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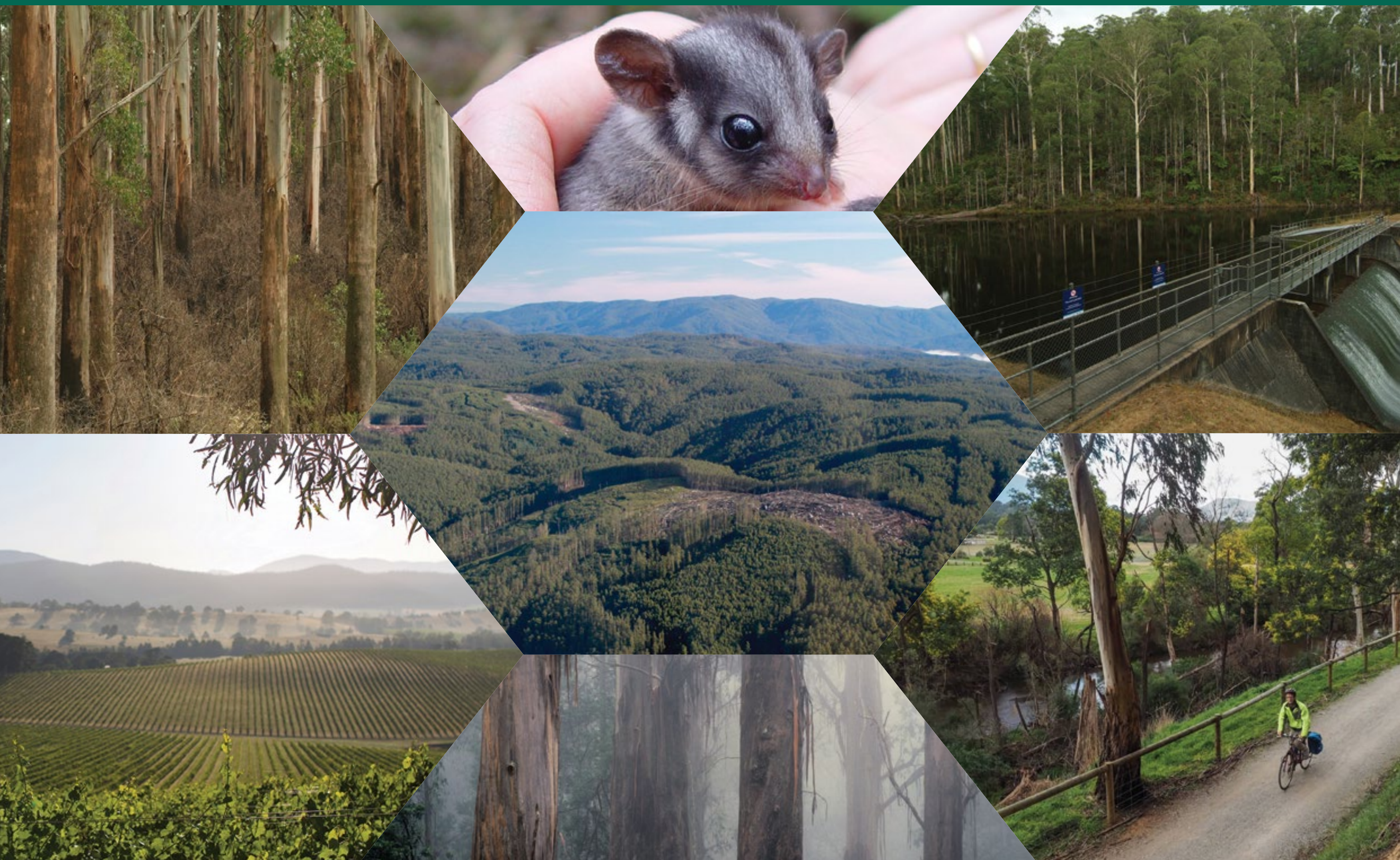

Experimental Ecosystem Accounts for the Central Highlands of Victoria

Final Report

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List of abbreviations and acronyms

ABS	Australian Bureau of Statistics
ANZSIC	Australian New Zealand Standard Industry Classification
BoM	Bureau of Meteorology
BSU	basic statistical unit
CICES	Common International Classification of Ecosystem Services
CPI	consumer price index
DELWP	Department of Environment, Land, Water and Planning, Victorian Government
DotEE	Department of Environment and Energy, Commonwealth Government
EAU	ecosystem accounting unit
EPBC	Environmental Protection and Biodiversity Conservation Act
ERF	Emissions Reduction Fund
EVC	ecological vegetation classes
FMA	Forest Management Areas
GDP	Gross Domestic Product
HBT	hollow bearing tree
IUCN	International Union for Conservation of Nature
LBP	Leadbeater's Possum
LCEU	land cover ecosystem functional unit
IVA	Industry Value Added
RFA	Regional Forest Agreement
SA	statistical areas
SEEA	System of Environmental-Economic Accounting
SFRI	State-wide Forest Resource Inventory
SNA	System of National Accounts
UN	United Nations

Acknowledgements

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Mountain Ash forest. Image: Heather Keith

Executive Summary

Policy context for natural resource management in the Central Highlands

- Public controversy arising from conflicting land use activities in the Central Highlands region is long standing. Managing the various land use activities within the region is complex and requires evaluation of trade-offs between different land uses.
- Land use activities include native forest and plantation timber production, agricultural production, water supply, carbon sequestration, recreation, and biodiversity conservation.
- These activities are dependent on ecosystem services, and their use can be either conflicting or complementary. In particular, native timber harvesting is potentially in conflict with other land uses, such as tourism, water supply, carbon sequestration and biodiversity conservation.
- Ecosystem accounting provides a means of quantitatively comparing various land use activities and trade-offs between different activities.
- The Regional Forest Agreement, which is a 20-year plan for allocation of natural resource use within the forests, is due for re-negotiation by 2018.
- Proponents within the native timber industry have called for an expansion of wood supply allocated for native timber harvesting. By contrast, stakeholders within the environmental and tourism sectors have proposed additions to the national park network as the Great Forest Reserve System.

Key findings of the ecosystem accounts for the Central Highlands of Victoria

- The value of ecosystem services used in 2013-14 for agricultural production was $121m while the water provisioning service was $101m, which were an order of magnitude greater than the native timber provisioning service ($19m).
- The contribution to GDP (Industry Value Added value) of the agriculture ($312m), water supply ($310m) and tourism ($260m) industries were all more than twenty times higher than for the native forestry industry ($12m).
- The potential IVA of carbon sequestration was estimated at $49m, based on the recent national carbon price, which is higher than the IVA of native timber production ($12m). Access of native forests to the carbon market is currently excluded by government regulation.
- Ecosystem condition declined over time, with a decrease in areas of older forest. Notably, the total area of older montane ash forest and rainforest reduced by one third over a 25 year period.
- Biodiversity declined over time. This is indicated by the:
  1. increase in the number of threatened species from 28 in 2000 to 38 in 2015 and the severity of their threat category;
  2. decline in the number of arboreal marsupial animals;
  3. decline in condition of the habitat consisting of large, old, hollow-bearing trees within a complex forest structure.
- The key threatening process for arboreal marsupials is native forest logging, which results in the accelerated loss of existing hollow-bearing trees and the impaired recruitment of new cohorts of these trees. Areas impacted by logging lose more than half of the retained large trees within a few decades.
- Spatial distributions of ecosystem services across the region identified ‘hotspots’ where provisioning of native timber conflicts with maximising services of water provisioning and carbon storage.

Key findings with implications for management decisions

- The economic benefits from native forest logging are small compared to other industries in the region.
- Loss of IVA in native forestry could be offset by increases from other industries and by entering the carbon market.
- The main product from native forest harvesting is pulp logs; these can be substituted by wood products from plantation forests and recycled paper. Additionally, plantations can provide some substitute sawlog products.
- The impact of altered native forest logging regimes on the profitability of wood product processing cannot be determined from the publicly available information.
- The net value of ecosystem services would increase if native forest logging were phased out, due to improved ecosystem condition in older forests that continued growing.
- Additional, as yet unquantified, benefits would likely occur through increasing the values of cultural and recreational services, the ecosystem services used in agricultural and plantation timber production, and habitat provisioning.

Ecosystem accounting as a tool for decision-makers

- Ecosystem accounts provide information on the ecosystem services and economic value of land use activities in a format that allows for quantitative comparison and analysis of trade-offs. Ecosystem accounting is thus a powerful tool to guide policy-making about regional land management issues.
- Evaluating the contribution of ecosystem assets and services to human well-being is increasingly considered critical to decision-making about natural resource use.
- The ecosystem accounts presented here follow the internationally recognised statistical standard of the United Nations System of Environmental-Economic Accounting (SEEA) (UN *et al.* 2014a, UN *et al.* 2014b). Goods and services accounted for include those already within the economy, and thus currently assessed within calculations of Gross Domestic Product (GDP) and the System of National Accounts (SNA) (ABS 2016a), as well as those that are hidden or lie outside the SNA but are within the SEEA.
- The accounts prepared:
  - systematically synthesise environmental and economic data for the region;
  - quantify ecosystem assets (extent and condition), and assess the use of these assets by people (ecosystem services and derived products);
  - link economic and other human activity to changes in ecosystem condition, and track this change over time; and
  - highlight the dependencies of economic activity on ecosystems, and the risks to these ecosystems.
- The ecosystem accounts for the Central Highlands demonstrate that the SEEA can be applied in Australia to deliver information for government decision-making.

Approach to developing ecosystem accounts

- Biophysical and economic data from a range of sources were linked spatially and based on classifications of land cover, land use and forest age.
- Accounts using physical metrics were developed for water, land, timber and carbon as well as for the habitat provisioning services for biodiversity.
- Monetary valuations were prepared for the provisioning of water, timber from native forest and plantations, agricultural production of crops, fodder and livestock; cultural and recreational services; and regulating services of carbon sequestration.
- Valuations employed exchange values used in accounting, rather than welfare values (such as willingness to pay) used, for example, in cost benefit analysis.
- Environmental-economic interactions were evaluated at three levels:
  i. values of ecosystem services, both currently valued within SNA and previously unrecognised;
  ii. values of economic uses of ecosystem services by industries as their contribution to industry value added (IVA). The sum of all IVA in an economy equals GDP.
  iii. potential gains and losses in IVA and ecosystem services involved with impacts and trade-offs between land uses.

1. Introduction

1.1 Rationale for ecosystem accounts in the Central Highlands

This report presents the Experimental Ecosystem Accounts for the Central Highlands of Victoria. The primary aims of the report are (i) to provide information relevant to decision-making about natural resource management in the region, and (ii) to determine the extent to which the System of Environmental-Economic Accounting (SEEA) (UN *et al.* 2014a, UN *et al.* 2014b) can be populated with existing data. This version of the report is a revision of the draft used for discussion in mid-2016. Revisions have been made based on feedback from a workshop in Melbourne, comments from national and international experts, updated spatial data from the Victorian government and other data, as well as additional analyses of the results.

The study area in the Central Highlands region of Victoria (Figure 1.1) was chosen because it exemplifies the issues for land management policy and decision making where land use activities are conflicting. The boundary of the study area reflects the priority area for land management decisions and availability of key data. Selection of a boundary is complex because many sources of data are integrated in the accounts, and each source has different boundaries. The study area contains a range of landscapes including human settlements, agricultural land, forests and waterways. The Central Highlands is used for a variety of activities, including timber production, agricultural production, water supply and recreation. It is also home to a range of species, including the endemic and critically endangered Leadbeater's Possum and Helmeted Honeyeater, the faunal and bird emblems of Victoria. These activities are dependent on ecosystem assets and services, and their use can be either complementary or conflicting. Managing the various activities within the region is complex and requires evaluation of the trade-offs between different land uses. Synthesising environmental and economic information in the form of ecosystem accounts provides a guide for policy-makers.

The region forms part of the Central Highlands Regional Forest Agreement that is due for re-negotiation within two years. Proponents within the native timber industry have called for an expansion of supply allocated for native timber harvesting. By contrast, stakeholders within the environmental and tourism sectors have promoted an expansion of the national park network proposed as the Great Forest Reserve System.

This is the first time a suite of ecosystem accounts has been prepared specifically for the Central Highlands, although a range of accounting work has taken place in Victoria (as discussed later). Accounts have been prepared for land cover and use, water, carbon and timber; as well as information in an accounting format for biodiversity, agricultural production and tourism. Generating the value of these ecosystem services and their contribution to economic production in the region provides new evidence for decision making about natural resource management. The accounting platform can be continually updated and improved over time. The ability to produce accounts regularly, and to improve their coverage and quality, will be possible with identification of additional data sources, guidance for improved monitoring systems, data collection to fill gaps, and new methods for integrating data across scales.

The experimental ecosystem accounts for the Central Highlands draw together a wide range of information and provide a focus for discussion. Objectives for discussion about the accounts include: (i) identifying ways to improve their quality; (ii) how they may be used by governments and others in natural resource management and; (iii) how the experience of producing the accounts can contribute to the on-going development of the SEEA Experimental Ecosystem Accounting (UN *et al.* 2014b).

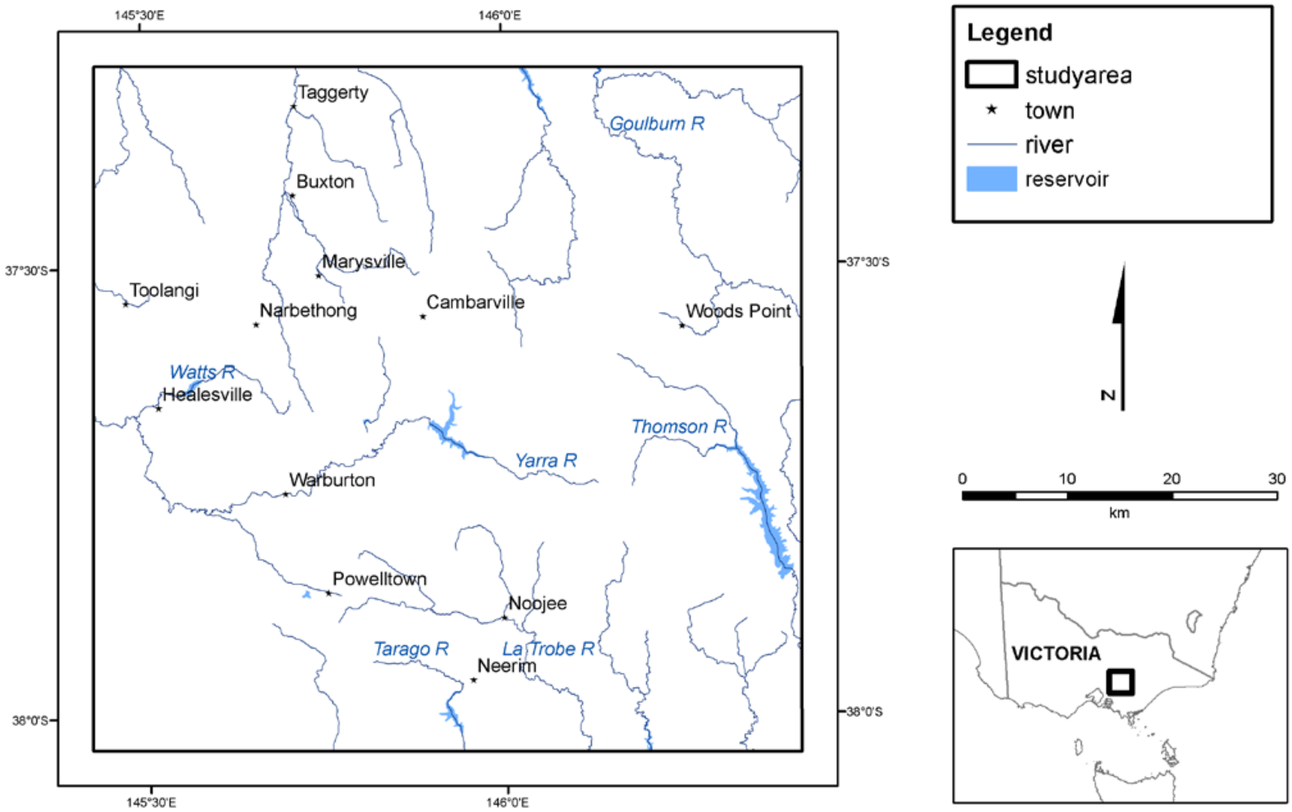


Figure 1.1 Location of the Central Highlands study area, approximately 100 km northeast of Melbourne.

1.2 System of Environmental-Economic Accounting (SEEA)

The SEEA has been developed by the international community to provide a statistical standard for measuring the Earth system that complements the economic accounting of the System of National Accounts (SNA) (UNSD 2009) by adding environmental information. The goal is to mainstream the benefits of nature into decision making.

Accounting records exchanges of stocks and flows between different agents. Within the economy, the transactions are between people, businesses and government. Exchanges can also be recorded between the economy and the environment or ecosystems. In addition, accounts report changes in quantity and condition of stocks and flows over time in response to human activities, disturbance events and other temporal effects.

