available satellite image time-series (e.g. Landsat TM/ETM and MODIS (U.S. Geological Survey, 2013)) now provide a cost-effective means to consistently monitor and measure changes – both abrupt disturbance and slow, subtle trends – in forest condition overtime (Kennedy et al., 2007; Zhu et al., 2012) and assess spatial dynamics of forest cover in inventories.

Multi-stage sampling has been shown to be an efficient sampling approach when precision of estimates and associated costs are taken into account (Schreuder et al., 1993). It is common practice for strategic forest inventories to introduce stratification into each stage of the sampling. This stratification is often based on physical factors (climate, geology, landform, soil), biological factors (vegetation composition and function), anthropogenic factors (administration boundaries, management practices, disturbances history) or a combination of factors.

Australia remains one of the few developed countries yet to implement a sample-based strategic forest inventory program, either nationally or in individual states or territories. Prior to the establishment of the National Forest Inventory (NFI) Unit within the Australian Government in 1989, capacity to report nationally on Australia's forests was extremely limited (Lee et al., 2003). Over its first 20 years the NFI team has relied on a compilation approach for national reporting, involving the aggregation of data from individual state and territory jurisdictions into the NFI. This approach was taken due to limited resources, demands for immediate reporting, the federated system of government in Australia, and land and resource management being the responsibilities of individual states. The data input to this compilation process have relied heavily on the time, staffing and financial resources provided by Australia's States and Territories. This resulted in the Australian Government compiling data for the NFI from a variety of pre-existing sources and collected to a variety of standards. This approach was largely successful in meeting the immediate need for a snapshot of Australia's native forest and plantations, but its limitations have been evident in attempts to report comprehensively against condition or trends, e.g. Australia's First Approximation Report for the Montreal Process (Commonwealth of Australia, 1997) and Australia's 1998, 2003 and 2008 State of the Forests Reports (Montreal Process Implementation Group for Australia, 2008; National Forest Inventory Steering Committee, 2003; National Forest Inventory, 1998). The NFI team thus adopted a hybrid approach for forest cover mapping in Australia's 2013 State of the Forests Report, combining data from individual states and territories with national data from a range of remotely sensed sources, in a Multiple Lines of Evidence Process (Montreal Process Implementation Group for Australia and National Forest Inventory Steering Committee, 2013; Mutendeudzi et al., 2013). This process has been designed to allow future reporting of trends over time in Australia's forest cover.

Although a range of sample-based forest inventory frameworks (Wood et al., 2006, 2014) have been proposed for Australia none so far have been implemented at the National or State level. Significant challenges are faced when implementing a new sample-based forest inventory, these include initially high implementation costs, availability of technical expertise and infrastructure and obtaining a long term commitment to continuously funding a monitoring program that gains value over time. To our knowledge, we present the first implementation of a state-level public land sample based forest inventory approach within Australia, generating information based upon a uniform and statistically consistent methodology. Inventory estimates are based on multi-staged sampling, including low intensity field sampling, aerial photography and moderate resolution remote sensing data. This paper focuses on the field sampling and aerial photography sampling components. Details on the application of the moderate resolution remote sensing with the forest inventory can be found in Mellor et al. (2013).

It is anticipated that the lessons learnt in this study will support the discussion on planning and implementing strategic (large area) forest inventories elsewhere in Australia. In addition, the study explores whether combining low intensity field sampling and remote sensing data can be a cost-effective approach for a strategic inventory when the required precision targets are moderate. The study also provides the framework for comparing different management approaches (e.g. National Parks versus State forest) on a range of values. Although the strategic approach in this study does not support the production of precise estimates for areas smaller than bioregions × tenure, it does produce important estimates at an appropriate scale to support state and national level forest land policy and decision making. This may be important for jurisdictions that are currently not able to deliver detailed estimates in a cost-effective and sustainable manner.

1.1. Some forest information of Victoria

Victoria has a high degree of topographic and vegetation diversity (Costermans, 2009). Covering an area of about 237629 km^2, the State was previously 90% forested (Woodgate and Black,