The SNA describes the economic state of a nation in terms of monetary transactions between parties in the economy, and is the source of the aggregate indicator Gross Domestic Product (GDP). Environmental and ecosystem accounts extend this system to incorporate physical transactions between the environment and economy. Environmental accounting is described in the SEEA Central Framework (UN *et al.* 2014a) and is an international statistical standard that includes particular resources as natural inputs (for example, land, water, timber, energy and minerals), or residuals (for example, solid waste, effluent, water and air emissions), and transactions related to environmental protection. Ecosystem accounting is described in the SEEA Experimental Ecosystem Accounting (UN *et al.* 2014b) and has been developed via United Nations processes. Although ecosystem accounting is not yet an international standard, countries are being encouraged to use and further develop and enhance the framework. Ecosystem accounts describe interactions of living organisms and components of the environment within specific geographical areas, including ecosystems services that support human well-being. The key concepts, terms, units, classifications and accounting principles used in this report are based on these SEEA frameworks. Further references to SEEA documents and examples of accounts are given in Appendix A1.2

Ecosystem accounting is based on a model of stocks and flows (Figure 1.2). In this model, ecosystem assets or stocks are amounts at a particular point in time, within spatially defined areas. Assets are identified and their physical state measured in a spatially explicit manner in terms of extent and condition, their ownership, and management (by individuals, industries or government). Thus, ecosystems are linked directly to uses by people. The flows from ecosystem assets that are used by human activities are known as ecosystem services. Flows can also be additions or subtractions to stocks over a period of time, which can be due to natural processes or human activity, and can also be in the form of income and expenditure. Ecosystem services are classified as provisioning, regulating or cultural services (UN *et al.* 2014b). These services are combined with human inputs, such as capital and labour, in the production of goods and services, which produce benefits when used by people. Different sectors of society are the beneficiaries of these products. Production of goods and services can impact other ecosystem assets, and these trade-offs can be assessed.

Ecosystem assets and services can be measured in physical terms (for example, litres, hectares, parts per million) or monetary terms (for example, dollars). All areas are included as ecosystems, regardless of the level of human modification, such as, crops, pastures and built-up areas. The starting point for ecosystem accounts is usually land cover, for example, forest, woodland, grassland, as a proxy for ecosystem extent. From these areas, a range of ecosystem services may be produced and used by people.

Ecosystem accounts create a structure for integrating complex biophysical data, tracking changes in the condition and extent of ecosystems, and linking these changes to economic and other human activity, and the benefits they provide to society. The accounts are an integrated presentation of the environmental and economic characteristics of the region, showing both ecosystem assets (in terms of extent and condition), together with the flows or uses of these assets by people (in terms of ecosystem services and derived products). Ecosystem accounts synthesize data on all assets, goods, services and values, both those accounted for within economic systems of markets, calculations of GDP and the System of National Accounts (ABS 2016a), and those that lie outside these systems as unrecognised non-market contributions of ecosystems to economic activity and human well-being (UN *et al.* 2014b).

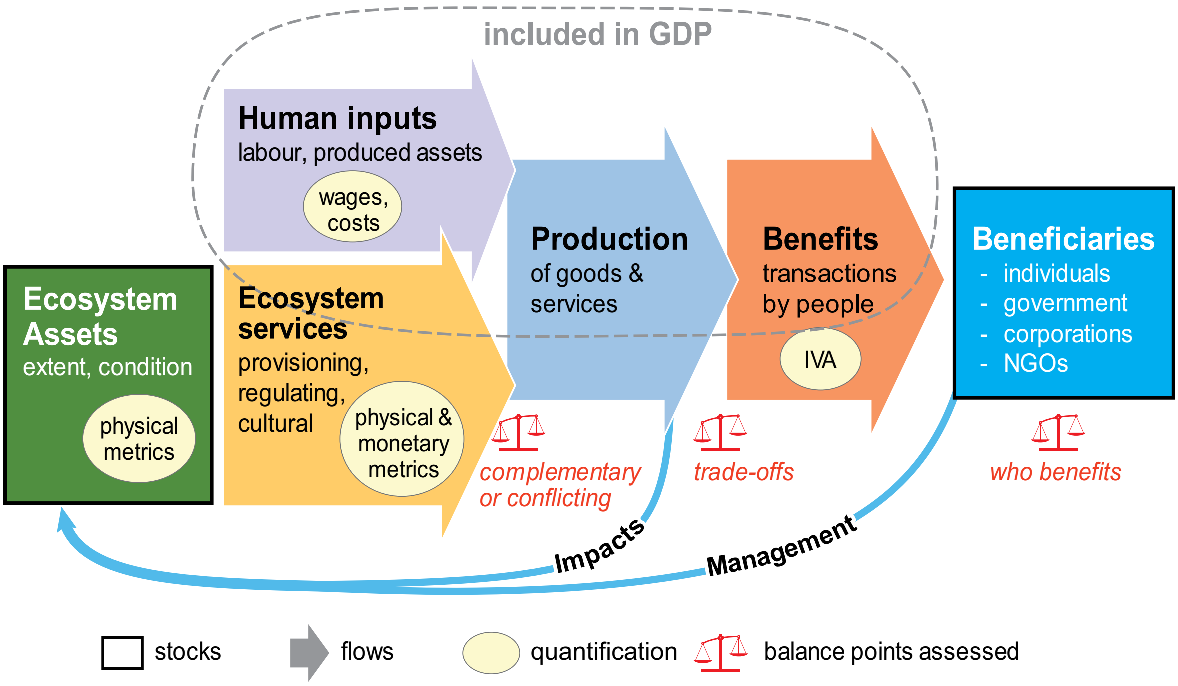


Figure 1.2. Model of ecosystem accounting

[Source: Derived from SEEA Experimental Ecosystem Accounting (UN et al. 2014b)].

The environmental-economic system shows the relationship between ecosystem stocks, the flows of ecosystem services, and how these are related to traditional economic measurement in the SNA. Components of the system can be quantified using physical or monetary metrics. Only parts of the system (indicated by the dashed line) are included in the calculation of GDP, which accounts for flows of market goods and services, such as agricultural products, timber products, water supply, tourism and recreational services. Non-market goods and services not accounted for in GDP include clean air, water filtration, protection from flooding and soil erosion, biodiversity, aesthetic benefits and climate change mitigation. The boundary of contributions of ecosystem services to markets or non-markets is difficult to define (that is, the position of the dashed line). Activities can be assessed at balance points where components of the system are reasonably comparable: the use of ecosystem services can be complementary or conflicting; trade-offs resulting from the relative impacts or benefits of producing goods and services; and who benefits within human society.

1.3 Outcomes from accounts

Structuring information in the form of accounts reveals the interactions between human activities and ecosystem assets, which may have positive or negative impacts on ecosystem extent and condition. We evaluated natural resource management issues within the region at three levels of the environmental-economic interaction:

1. values of ecosystem services, both currently valued but hidden in other information, and previously unrecognised;
2. values of economic output of industries that use ecosystem services as their contribution to industry value added (IVA) (with the sum of all IVA equal to GDP for the entire economy); and
3. potential gains and losses in IVA and ecosystem services involved with impacts on assets and trade-offs between land uses.

The key outcome was the capacity to quantify ecosystem services and their contribution to industries, and hence explicitly reveal the trade-offs made or required when use of services by different industries conflicted or resulted in a reduction in ecosystem extent or condition.

For the Central Highlands, ecosystem accounts can inform decision-making by:

1. identifying drivers of change in ecosystem extent and condition, including the changing balance of economic activities in the region, biodiversity loss, carbon emissions and reduction in carbon stocks, influence of climate change and variability on water supply, expansion of built-up land and infrastructure and fragmentation of habitats;
2. tracking progress towards policy targets, such as improving regional economic outlook or decreasing risks to threatened species and ecosystems;
3. assessing the sustainable use of natural resources, especially timber and water;
4. assessing the cost-effectiveness of expenditure on conservation of species or habitats;
5. enabling analysis of trade-offs between different land uses and scenario modelling.

The purpose of this report is to produce information that can inform these issues.

Environmental–economic accounts will be increasingly required to provide information for policy- making about regional and national management of natural resources by governments and private organisations. This process is relevant at many levels, for example, regional land use conflicts; national conservation polices, State of the Environment reporting; and international agreements such as the Sustainable Development Goals that aim to achieve sustainable development by 2030 (UNDP 2015).

2. Accounting methods

2.1 Approach

The accounts presented for the Central Highlands follow the concepts and terminology of the SEEA (UN *et al.* 2014a,b). Accounts have been prepared for ecosystem extent and condition (based on land cover, land use and disturbance history), water assets and supply, carbon stocks and sequestration, native and plantation timber assets and supply; as well as information in an accounting format for biodiversity, agricultural production and tourism.

The general approach was to use publically available data sources (from websites, already published accounts, annual reports, published literature, etc.) and to adapt these as best as possible to fit SEEA accounting structures, and the study area. In some cases, clarification or additional information was sought from primary data sources (for example, the Australian Bureau of Statistics (ABS), Victorian Department of Environment, Land, Water and Planning (DELWP), and VicForests). The particular data sources and methods used for each account are outlined in detail in each section of this report.

2.2 Accounting units

In economics, environmental science and accounting, the units of observation, their aggregation and classification are key issues. In national accounting, the units of observation are economic agents that are classified based on legal standing to a sector as households (or people), corporations (businesses), government and not-for-profit institutions (or non-government organisations). These same units can also be classified by type of productive activity in terms of industries, for example agriculture, mining, manufacturing, health, education, financial services, etc. All units can produce and use goods and services traded in the economy as well as extract natural resources and return residuals (or pollution) to the environment. These units are not spatially bound, although the assets that they own or use and the activities that they undertake can be spatially located in most cases.

In ecosystem accounting, the units of observation are particular areas and hence are spatial units. The SEEA Experimental Ecosystem Accounting specifically identifies three spatial units for accounting:

1. Basic statistical units (BSU), which can be rasters (grids-based) or polygons. Remote sensing data and plot-based sampling is usually raster. Cadastral data, that is the spatial boundaries of the areas of land that can be owned, consists of polygons.
2. Land cover / ecosystem functional units (LCEU) are aggregations of BSUs with the same land cover, for example forest type.
3. Ecosystem accounting units (EAU) are aggregations of BSUs based on some type of management unit, for example catchment or local government area.

In this report, the BSU varies between datasets and, in many cases for the economic data, only aggregated data were available, that is, aggregations of BSUs to output areas equivalent to EAUs. A range of different spatial boundaries was considered for defining the study area: local government areas, natural resource management regions, ABS statistical regions, biogeographic regions and watersheds. None approximated closely the areas being considered for addition to the national park network or the available site-based data, and so a simple grid encompassing this area was used as the EAU or output area, although it is not a management area. The LCEUs used in this report were based on the classification of vegetation in Victoria (see section 3.2).

A key challenge for the development of ecosystem accounts is the diverse data sources and methods needed for their compilation. The available biophysical data tends to be small-scale data with clear spatial references, whereas the available economic data are generally aggregated to industries (agriculture, mining, manufacturing, education, etc.) and sectors (public, private, households) for all of Australia. When available, sub-national spatial economic data are usually for large administrative areas (such as, states or local governments) or statistical areas defined by the ABS. When biophysical and economic data are linked spatially, assumptions and models are needed to scale-up biophysical data and to disaggregate economic data to lower level areas.

2.3 Classifications

A range of classifications is used in accounting, including biophysical classifications, and sector and industry classifications defined in the SNA and SEEA, together with the ecosystem services provided. The accounts derived for agriculture, forestry and water supply industries are defined according to the Australia New Zealand Standard Industry Classification (ANZSIC 2016) (ABS and SNZ 2006), which is used by the ABS for the production of the national accounts and the environmental-economic accounts. The ANZSIC classification is used to classify businesses to industries based on the predominant productive activity. ANZSIC has a hierarchical structure, with the highest level called a Division, with Subdivisions, Groups and Classes beneath. The classification is comprehensive (i.e. covers all economic activity) and is mutually exclusive (i.e. there is no overlap of categories). Industries are defined within ANZSIC on the basis of the goods and services produced. Definitions of the categories used in the report are described in Appendix A2.3.

Primary production activities of agriculture, forestry and water supply are classified in separate Divisions to those of manufactured goods. Consideration of the down-stream use of the resources produced by the Agriculture, Forestry and Water Supply industries is an important consideration for the industry as a whole, but is not included in the accounts for the study area. For example, the water retailers that receive water from Melbourne Water are not considered.

Tourism is not defined in ANZSIC but in a satellite accounting framework of the System of National Accounts (ABS 2016d). While all the products that are produced and consumed in meeting tourism demand are embedded in the national accounts, they are not apparent because 'tourism' is not identified as an industry in ANZSIC. The tourism industry is defined according to the status of the consumer, in terms of their location and visitor status. Additional information on the definition of tourism is found in the Explanatory Notes of the ABS (2016d) Tourism Satellite Account.

The Common International Classification of Ecosystem Services (CICES 2016) is recommended for the classification of ecosystem services by the SEEA Experimental Ecosystem Accounting (UN *et al.* 2014b). In this report, we use the highest level of classification in the CICES (that is, the 1-digit level: provisioning, regulating and cultural services) and follow the intent of the lower level classifications (that is, 3-digit level), but use different names for the services to better align them with local existing terminology. The ecosystem services relevant to the Central Highlands study area and included in the accounts are listed in Table 2.1. Services listed but not quantified are considered important for the region, but insufficient data were available.

Table 2.1. Ecosystem services accounted in the Central Highlands study area classified according to Common International Classification of Ecosystem Services (CICES 2016).

Section	Division	Group	Class	Quantified
Provisioning	Nutrition	Biomass	Cultivated crops	No*
			Reared animals and their outputs	No*
		Water	Surface water for drinking	Yes
	Materials	Biomass	Fibres from plants for direct use or processing	Yes
			Materials from plants for agricultural use	Yes
			Genetic materials from all biota	Yes
		Water	Surface water for non-drinking purposes	Yes
Regulation & maintenance	Mediation of waste	Mediation by ecosystems	Filtration of water and air by ecosystems	No
	Maintenance of biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination and seed dispersal	Partial
		Atmospheric composition and climate regulation	Global climate regulation by reduction of greenhouse gas concentrations	Yes
Cultural	Interactions with biota, ecosystems and landscapes	Physical and intellectual	Physical and experiential uses, scientific, educational, heritage, cultural, entertainment and aesthetic	Partial
		Spiritual and cultural	Sacred, symbolic, religious	Partial

**The value of the contributions of the regulation and maintenance services to agricultural production were calculated.*

2.4 Valuation

Monetary valuation of environmental and ecosystem stocks and flows is a critical issue for accounting. Valuation of human well-being within the environmental-economic system requires appropriate metrics applied at balance points where components of the system are comparable (Figure 1.2). The accounts for the Central Highlands span environmental and ecosystem accounting, and clearly distinguishing what is being valued is important. Valuation was assessed at two stages in the accounts: the benefits in terms of the economic activity of supply of goods and services, and the contributions of ecosystems services to those benefits.

Definitions of valuation and descriptions of a range of approaches are provided in the SNA (paragraphs 3.118 to 3.158), SEEA Central Framework (Section 2.7.3), and SEEA Experimental Ecosystem Accounting (Section 5.5.2), Forest Accounting Sourcebook (Castañeda et al. 2017), and additional information in Atkinson and Obst (2016).

A standard metric used to quantify economic activity is Industry Value Added (IVA), which is part of the SNA. IVA can be calculated in three ways: expenditure, income and production. The latter two methods were used in this report depending on the data available. In the income method, IVA is equal to Gross Operating Surplus plus Mixed Income plus Wages. In the production method, IVA is equal to Revenue from Sales less Intermediate Consumption. IVA is a measure of human production and consumption, and represents the contribution of each industry to Gross Domestic Product (GDP). IVA is only applied to goods and services that are traded within the economy, or could have been traded in the economy, that is, there is a current market (UNSD 2009).

The key principle of valuation of economic activity in accounting is the exchange value, which is used when transactions are valued at the price at which they were exchanged (or could have been exchanged) between willing buyers and sellers. Total value of production is the price times the quantity sold, where the price usually represents the production cost plus a profit to the producer. An exchange value is distinct from the notion of value used in welfare economics, which is associated with utility (Obst et al. 2015). Different people paying the same price for a particular good or service get different levels of utility, while the preferences of individuals will determine which of all the available goods and services they will buy. For example, particular consumers may have been willing to pay more for a particular good or service because it gives them greater utility, but they did not because the price those producers were willing to accept from all purchasers was lower. This difference is known as the consumer surplus. Exchange values do not include consumer surplus.

In this report, timber, water, agricultural commodities, and the goods and services associated with tourism, which are exchanged within the economy are valued at the price of exchange. This information is recorded in the various publications of the ABS and summarised at a national level in the Australian System of National Accounts (ABS 2016a) and other publications (e.g. Australian Environmental-Economic Accounts ABS 2014a, Tourism Satellite Account ABS 2014b, Value of Agricultural Commodities Produced ABS 2016c). The Annual Reports of VicForests and Melbourne Water contain information on the revenue of these companies and the goods and services that they supply, which are generated from use of ecosystem services within the study area. In the case of VicForests, the information covers all operations in Victoria, not just the study area.

There is no exchange value for carbon sequestration in native forests because forest protection is not an approved abatement activity under the Australian Government regulations (Clean Energy Regulator 2016). However, carbon is sequestered by forests and this benefits the public and state and national emissions reduction targets. Hence, the value of carbon sequestration could be exchanged if market access was permitted under the Emissions Reduction Fund (DotEE 2017). Based on SNA approaches to valuation when market prices are not observable, the SEEA (SEEA 2014b, p113) uses a market price equivalent. This is usually based on the market price of similar goods or services. In the case of carbon sequestration, the price of carbon abatement is set by government auction irrespective of the activity or methodology for abatement (Clean Energy Regulator 2015). This carbon price is equivalent to the revenue from production. The IVA is estimated from revenue less costs of managing the forest.

The contributions of ecosystem services to the goods and services supplied within the economy, that is the benefits, are only partly included in the SNA. At present, the contributions of some services as inputs to production are not recognised or valued. The aim of ecosystem accounting is to value all ecosystem services and include them in the accounts. A selection from the range of valuation approaches described in the SEEA (UN *et al.* 2014b) was used to value the different ecosystem services in the Central Highlands, depending primarily on the data available, and these are summarised in Table 2.1. Details can be found in the relevant sections later in this report.

Table 2.1. Summary of valuation approaches used to value ecosystem services in this report

Approach	Description	Use in this report
Unit resource rent	Estimated as the market price less the unit costs of labour, intermediate inputs and produced capital	Ecosystem services used in agricultural production and plantation timber production*
		Cultural and recreational services ("tourism")
Stumpage	The value of timber sold, less harvesting and haulage costs	Native timber provisioning
Replacement cost	Based on the cost of replacing the ecosystem services from alternative sources	Water provisioning
Payments for ecosystem services / trading schemes	Use of values from market based systems set up to either minimise or off-set negative environmental impacts or for the provision of particular services	Carbon sequestration

**This is the regulation and maintenance ecosystem services used in agricultural production and plantation timber production (see UN et al. 2014b, pp. 62-63)*

The unit resource rent method was used for the ecosystem services of agricultural and plantation timber production (Castañeda et al. 2017), and cultural and recreational services, because suitable data on the value of benefits and input costs were available from the ABS at a national level. In addition, estimates of regulatory services used in agricultural production, and cultural and recreational services have been successfully produced by the ABS in the Experimental Ecosystem Accounts for the Great Barrier Reef (ABS 2015a). For timber, information on stumpage (Castañeda et al. 2017) was included in the Annual Reports of VicForests and used together with additional data on harvest areas and timber volumes for the study area.

Similar data were not available for water provisioning, and so the unit resource rent approach could not be used. Information about the costs of water supply is not separated from the costs of sewerage, in both the national level data from the ABS and the regional level data in Annual Reports of Melbourne Water. In addition, the price of water is regulated (see Melbourne Water 2008), and hence the seller's price is constrained. Information was available for the replacement cost of water from desalination, use of recycled water, and water purchase from other areas. This replacement cost method for water was used in the Netherlands (Edens and Graveland 2014). The replacement cost method assumes that (i) if the service was lost it would be replaced by users, and (ii) users would not change their pattern of use in response to a price increase.

The value of carbon sequestration was determined by the price paid in the second Emission Reduction Fund Auction, with an average of $12.25 per tCO_{2_e} in November 2015 (Clean Energy Regulator 2015). Ideally, a marginal price (or the last price paid in the scheme) would have been used, but the price paid for individual contracts is not available, and so a marginal price could not be determined.

Monetary valuation of biodiversity was not attempted although they have been reported elsewhere. For example, a value for Leadbeater's Possum was calculated to be in the range of $40-84 million in 2011 by Jakobsson and Dragun (2001) using the contingent valuation method in welfare economics. As noted by the authors, the estimate of the value of Leadbeater's Possum is based on welfare economics, and hence is not compatible with the exchange values of SEEA and the SNA (Obst et al. 2015).

Habitat services, and particularly those for threatened species, such as Leadbeater's Possum, are specifically identified by Varcoe et al. (2015) as a service from parks. While physical measures of these were presented by Varcoe et al. (2015), no monetisation was attempted. The species within the study area clearly have value, as evidenced by the efforts made to conserve many of them, (for example, listing as endangered under various laws and the expenditure on their protection), but how to translate into monetary values in ecosystem accounting is not yet clear in the SEEA.

Values for environmental or ecosystem assets were not determined, although information contained in this report combined with other information (for example, the national balance sheet of the SNA) could be used to generate such values. For example, by using the net present value method (Obst et al. 2015). It is interesting to note that the accounts in the Annual Reports of VicForests include a value for biological assets (or unfelled timber available for harvest) based on a net present value approach. For all of Victoria, this value was $48.7 million in 2014-15 (VicForests 2015, p. 41).

3. Land

3.1 Introduction

The land account was based on land cover, with additional information about land use and land tenure or management. The land cover classes gave the structure for the accounting, showing the extent of ecosystem types, and the changing areas of these ecosystems over time. Land cover provides a link to the production of ecosystem services. Land use and land tenure provide links to the use of ecosystem services, the benefits and beneficiaries. Land use is shown by industry: agriculture, forestry, tourism and water supply. It should be noted that the land cover account of the SEEA Central Framework is identical to the ecosystem extent account of the SEEA Experimental Ecosystem Accounting. Integrating these spatial data about land cover extent and condition means that ecosystem characteristics can be linked to economic agents (or units), which are aggregated to industries.

Details of the spatial data sources used for all the land classifications are given in Appendix A3.1.

3.2 Land cover

Land cover refers to the physical cover of the land, including various combinations of vegetation types, soils, exposed rocks and water bodies, as well as anthropogenic elements such as cropland and built environments. The land cover information used in this report is derived from spatial gridded data from remote sensing at a resolution of 250 m, combined with ground-truthing. The 250m x 250m grids were the basic statistical units, and like units were aggregated to form land cover ecosystem functional units, which were the output classes for the accounts in the accounting tables and maps.

Native vegetation was classified according to Ecological Vegetation Classes (EVC) (DEPI 2005), which form the basic mapping units used for native vegetation assessment at the landscape scale in Victoria. EVCs are described through a combination of floristic, life-form and ecological characteristics, and through an inferred fidelity to particular environmental attributes. Specifically, they are based on the following information: plant communities and forest types including species and structure; ecological information including life-form and reproductive strategies; and biophysical information including aspect, elevation, geology, soils, landform, rainfall, salinity and climate zones. EVCs represent plant communities that occur in similar environments and have similar ecological responses to environmental factors, such as disturbance. There are 47 EVC classes within the Central Highlands study area. We amalgamated EVCs into larger groups for mapping and associating with other data sources.

Additionally, data on forest types, which are more detailed than EVCs, were available from the State-wide Forest Resource Inventory (SFRI) (DSE 2007a). These data were used to distinguish dominant species within the montane ash forest type; specifically Mountain Ash (*Eucalyptus regnans*) and Alpine Ash (*E. delegatensis*), and were more accurate for calculating the boundaries of ash-type forests and determining forest age. We reconciled our EVC groups with the SFRI classification of dominant species.

Information on non-native vegetation was derived from the VLUIS (Victorian Land Use Information System, Victorian Government 2015a) land cover and land use maps to identify grazing, cropping, horticulture, eucalypt and pine plantations. In total, there were 19 land cover classes and their extent in 2015 is shown in Figure 3.1.

3.3 Land use

Land use refers to the human activities on the land, or the purpose to which the land cover is committed, or the property type. Land use is administrative data based on the cadaster, which denotes areas of ownership as land parcels defined by polygons (see ABS 2013). Resolution varies with the land ownership boundaries. The data from the cadaster include information on land ownership, a land use classification, and an assessed value (for the purpose of levying rates). Land use in the study area in 2015 is shown in Figure 3.2.

Classification of public land was based on Forest Management Zones (see Appendix A3.1). The land use class of 'native forest timber production' includes the area in the General Management Zone and Special Management Zone and areas of Limited Timber Harvesting, but excluding areas under the Code of Forest Practice, such as stream buffers and slope restrictions. The Code exclusions were modelled in the DELWP Forest Management Zones and as such are only indicative. Special Management Zones occur in small patches (total of 18,852 ha), they are included in the area managed for timber production and do not form part of the reserve system. Many patches are managed as harvesting trials, but some patches do conserve specific features like buffers around a species location record or a landscape view or roadside.

The land use class of 'conservation' includes Commonwealth Land, Other Public Land, Other Parks and Reserves, Conservation Parks and Reserves, Special Protection Zones and Code of Forest Practice. Hence, the area of 'native forest timber production' represents a conservative estimate of the area available for harvesting (264,154 ha), rather than the area that is managed by VicForests primarily for timber production (323,715 ha). The area managed for an industry does not have to be entirely used for the production to support that industry.

The matrix of land cover by land use is shown in Table 3.1. Native forests are the dominant land cover with Mountain Ash and Alpine Ash, open and wet mixed forest and rainforest together accounting for 575,737 ha or 78% of the total area. Conservation was the largest land use with 298,238 ha or 41% of total land use, followed by native timber production with 264,154 ha or 36%. The area used by a particular industry includes areas owned or operated for different purposes, as well as the primary activity of the industry. For example, the total area of agricultural land use is 95,813 ha, but only 53,700 ha have land cover types of crops, pasture and horticulture. The rest of the area, while owned or operated by agricultural uses, is covered by native vegetation, plantations or residential buildings.

In subsequent sections, the land cover and land use are linked to the amounts and values of the stocks and flows of carbon, water, timber and biodiversity.

3.4 Land management

Land management refers to the tenure or ownership of land and the purpose of its management. Division is by public or private land, and then zoning within public land. The following classes occur in the Central Highlands region: State Forests (DELWP), National Parks (Parks Victoria), private land, and water catchment (DELWP and Melbourne Water). The classification is from the 2014 Land Use Tenure attribute data (Victorian Government 2015a) (Figure 3.3).

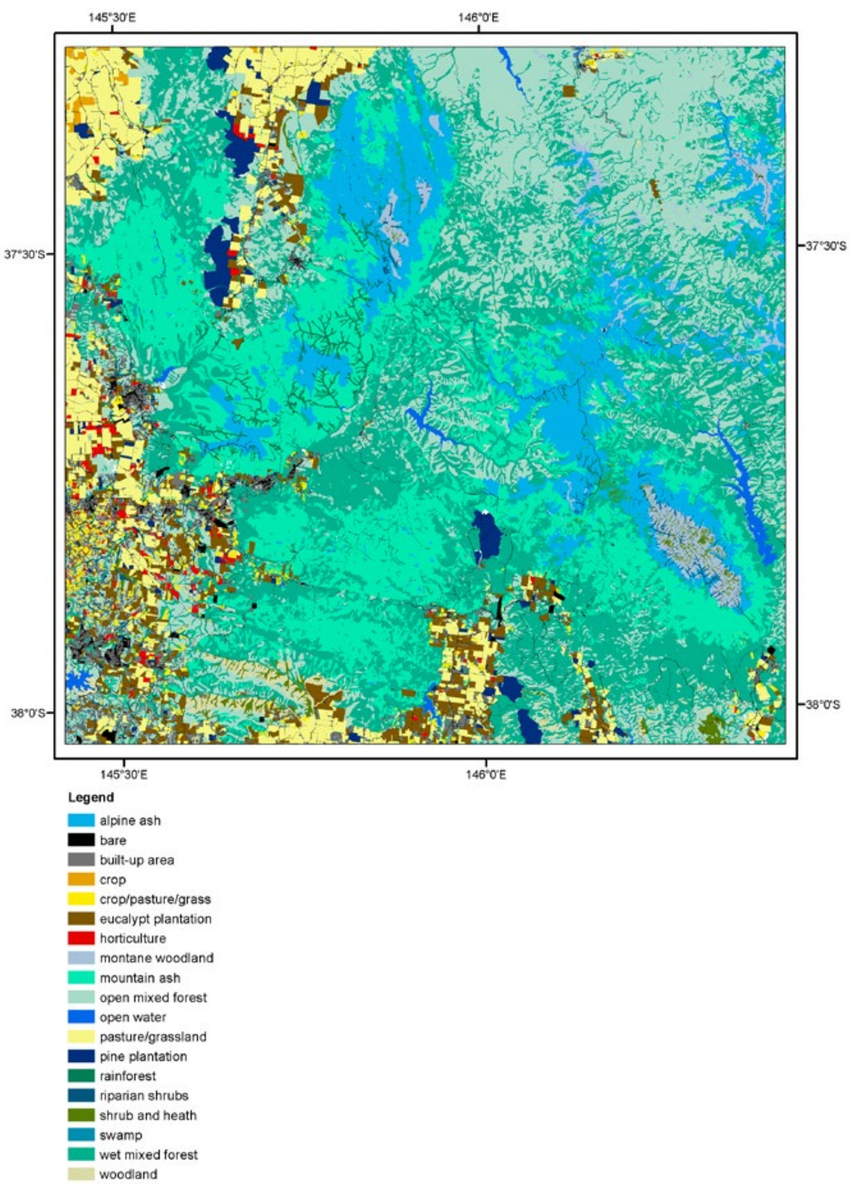


Figure 3.1. Map of land cover classes across the Central Highlands region in 2015.

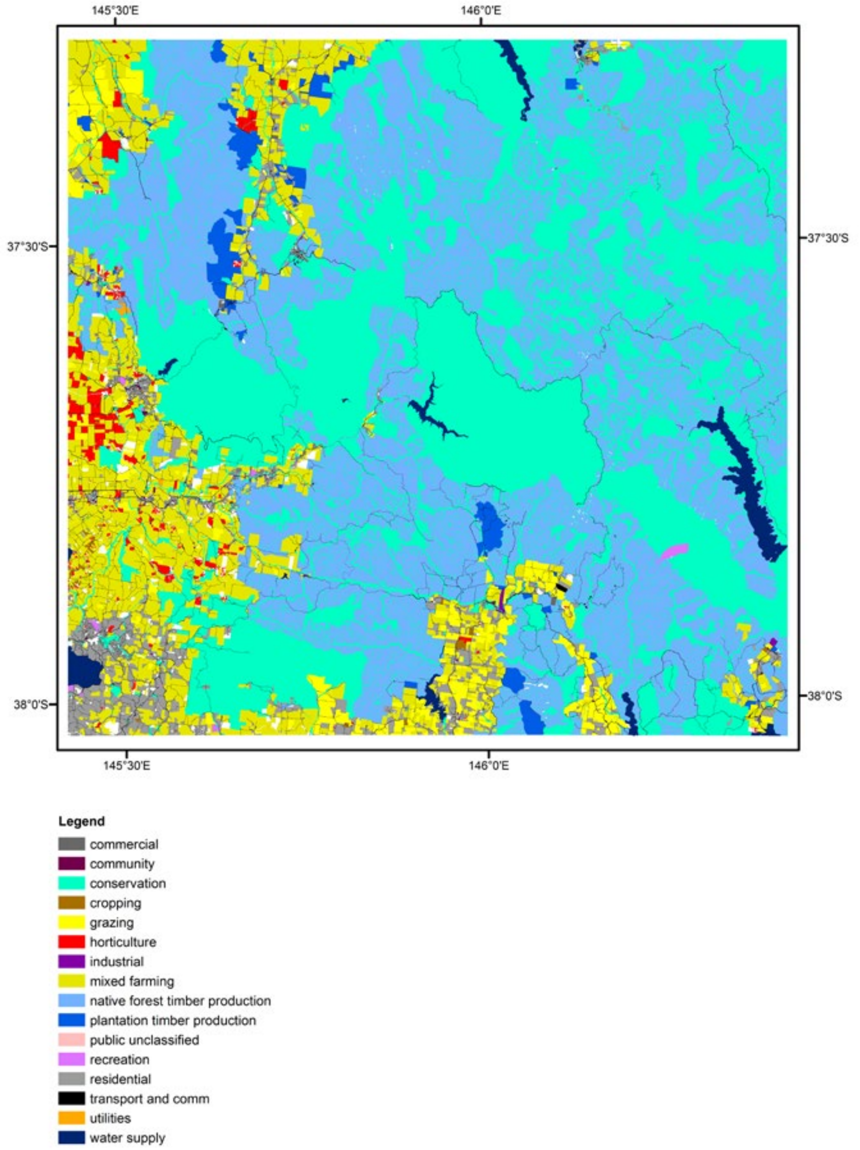


Figure 3.2. Map of land use classes across the Central Highlands region in 2015.

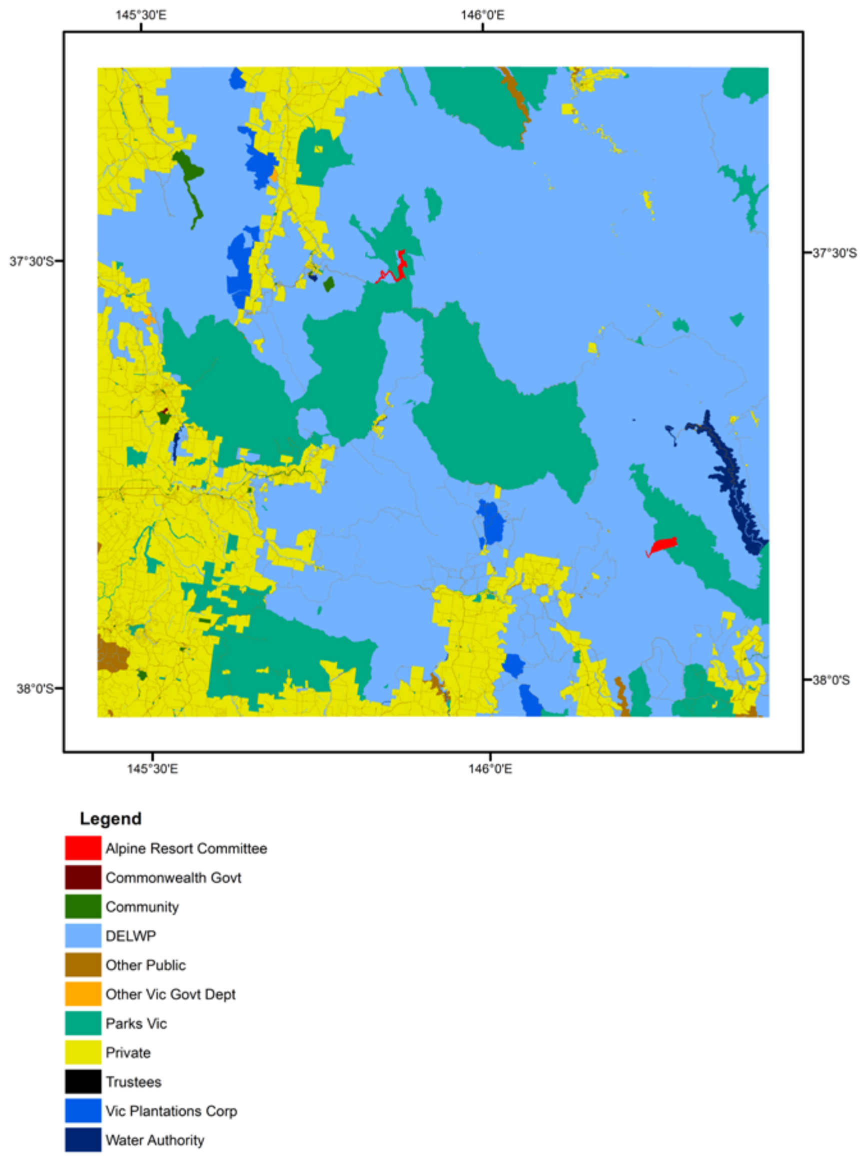


Figure 3.3. Map of land management classes across the Central Highlands region in 2015.

Table 3.1. Area of land (ha) in each land cover by land use class within the study area in 2015

Area										Land cover Classes										
Land Use classes	Alpine Ash	Bare	Built-up area	Crop	Crop/ pasture	Eucalypt plantation	Horticulture	Montane woodland	Mountain Ash	Open mixed forest	Open water	Pasture/ grassland	Pine plantation	Rainforest	Riparian shrubs	Shrub and heath	Swamp	Unclassified	Wet mixed forest	Woodland	Total
Commercial		192	114						24						10			25		6	370
Community		465	20						91	185		27			21			65	298	15	1,187
Conservation	34,387	390	1					11,216	66,143	78,514		38		5,552	2,017	4,002	4	885	90,735	4,354	298,238
Cropping				42		147	15		2			47	51						1		305
Grazing				607		4,549			377	485		11,409	1,121		23	17			1,214	12	19,814
Horticulture		5				967	2,178		62			3,295	297		61	3					6,870
Industrial		358																			358
Landfill															17			7	1		26
Mining		302																			302
Mixed farming	124	31		482	8,407	12,863	1,545		3,161	7,453		25,672	652	33	902	80			6,997	420	68,823
Native timber production	29,961	5	1					2,615	70,081	53,466				57				263	107,058	648	264,154
Plantation production						3,376							8,579								11,954
Recreation		53	48			193		3	53	94		93	50		37	5		35	87	12	764
Residential	3	544	16,701			3,211	318		419	8,058		3,818	259		1,466	152			4,012	620	39,582
Transport & communication		9,256							24	114					15			117	228	9	9,763
Water storage		63							59	2,178	4,361				35			215	1,639	381	8,931
Unclassified		158							87	1,404				4	206	136		1,306	813	100	4,212
Total	64,476	11,821	16,885	1,131	8,407	25,305	4,056	13,835	140,583	151,951	4,361	44,399	11,010	5,646	4,812	4,397	4	2,918	213,082	6,577	735,655

3.5 Anomalies in land classification

When the land cover and land use data were overlaid, anomalies occurred because the two spatial datasets were derived from different data sources and at different scales. Land cover data are based on remote sensing using gridded data. Administrative data are based on the cadaster, which denotes areas of land with different ownership as polygons. Resolving these issues was important to provide a coherent framework of statistical units for the accounts.

Land cover and land use types were checked from views of google earth to identify anomalies in the coding of categories, boundaries and different trends in changes over time. Discrepancies occur for several reasons:

1. cartographical differences due to the different resolutions
2. different times of the data collection
3. errors in coding of the classes
4. changes in the criteria or definitions for coding classes over time
5. apparently different land covers and land uses can co-occur. For example, grazing in native forest or plantations, or cropping and grazing on the same land area at different times of year. Where differences appear to be incompatible, the Land Cover classification was given priority because it is a higher resolution. A property as a single Land Use class may have more than one Land Cover type.

Conflicting classifications were resolved and errors corrected if the minimum area was 5 ha. Identifying and rectifying these anomalies was critical for the accounts so that changes in methodology of the spatial data collection were not interpreted as actual changes in land area of categories. The accounts require a unified framework of basic statistical units using consistent areas of land.

Interesting information emerged from the intersection of land cover and land use. For example, much native forest occurred on private land (classified as land uses of mixed farming, grazing, residential) and these areas could be managed for conservation in a similar manner to the same vegetation types on public land.

The intersection of land cover and land use also identified some anomalies. Examples of anomalies in land classification are given in Appendix A3.5. The detection and correction of anomalies meant that the resultant data on land cover and land use could be used with confidence. This work could be used to help improve primary data.

3.6 Forest age

Forest age was considered important because it is a determinant of the ecosystem services related to water, carbon, timber, aesthetics and biodiversity. Age is also needed to calculate various estimates contained in these component accounts. As such, forest age can be used as a measure of ecosystem condition (see section 10.2).

Forest age was determined for the area of forested land cover, based on the time since disturbance events that resulted in stand replacement. These events included wildfire or clearfell logging for montane ash and rainforest; and clearfell logging for wet mixed, open mixed, woodland and montane woodland. Forest age was not changed after selective logging because this silvicultural practice occurs mostly in mixed species forest types that are uneven-aged. Additionally, harvesting practices vary in the classes of stems removed, and often senescent trees are not removed (Florence 1996, Lutze et al. 1999).

Fires before 2009 were mapped as a fire boundary, and the impact on all ash forest within this boundary was assumed to be a stand replacement wildfire. Distinction about the effects of fire type on forest age was not possible for the earlier fires because there was insufficient information about fire severity. After the 2009 wildfire, fire severity was assessed and showed that ash trees were killed only in areas of high fire severity. Figure 3.4 shows the difference in the predicted impact of fire on forest age, depending on whether all ash forest within the fire boundary was considered to have stand replacement, or whether replacement only occurred in the areas of high severity fire.

Regeneration age was separated into events from fire or from logging because these disturbance types affect characteristics of ecosystem condition, such as the number of residual trees. The effect of the history of logging on the forest age distribution is illustrated in Figure 3.5.

Forest age classes were selected to correspond to the congruence of times since major disturbance events, inflection points in the response of water yield to age, and harvesting age (Table 3.2). Major wildfires occurred in 1939, 1983, 2007 and 2009. After disturbance, runoff increases for about 3 years, and then decreases with a maximum reduction in water yield in 25-30 year-old regenerating forest (see section 4.3.1). The nominal harvesting age is 80 years, although the median age of harvesting is 68 years (Keith et al. 2015).

Change over time in forest age was calculated from the disturbance history of fire and logging events each year. The analysis was based on a single classification of forest type or land cover to ensure that change was attributed to a disturbance activity, and not identified spuriously due to anomalous changes in classification systems.

Table 3.2. Forest age classes

Age Code	Years old	Regeneration period
1	> 75	before 1939
2	56 – 75	1939-1959
3	33 – 55	1960-1982
4	7 – 32	1983-2008
5	0 - 6	2009-2015

'Years old' refers to years before 2015

Table 3.3. Area (ha) within each forest type and age class in 2015

	Forest age class				
	before 1939	1939-1959	1960-1982	1983-2008	2009-2015
Rainforest		4,340	40	265	1,001
Alpine Ash		34,282	3,911	15,308	10,974
Mountain Ash	216	78,289	5,552	35,085	21,455
Wet mixed forest	180,928		23,832	6,911	1,053
Open mixed forest	139,618		9,266	2,857	299
Woodland	6,222		196	23	2
Montane woodland	13,314		509	12	

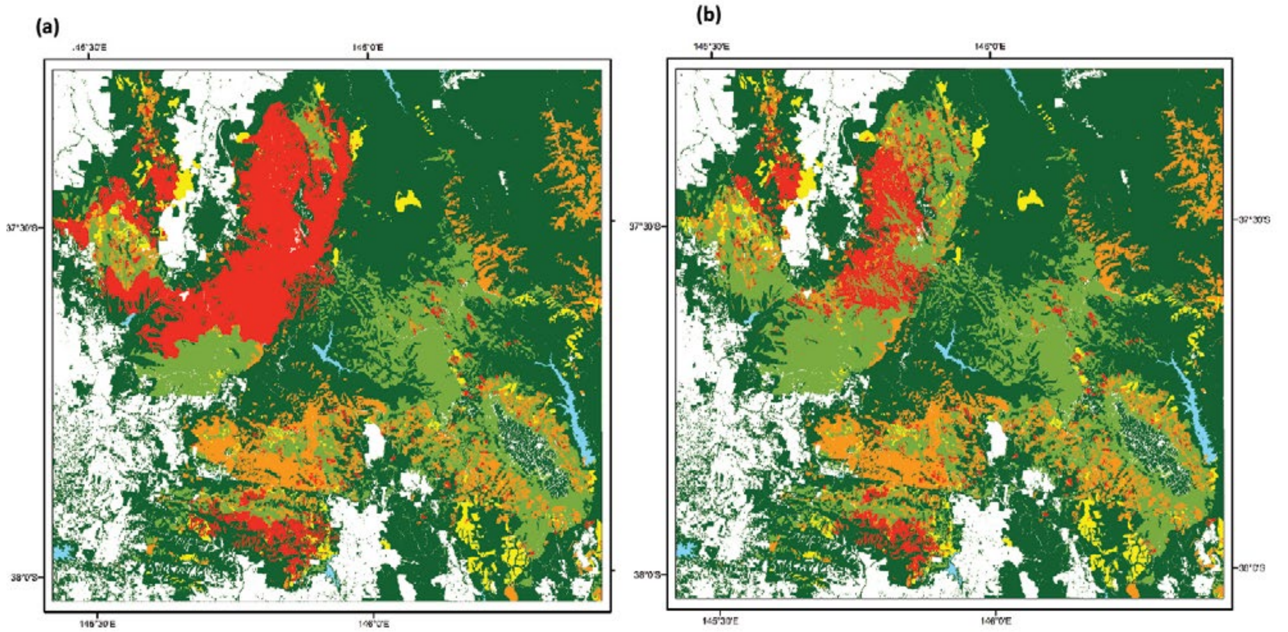
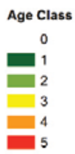
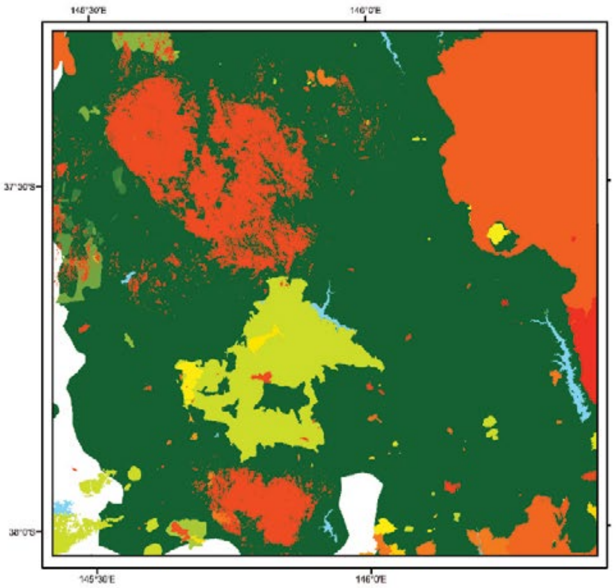


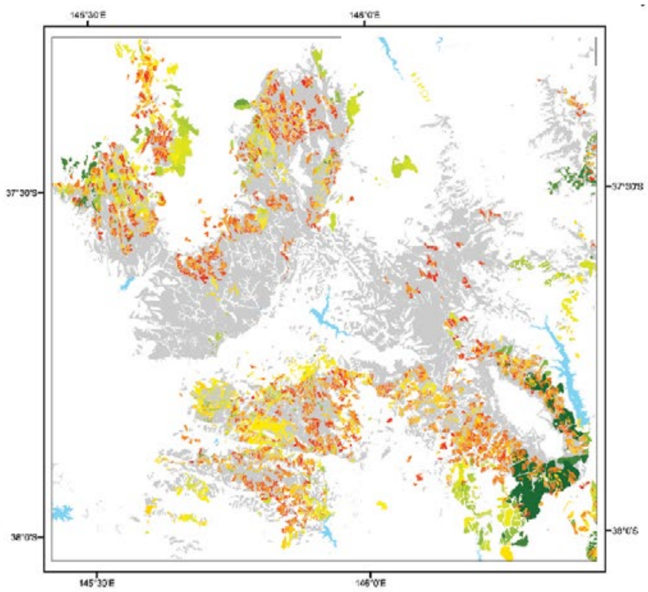
Figure 3.4. Spatial distribution of forest age in 2015, where regeneration of ash forest was assumed to occur in (a) all areas after fire, and (b) only areas subject to high severity fire.

Age classes: 0: non-forest; 1: before 1939; 2: 1939-1959; 3: 1960-1982; 4: 1983-2008; 5: 2009-2015.

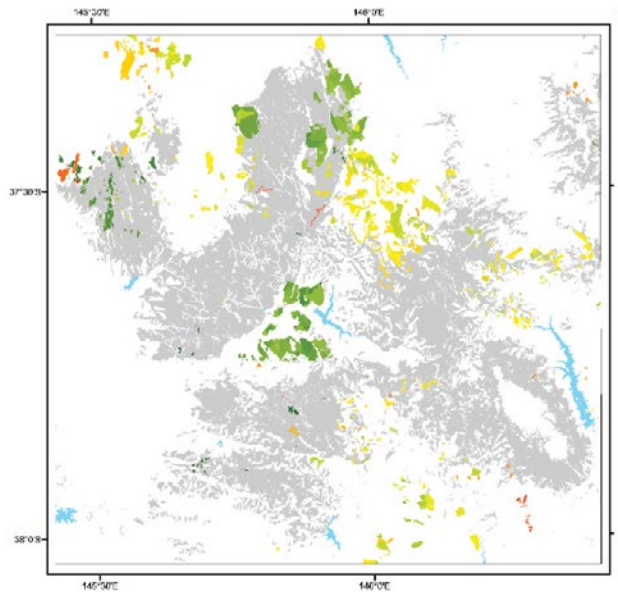




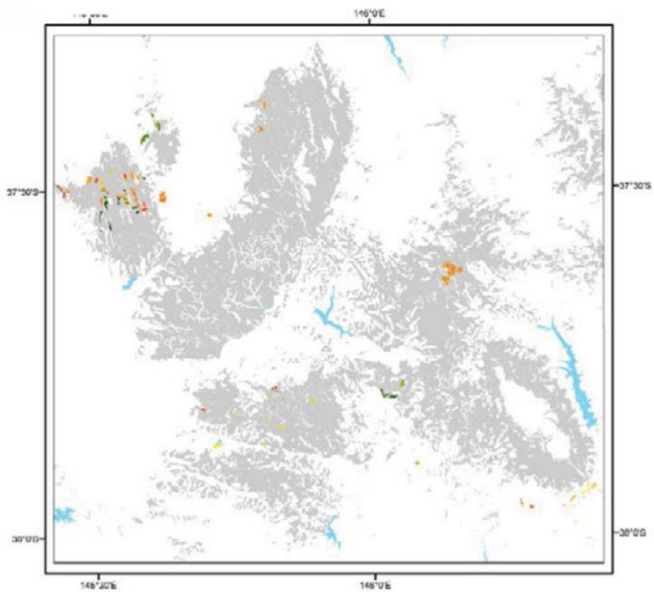
(a) History of wildfire
The main wildfires occurred in the study area in: 1939, 1983, 2007 and 2009. Wildfires are only considered stand replacing in Mountain Ash, Alpine Ash and rainforest.



(b) History of stand-replacing logging, such as clearfelling.
Areas of logging shown in all forest types, grey shaded background shows distribution of ash forest.



c) History of selective logging by single tree selection and thinning from above.



(d) History of logging by thinning from below.

Figure 3.5. Spatial distribution of disturbance events from wildfire and logging.

4. Water

4.1 Introduction

The study area in the Central Highlands contains the majority of the catchment areas for the ten water storage reservoirs for the Melbourne Water Corporation that supply water to the city of Melbourne (Viggers et al. 2016). Additionally, some water from the Central Highlands catchments is used for rural water supply in surrounding regions. Melbourne Water manages the storage and supply of water to retail water authorities in Melbourne: City West Water, South East Water and Yarra Valley Water. Water use from these retailers include residential, commercial and non-revenue use (including losses in distribution, leakage, use in fire fighting, etc.). Melbourne Water also has a water supply system from a desalination plant that is outside the study area.

The water supply catchments cover an area of 157,000 ha in the Yarra Ranges, with 115,149 ha within the study area. Some of this catchment area is protected but other areas are available for timber harvesting. Some 8,931 ha are dedicated specifically to water storage (Table 3.1). The total water storage of the ten reservoirs operated by Melbourne Water is 1,812 GL. Five of these reservoirs are located within the study area. The other reservoirs are further downstream and fed by the same catchments. The study area contributes to the catchments of the Yarra River, the Tarago / Bunyip Rivers, and the Thomson River. The Yarra River supplies the majority of water to Melbourne. The Tarago River and reservoir supply water to Westernport Bay and Mornington Peninsula. The Thomson River supplies Thomson reservoir, from which some water flows down the Thomson / Macalister River to Gippsland and some is piped to other reservoirs for supplying Melbourne. The location of the rivers and reservoirs in the region, and specifically within the study area, are shown in Figure 4.1.

Accounts were prepared for the water asset or stock of water in reservoirs, the ecosystem service of water provisioning as inflow to the reservoirs, and water supply from the reservoirs to consumers. The provisioning service is also likely to include the regulating service of water filtration (including dilution, filtration and sequestration of pollutants). However, the physical water filtration service was not separately estimated in this case but could be in the future.

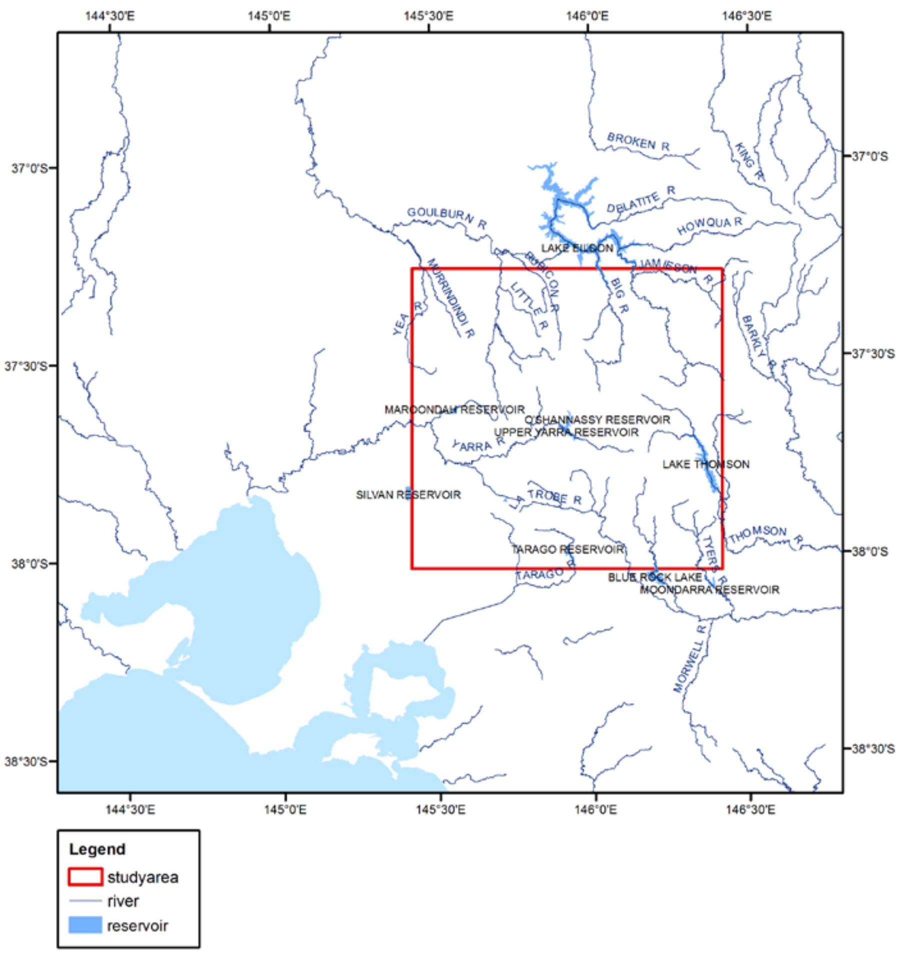


Figure 4.1. Location of rivers and reservoirs in the region, and specifically the five reservoirs and their river catchments within the study area

4.2 Water assets

A water asset account was prepared for the water stored in the reservoirs within the study area. This shows the stock, additions and reductions of water to these reservoirs. Change in the water stored in reservoirs represents the balance between inflows (the water provisioning service of water yield or runoff from the catchments), and outflows (the water supply to users plus evaporation from reservoirs). The scope of the water asset account does not include the water in rivers, farm dams and groundwater.

4.2.1 Data sources and methods

Data describing the characteristics of the ten reservoirs and annual water storage were obtained from the Melbourne Water website. Additionally, biophysical data were used for the study area. Other sources of data investigated but not used in the accounts included the Bureau of Meteorology National Water Account (Melbourne Region) (BoM 2016), and the ABS Water Account, Australia (ABS 2015b). Information on both surface and groundwater are available from the BoM National Water Accounts (BoM 2016). However, the boundary of the BoM Melbourne Region excludes a large part of the study area including the catchment for the Thompson River and reservoir. The accounts from BoM were investigated, and preliminary SEEA accounts were prepared based on these, but they were not used in the report, because of the difficulty of adjusting for the difference in geographic scope.

4.2.2 Results

Water asset accounts were prepared for the calendar years 1990 to 2015, in the form of a table (Appendix 4. Water), and shown in summary form as the histograms in Figure 4.4. The water stock or storage volume (GL) represents the average over the year for the combined ten Melbourne Water reservoirs. The total water storage of the ten reservoirs is 1,812 GL. The Central Highlands study area covers most of the catchments for the five upper reservoirs in the water supply system (Table 4.1).

Table 4.1. Characteristics of the reservoirs within the Central Highlands study area

Reservoir	Capacity	Catchment area	Area logged		Area available but not logged		Area protected	River supply
	(GL)	(ha)	(ha)	%	(ha)	(%)	(%)	
Thomson	1068	47,558	6,743	14	15,837	33	53	Thomson R.
Upper Yarra	200	34,047	217	1	432	1	98	Upper Yarra R.
Tarago	37	11,498	2,792	24	3,779	33	43	Tarago R.
Maroondah	22	10,191	24	0	28	0	99	Watts R.
O'Shannassy	3	11,888	73	1	57	0	99	O'Shannassy R.

Reservoir capacity refers to total water storage capacity. Approximately 2.5% of the capacity is 'dead storage', that is unavailable for use at the bottom of a reservoir.

4.3 Water provisioning service and water supply

The water provisioning service is described in physical terms by the runoff or water yield from the catchments in the study area, which provides inflows to the reservoirs. The provisioning service was deemed to be used by Melbourne Water at the time when it enters the reservoir, and not when water leaves the reservoir and is supplied to customers. This treatment distinguishes the ecosystem service from the supply of water to consumers, with ecosystem service of water provisioning being the inflow to the reservoir and recorded in the time period of the inflow, and the supply of water to consumers that occurs at a different time and is unlikely to be equal to the inflow. The ecosystem service of water provisioning is used by Melbourne Water as input to the production of water supplied and used in the economy.

A range of economic and environmental data were used to estimate the volume and value of the water provisioning service obtained from the study area. The value of the service (V) is equal to the volume of the service supplied (Q) multiplied by the price per unit of the service (P), that is:

$V = P * Q$

Accounts were compiled for the water provisioning service in physical and monetary terms, as the volume and value of water inflows.

4.3.1 Data sources and methods

4.3.1.1 Water provisioning service

Water yield was calculated spatially across the study area and disaggregated for each of the five reservoirs. These data provided information about the spatial distribution of water inflow and the change each year in response to climate variability, land cover change, and disturbance history. Applying the response of water yield to forest age allowed some understanding of the causes of change in yield over time in relation to forest management and disturbance events.

Water yield is determined by the balance between rainfall and evapotranspiration, soil water storage capacity, and vegetation cover. Water yield was estimated each year using a spatially-explicit continental water balance model calculated monthly across our study area (Guo *et al.* 2002, eMAST 2016). Rainfall and pan evaporation data were derived from the eMast database (eMast 2016). These data represent the average across the landscape of the study area derived as the average of the eMast 0.01 degree raster cell numbers resampled to 0.0001 degree to align with the study area. Actual evapotranspiration was calculated on a monthly time step from precipitation and pan evapotranspiration at a 1 km^2 scale. Runoff was calculated as the water in excess of the soil water field capacity of the catchment. The model was calibrated for the ecohydrological region (Stein et al. 2009) against gauged streamflow data (n = 347 flow gauges) (Peel *et al.* 2000, BoM 2013b). These gauging stations were selected to be in catchments with minimal disturbance, but there may have been some forest harvesting or fire in the past that would have resulted in a range of forest ages. Runoff for each grid cell was accumulated for each stream segment within the catchment to give a volume inflow to each reservoir. The spatial analysis covered a range of scales. The runoff estimates were derived at a grid resolution of 0.01 degrees, and the catchment delineation and flow routing were undertaken at 9 second resolution (approximately 270m). The forest age polygons were gridded at 0.0001 degrees resolution to minimise the information lost from the polygon boundaries. The runoff depth was resampled to the finer resolution, converted to a volume and adjusted for forest age (where applicable), then aggregated to 9 second resolution for routing (Stein *et al.* 2014).

Annual variability in the water balance model is driven by climate variability, in particular, precipitation and evapotranspiration. However, actual water yield is also influenced by the condition of the vegetation in the catchment, with the main factor being age of the forest. Evapotranspiration depends on leaf area index and leaf conductance, which vary with forest age and thereby determine the shape of the water yield response curve (Vertessy *et al.* 2001). Forest age was determined from the last stand-replacing disturbance event, which refers to high severity fire or clearfell logging for montane ash forest and rainforest, and clearfell logging for mixed species forest. Change in water yield is shown as a proportion of the pre-disturbance amount (Figure 4.2). An increase in water yield occurs for the first 1 to 3 years after stand-replacing disturbance in all forest types. In montane ash forest and rainforest, a decrease then occurs with the greatest reduction between the ages of 13 to 49 years and peaking at 25 years. Maximum reduction from a pre-disturbance 1939 regrowth forest is 29%, and from an old growth forest is 48%. Water yield is not fully restored for at least 80 years if a forest is regrowth at the time it is disturbed, and 200 years if a forest is old growth at the time it is disturbed.

The water yield calculated from the water balance model was derived for a constant vegetation condition, thus producing a baseline yield. This baseline yield was compared with the yield when forest age, and the change in age, were taken into account. The difference in water yield with and without disturbance events, and disaggregated into fire and logging events, provided information about the attribution or cause of the change in water yield. Details of calculations of the water yield function with forest age taken into account are provided in Appendix A4.3.

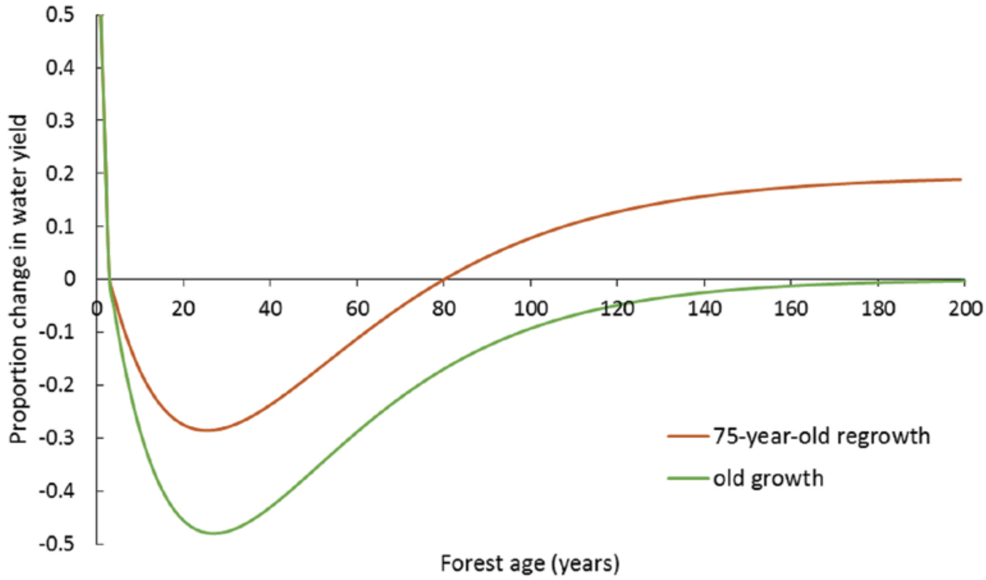


Figure 4.2. Reduction in water yield in montane ash forest estimated as a proportion of the pre-disturbance amount in regrowth and old growth forest.

Source: Kuczera (1987) for old growth model

4.3.1.2 Water supply

Water supply from the reservoirs includes supply to water retailers which in turn is supplied to consumers in Melbourne, releases of water for environmental flows and irrigation, and a small amount for hydroelectricity generation. Final consumers consist of households and businesses, government and non-governments organisations, including water used by schools, universities, hospitals, parks, sportsgrounds, and other institutions. Non-revenue water abstraction includes that used for firefighting and leakage from pipes.

The water supplied by Melbourne Water is given in their annual reports (Melbourne Water 2000 – 2015), and includes drinking water, environmental releases, irrigation entitlements, and extra allocations. Minimum environmental flows are specified in the Environmental Bulk Entitlement for each river. The basic water release entitlements are given in Table 4.2, but there are additional regulations concerning minimum quantities of downstream flows, both daily and seasonal. These rights to water may be suspended, reduced, increased or changed after water shortage has been declared (Victorian Water Act 1989 Section 33AAA(2), DEPI 1989). Surface water allocations are made for high reliability and low reliability water shares. Water is diverted from rivers under licensed water access entitlements as non-allocated surface water to users, for irrigation, stock and domestic water use, commercial and industrial purposes. Take and use licences specify a maximum entitlement volume, but this does not represent a surface water liability. Mean annual river flow for the Yarra River is 429 GL yr^{-1} and the Tarago/Bunyip River is 114 GL yr^{-1}.

Table 4.2. Sources of water releases from reservoirs within the Central Highlands

Reservoir	Water supply (GL)	Source of Entitlement
Thomson	639 $_{\text{(in 2012)}}$	Supply to Melbourne Water via pipe to Upper Yarra reservoir (share of inflow)
	25.1	Victorian Environmental Water Holder, 15.1 GL for controlled daily flows + 10 GL additional allocation
	45 (+ 6% of inflow)	Southern Rural Water for Thomson-Macalister Rivers irrigation district
Tarago	4.8	Gippsland Water for urban water supply
	3 (or 10.3% of inflows)	Tarago & Bunyip Rivers Environmental Entitlement
Yarra	17	Yarra River Environmental Entitlement

4.3.2 Results

The volume of the water provisioning service based on calculated runoff (water yield) from the catchments within the study area was classified by land cover type (Table 4.3), and forest type and age (Table 4.4). The results are shown for the calculation of runoff using the pre-disturbance vegetation condition of the 75-year old regrowth forest. This age is considered the most realistic scenario for this region because the majority of the forest was burnt in 1939. Details of results using different pre-disturbance vegetation conditions and reasons for differences in water yield in different catchments are given in the Appendix (Section A4.2.3). Water yield in each of the land cover and age classes depends on the area of land in each class, the precipitation and evaporation in that area, and the effect of the land cover on runoff. Additionally, the effect on water yield of the assumption that an initial increase in runoff occurs post-disturbance until leaf area is restored is demonstrated in the Appendix (Figure A4.9). Any increase in water yield will depend on the antecedent soil water content and post-disturbance weather conditions, which determine the proportion of rainfall that infiltrates. Given that these conditions are highly variable after different disturbance events, an average increase in yield has been used in the summary results.

Table 4.3. Water provisioning service of water yield (ML yr^{-1}) for the whole study area classified by land cover, using an average annual total for each 5-year period

Land cover	1985-89	1990-04	1995-99	2000-04	2005-09	2010-12
Bare	33,522	38,820	28,870	21,435	13,019	42,066
Swamp	61	59	48	47	38	61
Built-up area	40,237	47,497	36,572	25,923	14,052	52,559
Crop	1,964	1,945	1,497	1,142	510	2,321
Crop/ pasture/ grassland	19,729	23,408	17,973	12,635	6,822	25,711
Pasture / grassland	81,576	88,391	67,224	48,903	24,376	97,546
Horticulture	8,755	10,289	7,946	5,506	2,752	11,271
Pine plantation	30,794	34,382	25,282	18,987	11,129	37,258
Eucalypt plantation	61,455	72,314	54,654	38,892	21,848	79,598
Shrub & heath	24,470	25,108	19,669	17,505	13,077	26,668
Riparian shrubs	26,189	26,687	20,912	18,250	13,079	28,507
Woodland	12,712	15,260	11,949	8,184	4,357	17,273
Montane woodland	140,066	137,990	103,426	96,688	72,876	144,984
Open mixed forest	594,173	643,267	440,591	353,956	228,955	675,159
Wet mixed forest	904,808	1,000,743	708,858	550,497	387,057	1,062,748
Alpine Ash	500,190	502,009	378,299	349,860	268,102	624,202
Mountain Ash	750,495	807,288	606,153	511,585	377,444	969,954
Rainforest	41,651	42,162	32,632	29,381	22,159	54,648
Unknown	15,125	17,707	11,746	8,856	5,803	18,282
Total	**3,287,971**	**3,535,325**	**2,574,300**	**2,118,232**	**1,487,455**	**3,970,818**

Table 4.4. Water provisioning service of water yield (ML yr^{-1}) classified by land cover forest type and forest age-class for the forested area within the study area, using an average annual total for each 5-year period

Forest type	Age (yrs)	1985-89	1990-04	1995-99	2000-04	2005-09	2010-12
Woodland	< 4	33	0	0	0	0	7
	4 - 12	141	95	26	0	0	0
	13 - 24	255	319	156	59	18	0
	25 - 49	4	83	161	198	140	567
	50 - 75	0	0	0	0	0	59
	> 75	12,277	14,764	11,613	7,924	4,198	16,643
Montane woodland	< 4	43	7	6	0	1	5
	4 - 12	1,031	108	37	10	2	2
	13 - 24	3,325	2,142	947	280	32	35
	25 - 49	400	2,387	2,392	2,758	2,110	4,950
	50 - 75	0	0	0	0	0	130
	> 75	135,199	133,290	100,221	93,677	70,726	139,848
Open mixed forest	< 4	1,295	731	1,466	1,168	468	1,328
	4 - 12	16,871	5,527	1,944	2,214	1,764	4,808
	13 - 24	22,567	30,798	18,504	5,568	1,353	5,266
	25 - 49	1,881	7,256	11,281	19,498	15,305	45,323
	50 - 75	0	0	0	0	0	2,148
	> 75	550,576	588,821	402,709	325,542	207,264	600,685
Wet mixed forest	< 4	7,279	4,306	2,285	2,441	1,247	3,132
	4 - 12	41,843	26,671	9,701	5,045	3,887	9,555
	13 - 24	56,303	65,693	43,699	21,360	7,245	14,554
	25 - 49	6,953	29,362	35,952	47,669	41,071	124,040
	50 - 75	0	0	0	0	0	12,903
	> 75	823,536	897,512	628,624	501,257	343,739	922,919
Alpine Ash	< 4	6,615	14,680	7,067	6,869	21,395	149,592
	4 - 12	20,141	16,372	16,669	16,051	10,353	69,521
	13 - 24	24,711	20,615	15,634	13,086	10,056	18,391
	25 - 49	344,560	15,590	16,486	20,820	18,002	32,729
	50 - 75	103,614	435,983	323,560	293,583	208,498	358,755
Mountain Ash	< 4	54,170	28,639	20,363	18,721	12,916	183,508
	4 - 12	62,304	108,543	51,995	36,042	28,494	60,543
	13 - 24	14,152	21,862	52,077	56,182	37,535	61,781
	25 - 49	474,494	8,487	9,486	12,397	22,760	92,555
	50 - 75	155,761	655,563	476,287	391,858	279,811	580,527
	> 75	649	791	635	444	251	919
Rainforest	< 4	748	5	6	0	0	13,673
	4 - 12	973	1,543	281	7	2	0
	13 - 24	300	232	846	820	318	13
	25 - 49	29,762	116	169	205	418	1,586
	50 - 75	9,867	40,274	31,320	28,350	21,421	39,382

The effect of changes in forest age on the spatial distribution of water yield are demonstrated in maps of runoff volume across the landscape. Figures 4.3a and 4.3b show the spatial distribution calculated for constant forest age (a), and taking into account the reduction in water yield due to forest age (b). These maps highlight the impact on water yield of stand-replacing disturbance events, that is, high severity fire and clearfell logging. After an initial increase in runoff for up to three years, the runoff is then reduced for many decades while the forest regenerates. This impact is illustrated by the mosaic of individual light blue grid cells within patches of dark blue in Figure 4.3b, which indicate areas of forest that have been clearfelled and are now regrowth, and the subsequent reduction in runoff.

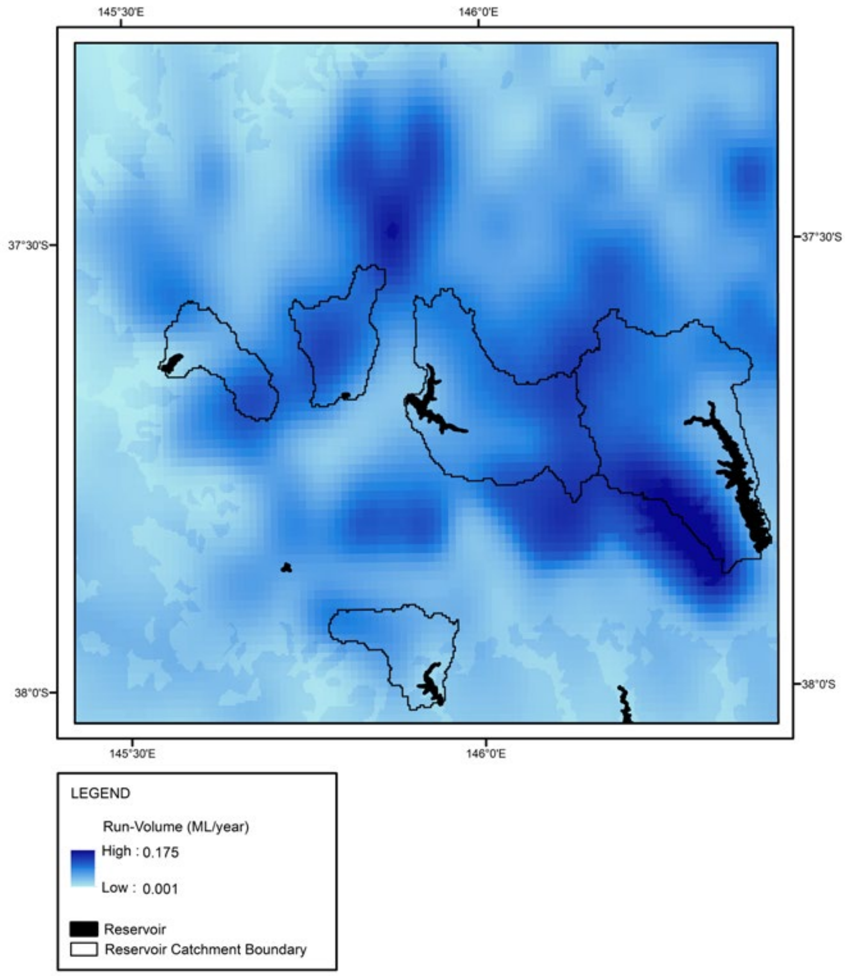


Figure 4.3a. Spatial distribution of runoff in 2012 calculated assuming a constant age of the forest

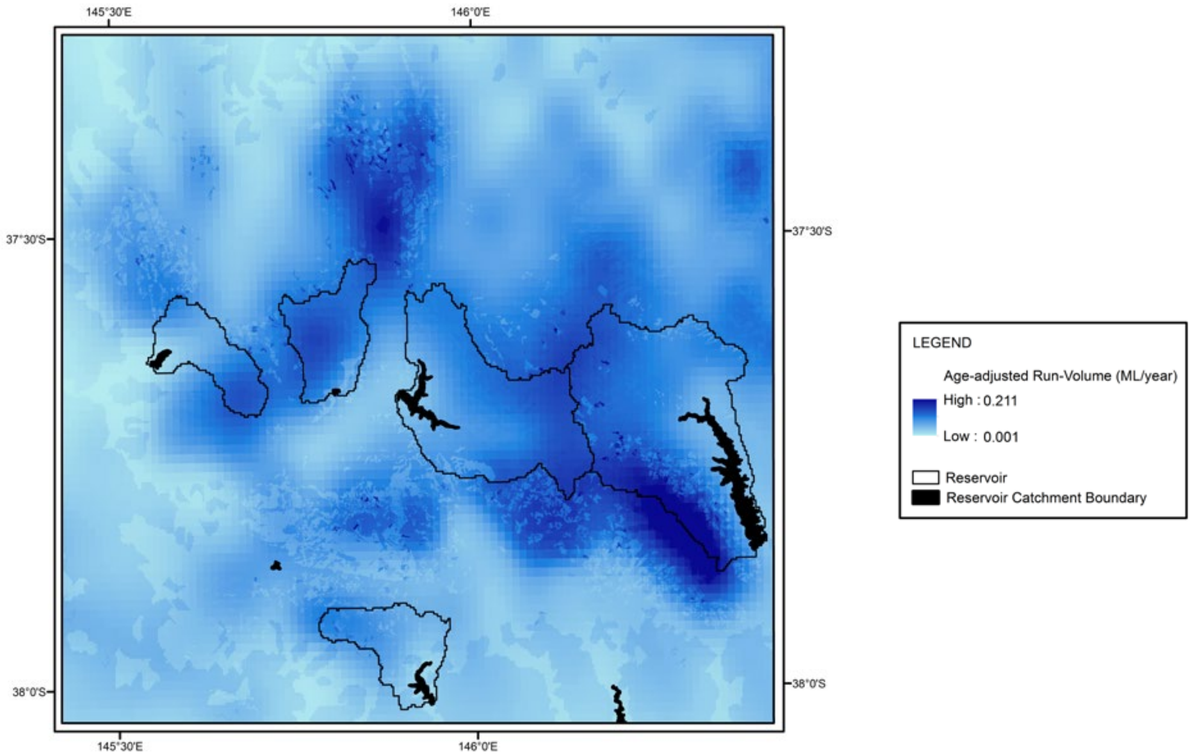


Figure 4.3b. Spatial distribution of runoff in 2012 calculated with changing forest age due to regeneration from wildfire and logging

The effects of fire and logging on water yield were disaggregated to analyse the counterfactual case; that is, the case where logging had not occurred in the catchments. The differences in water yield (Table 4.5) show that the greatest difference occurs in the Thomson and Tarago catchments, where 47% and 57% of the catchment area is available for logging (Table 4.1). The increasing difference in water yield over time demonstrates the effect of greater areas of younger-aged forest regenerating after clearfelling. The counterfactual case was the 1939 regrowth forest and hence the differences in water yield will be underestimated compared with the case of old growth forest.

Table 4.5. Difference in water yield (ML yr^{-1}) due to areas that have been logged in the catchments compared with no logging, using an average annual total for each 5-year period

Catchment	1985-89	1990-94	1995-99	2000-04	2005-09	2010-12
Upper Yarra	-70	-126	-115	-124	-127	-334
O'Shannassy	-37	-46	-59	-69	-68	-168
Maroondah	-16	-14	-13	-15	-12	-31
Lake Thomson	-1852	-2028	-1942	-2911	-3053	-7687
Tarago	-42	-185	-182	-293	-470	-1628
Total	-2017	-2399	-2311	-3412	-3730	-9849

The water accounts are summarised in Figure 4.4, showing the time series of water stocks, inflows from precipitation and runoff, and reductions due to abstractions from water supply and evaporation. Large variations in stocks, inflows and abstractions of water occur annually and as trends during the 25-year period. The water stock or storage volume (GL) represents the average over the year for the combined ten Melbourne Water reservoirs. The pattern of inflow closely follows the pattern of precipitation. However, runoff is also influenced by season of rainfall and antecedent soil water content. The pattern of water abstraction is reasonably constant and does not follow the annual variability in inflow. Supply and consumption of water is influenced by human population size, which has been increasing over time; and efficiency of water use, which has been improving (ABS 2017). Overall, there is a trend of decreasing water consumption, which is seen in state estimates by the ABS (ABS 2015b). The decrease in abstractions from water supply during, and since, the Millennium Drought is due to water restrictions, greater water use efficiency and investment in alternative water projects, resulting in 23% lower water use per person than pre-drought levels. However, water abstraction has increased slightly in the last four years, partly attributed to a growing population, although levels are still lower than pre-drought conditions (Melbourne Water 2016).

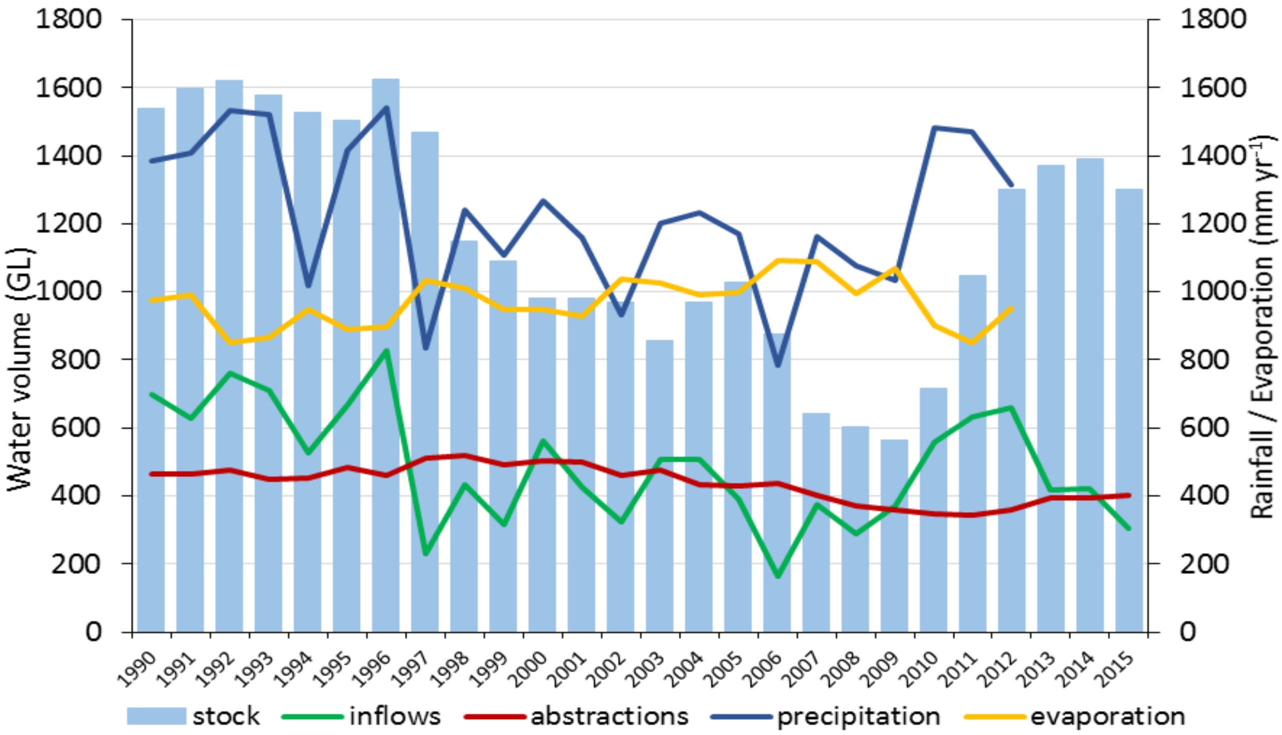


Figure 4.4. Time series of water storage (stock), precipitation, evaporation, inflow (runoff), and abstraction (supply) for the Melbourne Water reservoirs and catchments within the study area.

4.4 Valuation of the water provisioning service and water supply

Water supplied into the economy, valued as revenue by Melbourne Water, is the end result of a combination of fixed capital (reservoirs, water mains, pumps, etc.), labour and other inputs, in addition to the ecosystem service of water provisioning. Hence, the value of the water provisioning service is not the same as the value of the water supply. An additional complicating factor is that the price of water in Victoria is regulated by the Essential Services Commission (see Melbourne Water 2008). The water supplied to the economy also uses the additional ecosystem service of water filtration by forest ecosystems, but separate estimates of this have not been made.

Valuation of the ecosystem service of water provisioning used a range of information, other than financial reports, and three methods for calculation were considered: (1) resource rent, (2) production function, and (3) replacement cost.

4.4.1 Data sources and methods

The value of sales of water supply is provided in the Annual Reports of Melbourne Water, which is owned by the Victorian Government (Melbourne Water 2015). The volume of water supplied, the revenue received from this supply, and the costs of producing the water (wages and salaries, consumption of fixed capital and other running costs) are given in the reports. These data were used to generate an estimate of the value added by the company, aligned with the concepts of Industry Value Added in national accounting. Water supply is deemed to be the total supply for Melbourne Water derived from the yield in the catchments, as well as the potential supply from the desalination plant. If water is generated from the desalination plant, it is pumped into the reservoirs within the study area (Viggers et al. 2013).

Three methods were investigated for valuing the water provisioning service. The resource rent method was not used owing to the constrained nature of the water market in Victoria, where prices are regulated by the Essential Services Commission. Previous calculations of resource rent in Australia by Comisari *et al.* (2011), and in the Netherlands by Edens and Graveland (2014), have found negative rents. An additional factor in the rejection of the resource rent method was the lack of data in the Annual Reports of Melbourne Water about the value of the water supply infrastructure and the costs associated with water supply. While the Annual Reports contain some information about these costs, the data are presented as the combined values of water supply and sewerage, whereas separate information about these two activities is required for resource rent calculations. Similarly, the information about water supply is included with the sewerage industry in the Australian System of National Accounts.

The production function approach also was rejected for this study because of lack of data. In the case of water from the Central Highlands, the water provisioning services are used by Melbourne Water, but the revenue received for the supply of water is price constrained. The benefits of the price constraint are passed to the consumers of the water supplied by Melbourne Water. This is firstly the water retailers and then the users of the water from these retailers. The production function approach would require detailed information on the water retailers and the subsequent water consumers in Melbourne. This is not just the price of the water received but the value of all other inputs to the productive activities of the businesses.

Therefore, the replacement cost method was used to value the water provisioning services, broadly following the method recommended by Edens and Graveland (2014). The replacement cost method assumes two things: (1) that the service if lost would be replaced by consumers, and (2) that the consumption pattern would be unaffected by any increase in cost. Three options were investigated for the replacement cost of water: (1) transfer of water from other regions; (2) use of desalination; and (3) use of recycled water.

(1) Transfer of water from other regions

Water can be traded between regions in Victoria, with the price of water allocations varying over time and between locations. Between 2010-11 and 2013-14, the price ranged from $30 to $100 per ML (DELWP 2015). The purchase of water from other regions (for example, from northern Victoria) and its transport to supply Melbourne is possible, although subject to regulatory approval. Melbourne Water could transport water to its distribution network (and hence customers) via an existing pipeline, the 70 km long Yea-Sugarloaf pipeline, which can transport up to 75 GL yr^{-1}. It was completed in 2010 at a cost of $750 million (Melbourne Water 2010). Assuming a 75 year asset life for the pipeline and a linear depreciation (that is, $10 million per annum), the capital cost is $133 ML^{-1}.

However, operation of the pipeline is energy intensive and this adds significantly to the costs of energy for water supply. Energy cost is typically the biggest cost in water systems (World Bank 2012). Energy use by Melbourne Water increased by 222,000 GJ between 2008-09 and 2009-10 due to the operation of the Yea-Sugarloaf pipeline, as well as the energy requirements of another pumping station and a wastewater treatment plant (Melbourne Water 2010, p. 26). Assuming the pipeline used one-third of the additional energy, this is 74,000 GJ to transport 16.7 GL (Melbourne Water 2010 p. 26). In 2009-10, Melbourne Water's total energy use was 1,638,000 GJ and energy expenditure was $20.2 million (Melbourne Water 2010 p. 27). This represents an energy cost of $55 per ML transported. The total cost of replacing water would be around $218 per ML in 2009-10 based on the sum of: $30 per ML for purchase of water allocation (using the lowest value), $133 per ML for the estimated capital cost of the pipeline, and $55 per ML for the energy cost.

(2) Use of desalination

The cost of desalination was determined from the information available on the Wonthaggi Desalination Plant that was built to supply water to Melbourne in case of the failure of other water sources. The price was $1370 per ML in 2009 (Department of Treasury and Finance 2009), which was based on the assumption of the plant operating at full capacity for 27.75 years.

The Wonthaggi Desalinisation Plant has the capacity to supply 150 GL yr^{-1} when required. Construction of the plant cost $3.5 billion and was built between 2009 and 2012. The net present cost of financing, building and operating the plant over 30 years is $5.7 billion (assuming water orders of 150 GL yr^{-1}). The plant was opened in December 2012 and placed in stand-by mode, with the first release of water for public use not until March 2017 when the Victorian government introduced a guaranteed minimum annual water order from the plant. It is unclear if the cost of the plant also includes the cost of pipes and pumping to transport the water produced via desalination to the existing distribution network.

(3) Use of recycled water

The recycling and treatment of wastewater from the sewerage and stormwater systems and its supply to water users already occurs. The volume of treated wastewater available for recycling supplied by Melbourne Water in 2014-15 was 295 GL yr^{-1}, and this has been increasing steadily from 43.8 GL in 2005-06 (volume excludes environmental flows) (Melbourne Water 2009). The water supplied cannot be used for drinking and as such is not yet an equivalent product to most of the water supplied by Melbourne Water to households and businesses.

Treated wastewater could, however, be used for some purposes, such as irrigation of sports fields and industrial processing. Unfortunately, the costs associated with production of recycled water are not easy to determine from accounts of Melbourne Water owing to the value of capital assets for water supply and sewerage being presented together. Also this water cannot be transported via the existing water supply network, because its quality differs. The price for recycled water charged by Melbourne Water provides a guide: in 2006-07 revenue from recycled water was $2 million for the supply of 61 GL (Melbourne Water 2009 pp30-31) or $33 per ML. Given that recycled water is not an equivalent product and cannot be used as a replacement for all water currently supplied by Melbourne Water, this value was not used to estimate the replacement cost for the water provisioning service generated by the Central Highlands. This value might be useful for the estimate of the value of the ecosystem service of water filtration.

Comparison of values

The prices for water transfer and desalination were applied to all other years, adjusted for inflation using the Australian Consumer Price Index Inflation Calculator (ABS 2016b). For these calculations, the average annual price was used. No attempt was made to adjust the estimate for changes in technology. The implicit assumption is that the costs of water transfers and desalination and water recycling have remained constant over the time period, which is unlikely to be true, but our calculations are likely to be indicative of trend.

Water filtration services are also an input to production of water by Melbourne Water. Fires are known to impact water quality, requiring additional treatment costs and remediation activities in the region (for example, p8 of Melbourne Water 2010) and elsewhere (for example, in the ACT, see ACTEW 2003). However, these services were not estimated separately owing to lack of data for the study area.

The energy produced by the small-scale hydroelectricity plants is not considered further. The value of ecosystem services that contribute to the electricity produced would be embedded in the value of the water used and the overall profit of Melbourne Water.

4.4.2 Results

Summary information on the operations of Melbourne Water is shown as a set of accounts in Table 4.6. These include standard business accounting measures plus the use of ecosystems services by value and volume. The revenue, costs and profit (loss) reported and industry value added calculated are for all Melbourne Water activities, which include water supply and sewerage operations. As a first approximation of separating water and sewerage operations, it was assumed that industry value added of water supply was proportional to the revenue of water supply compared to total revenue. The volume of water supplied has decreased between 2000 and 2015, while the revenue received has increased by 500% since 2008 (Figure 4.5). There was a step increase in revenue from 2013 to 2014 that was associated with a water price rise to cover the cost of the new Wonthaggi Desalination Plant.

The total revenue received by Melbourne Water from water supply activities was $876 million in 2014-15. **The value of the ecosystem service of water provisioning was $75 million. The industry value added (or contribution to GDP) of water supply by Melbourne Water was estimated to be $318 million in 2015** (or $2759 ha^{-1} based on the catchment area within the study area of 115,149 ha).

Data on the physical volume and value of ecosystem services used by Melbourne Water are shown in Table 4.7. The results based on replacement cost via two sources are presented in this table; namely, water transfer and desalination. The least cost method is water transfer and hence this is the one presented in the summary Table 4.6. It is not known if the amount of water could be supplied by transfer from other regions, but current infrastructure can transport 75 GL per annum. The replacement cost is likely to fall within the range of estimates from these two sources. It is noted that the replacement value of the water provisioning service is consistently lower than the value of water revenue. From 2009 the revenue increased sharply due to significant increase in water prices (Melbourne Water 2000-2015) (Figure 4.6).

Figure 4.7 shows the volume of the water provisioning services generated from the study area that flow as runoff into the reservoirs operated by Melbourne Water, compared with the volume of water supplied to customers from these reservoirs. Note that in some years, the water provisioning service exceeds the amount of water supplied (for example, 2010 to 2012), and this is reflected in the water asset account as increases in storage (Appendix 4). The very function of reservoirs is to hold water for when it is needed. When water is in short supply, such as during a drought, a key response is to impose water restrictions (such as, no watering of gardens).

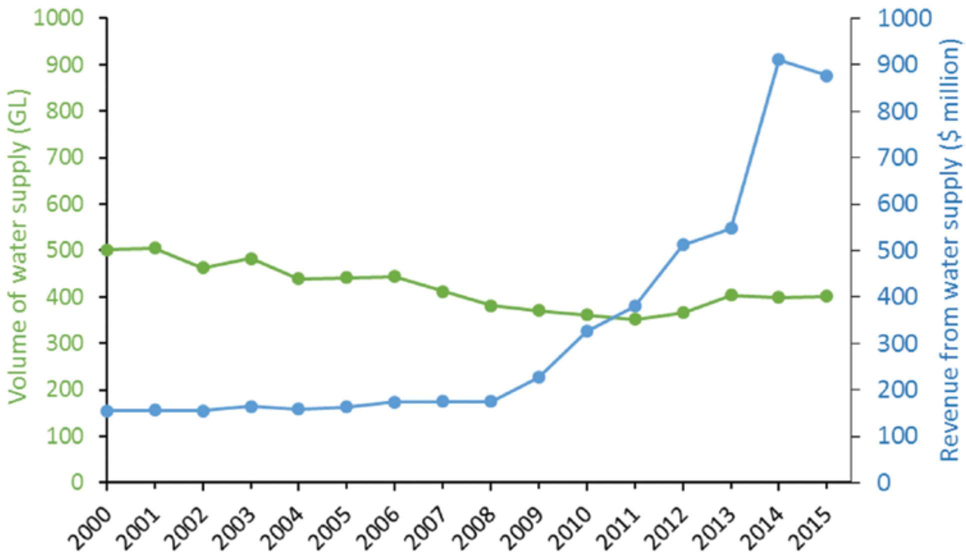


Figure 4.5. Volume and value of water supplied to Melbourne Water.

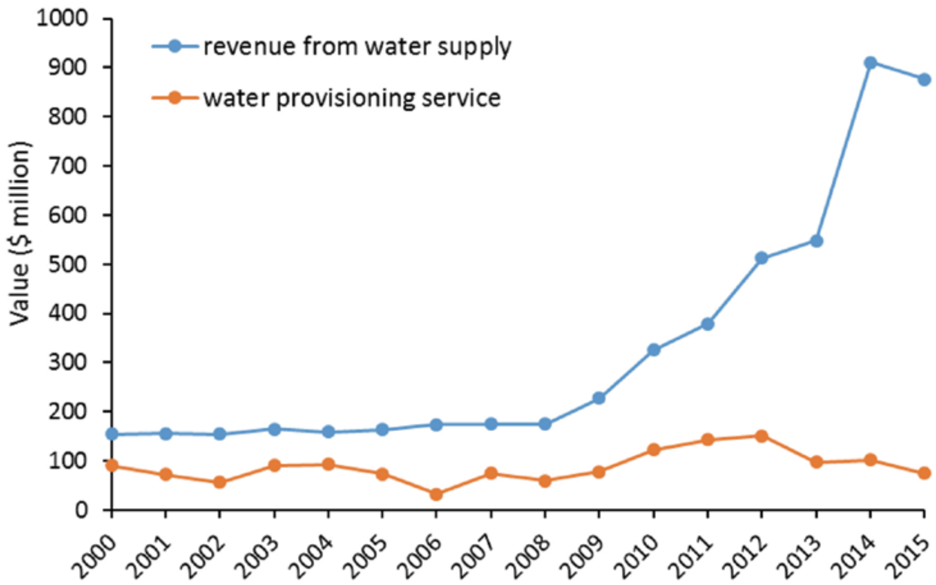


Figure 4.6. Value of water provisioning service and revenue from water supply

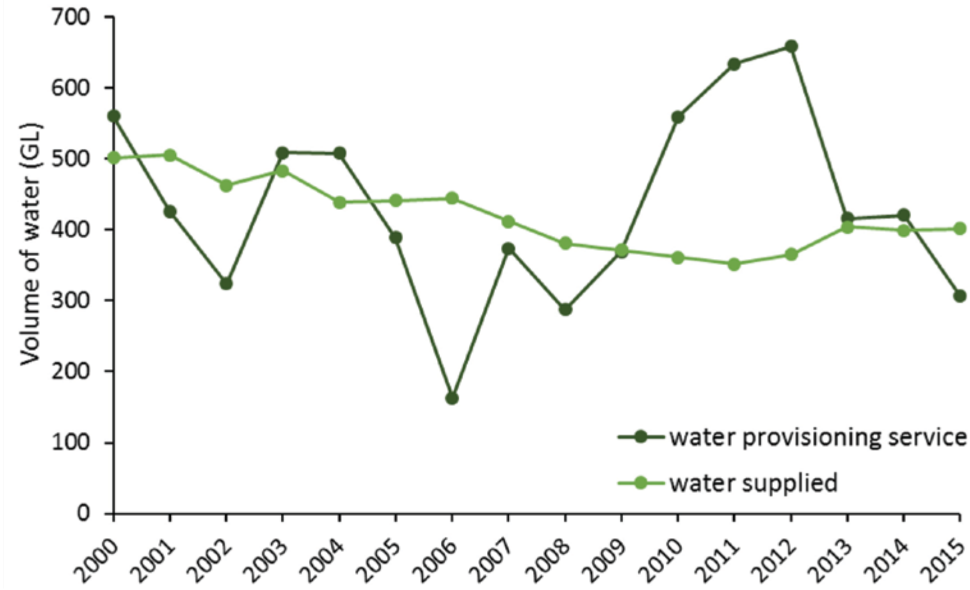


Figure 4.7. Volume of the water provisioning service and the water supplied

Table 4.6 Financial accounts for all Melbourne Water activities, and for volume and value of water supply and water provisioning service

	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16
Revenue ($m)																	
Revenue from water supply	154.9	155.8	154.4	164.5	158.8	163.7	173.8	175.4	175.5	227.3	325.5	379.7	512.3	547.6	911.2	876.2	964.2
Other revenue	322.9	305.0	325.8	346.2	345.0	364.3	418.8	412.9	424.8	504.9	532.9	617.6	727.9	710.6	805.5	873.5	889.1
Total revenue	**477.8**	**460.8**	**480.2**	**510.7**	**503.8**	**528**	**592.6**	**588.3**	**600.3**	**732.2**	**858.4**	**997.3**	**1,240.2**	**1,258.2**	**1,716.7**	**1,749.7**	**1,853.3**
Expenses ($m)																	
Operating & other expenses	(98.2)	(108.0)	(119.8)	(111.4)	(138.1)	(148.8)	(167.2)	(196.4)	(257.6)	(265.2)	(254.1)	(253.0)	(272.2)	(367.7)	(404.9)	(408.2)	(366.3)
Wages, employee benefits	(34.4)	(33.8)	(33.7)	(37.4)	(39.6)	(41.5)	(46.7)	(50.5)	(60.9)	(65.4)	(72.5)	(75.0)	(103.5)	(86.9)	(100.7)	(106.4)	(115.6)
Depreciation & amortisation	(63.2)	(62.9)	(64.8)	(69.3)	(70.3)	(71.2)	(69.8)	(77.4)	(87.5)	(105.8)	(122.0)	(231.9)	(242.6)	(315.9)	(351.6)	(367.5)	(373.8)
Financial expenses	(77.8)	(79.8)	(76.1)	(74.2)	(76.3)	(77.9)	(81.2)	(86.6)	(100.8)	(122.0)	(171.3)	(223.3)	(249.2)	(549.3)	(727.6)	(707.2)	(676.7)
Total expenses	**(273.6)**	**(284.5)**	**(294.4)**	**(292.3)**	**(324.3)**	**(339.4)**	**(364.9)**	**(410.9)**	**(506.8)**	**(558.4)**	**(619.9)**	**(783.2)**	**(867.5)**	**(1,319.8)**	**(1,584.8)**	**(1,589.3)**	**(1,532.4)**
Net result ($m)																	
Net result before tax	**204.2**	**176.3**	**185.8**	**218.4**	**179.5**	**188.6**	**227.7**	**177.4**	**93.5**	**173.8**	**238.5**	**214.1**	**372.7**	**(61.6)**	**131.9**	**160.4**	**339.2**
Tax (expense)/benefit	(7.3)	(47.2)	(55.6)	(68.5)	(56.1)	(62.9)	(59.0)	(43.9)	(25.9)	(45.8)	(52.1)	(56.2)	(102.8)	21.8	(42.0)	(44.2)	(185.9)
Net result after tax	**196.9**	**129.0**	**130.3**	**150.0**	**123.4**	**125.7**	**168.7**	**133.5**	**67.6**	**128.0**	**186.4**	**157.9**	**269.9**	**(39.8)**	**89.9**	**116.2**	**153.4**
Estimated IVA ($m)																	
For Melbourne Water*	301.8	273.0	284.3	325.1	289.4	301.3	344.2	305.3	241.9	345.0	433.0	521.0	718.8	341.2	584.2	634.3	828.6
For water supply**	**97.9**	**92.3**	**91.4**	**104.7**	**91.2**	**93.4**	**100.9**	**91.0**	**70.7**	**107.1**	**164.2**	**198.4**	**296.9**	**148.5**	**310.1**	**317.6**	**431.1**
Assets ($m)																	
Total assets	2,852.1	2,953.6	2,994.8	3,051.4	3,131.8	3,263.2	3,768.7	3,968.9	4,435.5	5,421.1	8,948.3	9,754.5	10,034.1	14,498.2	14,339.2	14,439.5	14,820.9
Total liabilities	1,685.1	1,656.8	1,666.7	1,670.0	1,722.6	1,769.7	1,928.6	2,082.8	2,448.6	3,419.3	4,929.9	5,379.7	5,495.1	10,117.4	9,856.3	9,714.6	9,675.2
Net assets	**1,167.0**	**1,296.8**	**1,328.1**	**1,381.4**	**1,409.2**	**1,493.5**	**1,804.1**	**1,886.1**	**1,986.9**	**2,001.8**	**4,018.4**	**4,374.8**	**4,539.0**	**4,380.6**	**4,482.9**	**4,724.9**	**5,145.7**
Number of employees (FTE)	481	488	498	512	501	537	614	645	729	807	828	841	834#	832	812	841	885
Water supply																	
Volume supplied (ML)	501,720	505,140	462,322	483,000	438,796	440,982	444,365	411,747	381,097	371,170	361,363	351,761	365,559	404,260	399,489	401,849	432,000
Revenue from supply ($m)	155	155.8	154.4	164.5	158.8	163.7	173.8	175.4	175.5	227.3	325.5	379.7	512.3	547.6	911.2	876.2	964.2
Water provisioning service																	
Volume used (ML)	560,063	426,363	324,202	508,840	507,961	389,269	163,240	374,236	287,465	368,941	559,363	633,776	658,286	415,665	420,935	306,258	
Value used ($m)	90.7	72.1	56.4	91.1	93.0	73.2	31.8	74.5	59.8	78.2	121.9	142.6	150.7	97.7	101.4	74.7	
Water in storage																	
Volume (ML)	980,307	968,937	854,388	968,892	1,027,661	877,597	641,161	603,321	563,608	716,752	1,045,479	1,299,733	1,371,971	1,388,928	1,300,186	1,237,716	1,076,432

*Estimated IVA for Melbourne Water = wages, employee benefits + depreciation and amortisation + net result before tax.

**Estimated IVA for water supply = Estimated IVA for Melbourne Water x percentage of revenue from water supply

Annual Report unclear whether FTE or total number

Table 4.7 Estimates of the value of the water provisioning services at replacement cost

	Water provisioning service	Water provisioning service, Replacement price		Water provisioning service, Replacement total value (Price x volume)	
	Physical volume	Water transfer	Desalination	Water transfer	Desalination
	ML	$ ML^{-1}	$ ML^{-1}	$ Million	$ Million
Year					
1990	697,519	130	841	91	587
1991	628,053	134	868	84	545
1992	759,890	136	877	103	666
1993	711,745	138	893	98	636
1994	526,585	141	910	74	479
1995	666,737	147	953	98	635
1996	826,375	151	977	125	807
1997	231,941	152	980	35	227
1998	432,954	153	988	66	428
1999	316,984	155	1,003	49	318
2000	560,063	162	1,047	91	586
2001	426,363	169	1,093	72	466
2002	324,202	174	1,127	56	365
2003	508,840	179	1,158	91	589
2004	507,961	183	1,184	93	601
2005	389,269	188	1,216	73	473
2006	163,240	195	1,260	32	206
2007	374,236	199	1,289	74	482
2008	287,465	208	1,345	60	387
2009	368,941	212	1,370	78	505
2010	559,363	218	1,409	122	788
2011	633,776	225	1,456	143	923
2012	658,286	229	1,482	151	976
2013	415,665	235	1,518	98	631
2014	420,935	241	1,556	101	655
2015	306,258	244	1,580	75	484

4.5 Trade-offs in water provisioning

Timber harvesting of ash forest on an approximately 80-year cycle means that most of the age classes of the regrowth forest across the landscape have high water demand (Vertessy et al. 1996, 1998, 2001), reducing the level of water provisioning services. The logging that occurs in the catchments supplies about a quarter of the log volumes from the study area. Therefore, we conducted an analysis of trade-offs of water and timber.

In this study, reduction in water yield after disturbance was calculated at a grid cell scale, and then aggregated to the catchment scale. The reduction in water yield due to logging in ash forests estimated in the study area is similar, although less than, the 11% reduction over a rotation predicted for the catchments of the Goulburn River (ACF 2009). The results from the study area also were similar to those from a physically-based hydrological model, which showed a maximum decline of 55% from a landscape unit and a decline of 20% from the whole catchment after mortality of 34% of the ash forest area, and a decline of 42% from the whole catchment after complete mortality. Return times were more than 200 years (Lane et al. 2010, Feikema et al. 2013). Modelling of the Maroondah catchment following stand-replacing wildfire resulted in a reduction in water yield of 1 to 6 ML ha^{-1} yr^{-1} (100 to 600 mm yr^{-1}) 20 years post-fire across the catchment (Vertessy et al. 1998). Additionally, modelling of paired catchments showed the impact of logging was a reduction in water yield of 1.8 ML ha^{-1} yr^{-1} (180 mm yr^{-1}) averaged over 12 to 23 years post-disturbance (Vertessy et al. 1998). A similar relative decrease in water yield per unit area was used in the modelling of value of water supply by Creedy and Wurzbacher (2001). The modelled response in water yield of phasing out harvesting by 2020 in the Thompson catchment resulted in an additional 20 GL yr^{-1} by 2050 (Water Resources Strategy Committee 2002, cited in MBAC 2006). A modelling study of the impact of forest management regimes in the combined catchments showed a maximum increase in water yield of 16 ML yr^{-1} by 2050 by ceasing logging. This is an equivalent increase in volume to that provided by the construction of the Tarago Treatment Plant to augment Melbourne's water supply system at a cost of $100 million (Mein 2008).

Our estimates of the reduction in water yield after logging are possibly underestimated at the landscape scale where mixed species have been logged. Regeneration of mixed species forest types does not have as rapid growth in leaf area as ash forest types, but studies have detected a similar, though lesser, response to logging (Cornish and Vertessey 2001, Lane and Mackay 2001, Roberts et al. 2001).

In the water accounts, we have quantified only the supply of water volume and have not included the value of water quality at this stage. Both quantity and quality are critical for the supply of water resources and further work is required to include water quality. Knowledge of the impacts of disturbance events, such as logging and fire, and information in the literature, demonstrate the potential importance of these factors on water quality depending on the nature of the event, condition of the forest and other environmental conditions. In general, clearfell harvesting, slash burning and unsealed roads are major sources of sediment contributing to water quality decline in catchments (Hairsine 1997). Major impact of the 2009 fire on water quality was averted because no heavy rainfall occurred for some months after the fire, allowing some regeneration and installation of sediment control measures and rehabilitation of firebreaks and road drainage by Melbourne Water. Additionally, lower severity fire along many creek lines in the catchments meant that canopy cover and riparian zones were maintained. These factors meant that sediment and nutrient loads reaching the storage reservoirs were minimised (Frame et al. 2009). Initial assessment of runoff rates post 2009 fire showed no increase in surface water runoff in the fire-affected catchments (Frame et al. 2009).

5. Carbon

5.1 Introduction

The Central Highlands region supports wet temperate, evergreen forests that are some of the most biomass carbon-dense in the world (Keith et al. 2009). One of the main species, Mountain Ash (*Eucalyptus regnans*) is the tallest flowering plant in the world (Ashton 1976). The conditions that produce these high carbon stocks include; relatively cool temperatures and moderately high precipitation resulting in high rates of growth but slow decomposition; and older ages of trees in some areas that have experienced minimal human disturbance resulting in multi-aged and multi-layered forest structures.

Maintaining terrestrial carbon stocks, such as those in the Central Highlands forests, by reducing carbon losses from degradation and deforestation, is a critical component of climate change mitigation (UNFCCC 2015). Understanding the carbon dynamics of ecosystems is important to maximise their mitigation potential. Key factors include how carbon stocks vary in relation to environmental conditions and human land use activities. Quantifying carbon stocks and stock changes across the landscape in the form of accounts provide tools for evaluating their mitigation value.

5.2 Carbon stocks and carbon stock change

5.2.1 Data sources and methods

5.2.1.1 Carbon stock map

Carbon stocks, or biocarbon, were estimated for the following components: above- and below-ground biomass, and living and dead biomass, but not soil carbon. Insufficient data exist to estimate soil carbon stocks spatially in relation to land cover types, and temporally in relation to change in carbon stocks over time and in response to disturbance events.

A model to predict biomass carbon stock spatially across the landscape was derived for montane ash forests in eastern Victoria, using spatial biophysical data and calibrated with site data (n = 930 sites) of biomass carbon stocks calculated from tree measurements (Keith et al. 2010). Carbon stocks were derived in relation to the environmental conditions at the site, forest type, age of the forest since last stand-replacing disturbance event, and previous disturbance history of logging and fire. Modelled carbon stocks were restricted to within the range of the calibration site data. For the carbon accounts in the current study within a defined regional boundary, the spatial carbon data needed to include all land cover types within the study area and the change in carbon stock over time. Hence, the carbon map was updated both spatially and temporally.

Biomass carbon stocks were estimated for all land cover types. For forest types where sufficient data were available to derive growth curves and compare biomass with ash species, biomass was estimated as a proportion of the modelled ash biomass. This approach allowed spatial variability in relation to environmental conditions to be retained in the spatial estimation. For other land cover types, carbon stocks were estimated using an average biomass density (Table A5.1), and this was kept constant as there were insufficient data available to determine change in carbon stock over time. It was considered that large changes in biomass would not occur for most non-forest land cover types. The exception is planted and harvested vegetation, such as plantations, horticulture and crops, but there were insufficient data about the timing of these changes to be included in the spatial calculation of change in carbon stock over time. Thus, a base carbon stock map was developed for the land cover condition pre-2009 fire based on the matrix of land cover types, forest age, and last disturbance event type.

Change in carbon stock over time was calculated from the base carbon map using forward projections from 2009 to 2015, and backwards projections from 2009 to 1990. Change was defined as due to disturbance events of logging or fire. A constant classification of land cover, using the most recent data from 2014, formed a stable base of vegetation classes. There has been little change in the extent of land cover classes in this region over the 25-year time period from 1990 to 2015, except an increase in the area of plantations. In general, the differences between spatial data for land cover classes reported at different times is confounded by changes in methods for determining class boundaries and assigning classes (see section 3.5), and thus was considered unreliable for estimating changes in carbon stocks. Changes in carbon stocks calculated with these projections included; growth of trees, emissions due to fire, collapse of dead standing trees, decomposition of dead biomass, and losses due to logging.

5.2.1.2 Accumulation in carbon stock due to growth

Carbon accumulation functions based on forest growth were derived from available data in the literature, and represented the mean carbon stock at a given age for each forest type (equations in Appendix A5.2.1.2). The base carbon map represented the current carbon stock, which was calculated for each grid cell based on spatial variation in environmental conditions and disturbance history. To combine these two sources of information, we assumed that the shape of the carbon accumulation curve for a forest type remained the same under all environmental conditions within the study area, and so the difference in carbon stock between the mean from the curve and each grid cell was the same over time. This was represented as parallel growth curves for each grid cell, around the mean curve for the forest type. The carbon stock for each grid cell was calculated for each year based on the modelled carbon stock density related to environmental conditions, age of the forest, the growth curve for the forest type, and disturbance events.

5.2.1.3 Change in carbon stock due to logging

Changes in carbon stock after logging were estimated separately for three types of silvicultural systems that reduce biomass by different amounts; (i) clearfell, clearfell salvage, group selection, seed tree and roading; (ii) single tree selection and thinning from above; and (iii) thinning from below. Areas logged by each silvicultural type and forest type were identified from the spatial data of logging history. Most logging in the study area during historical records since 1932, is by the first silvicultural type with the majority of trees harvested (86%). Only 14% of the area is logged by selective harvesting, mainly in mixed species forest types.

Change in carbon stock after clearfelling, or logging the majority of trees within an area, and then slash burning, was based on the results in Keith et al. (2015). Carbon stocks were reduced due to wood product removal and burning of slash, and the stock remaining on-site was calculated (Appendix A5.2.1.3). Change in carbon stock after selective logging was based on estimates of the proportion of biomass removed from the various selective silvicultural systems (Appendix A5.2.1.3). After logging, carbon stocks consisted of dead biomass from the remaining slash that decomposed over time; living biomass in the regenerating forest after harvesting the majority of trees where carbon accumulation followed the growth curve for the forest type (Appendix A5.2.1.2); or living biomass remaining after selective harvesting that continued growth.

5.2.1.4 Change in carbon stock due to fire

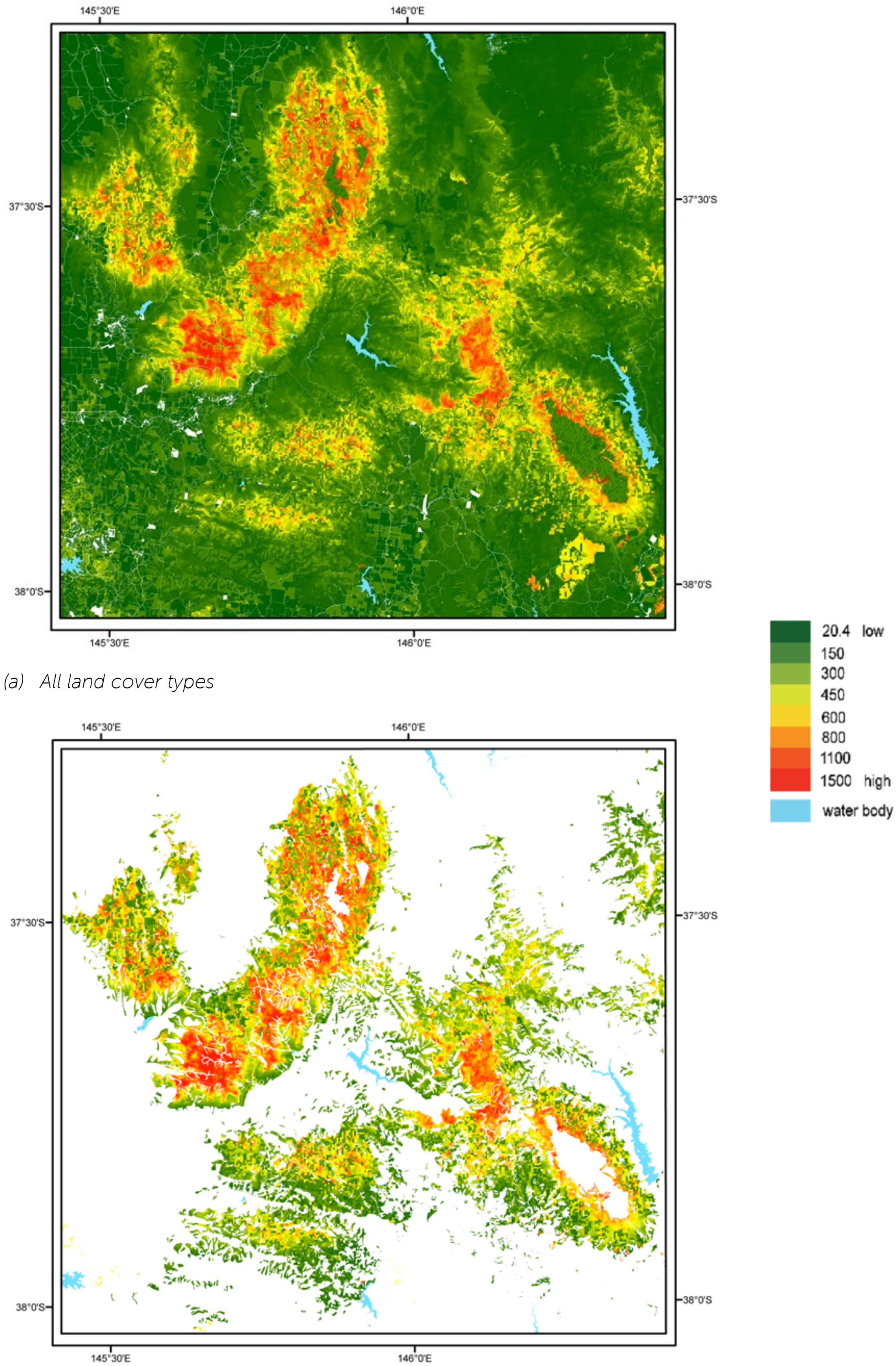
Changes in carbon stock after fire were based on the results in Keith et al. (2014b). Areas burnt were identified from the spatial data of fire history. All forest types that were burnt resulted in loss of carbon due to combustion emissions. Mixed species forest types were assumed to survive fire and continue growing. Mountain Ash, Alpine Ash and rainforest forest types were assumed to be killed by fire if it was high severity or the severity was not known. If the fire was low severity, these forest types were assumed to survive fire and continue growing.

Carbon stock loss due to emissions was calculated as a percent of the initial stock, and depended on fire severity and forest age (Keith et al. 2014b) (Appendix 5.2.1.4). Carbon stock post-2009 fire was calculated by reducing the stock in the areas burnt by the proportion of biomass combusted in low and high severity fire for each forest age category.

After the fire in forest types that were not killed, the trees continued growing according to the forest type carbon accumulation function (Appendix 5.2.1.4). In forest types that were killed, carbon stocks consisted of dead standing trees, dead biomass on the ground and regeneration of living biomass. Changes over time in these components were based on the results in Keith et al. (2014b) (equations in Appendix 5.2.1.4).

5.2.2 Results

The spatial distribution of carbon stock density across the landscape in the study area is shown in Figure 5.1. **The total carbon stock within the study region in 2015 was estimated to be 146 MtC, with a net annual increment of 1.64 MtC yr^{-1}.** The total carbon stock in each land cover class (Table 5.1) reflects the area (Table 3.1) and carbon stock density (Table A5.1) of each class.



(a) All land cover types

(b) Montane ash forest

Figure 5.1 Spatial distribution of carbon stock density (tC ha^{-1}) in the Central Highlands study area in 2015

Table 5.1. Total carbon stock in each land cover class within the study area

Land Cover	Total carbon stock (MtC)					
	1990	1995	2000	2005	2010	2015
Alpine ash	35.7	36.6	37.5	38.4	38.4	39.4
Bare	0.0	0.0	0.0	0.0	0.0	0.0
Built-up area	0.3	0.3	0.3	0.3	0.2	0.3
Crop	0.0	0.0	0.0	0.0	0.0	0.0
Crop/pasture	0.0	0.0	0.0	0.0	0.0	0.0
Eucalypt plantation	3.8	3.8	3.8	3.8	3.7	4.3
Horticulture	0.0	0.0	0.0	0.0	0.0	0.0
Montane woodland	2.0	2.0	2.0	2.1	2.1	2.1
Mountain ash	47.6	49.3	50.8	52.1	53.1	56.6
Open mixed forest	6.8	7.5	8.3	9.2	9.7	10.6
Open water	0.0	0.0	0.0	0.0	0.0	0.0
Pasture/grassland	0.2	0.2	0.2	0.2	0.2	0.2
Pine plantation	0.6	0.6	0.6	0.6	0.5	0.6
Rainforest	1.7	1.7	1.8	1.8	1.8	1.8
Riparian shrubs	0.2	0.2	0.2	0.2	0.2	0.2
Shrub/heath	0.1	0.1	0.1	0.1	0.1	0.1
Swamp	0.0	0.0	0.0	0.0	0.0	0.0
Wet mixed forest	19.0	21.0	23.1	25.3	26.8	29.0
Woodland	0.9	0.9	1.0	1.0	1.0	1.0
Total	**119.0**	**124.5**	**129.8**	**135.1**	**137.9**	**146.1**

5.3 Ecosystem services from carbon sequestration

5.3.1 Change in carbon stocks

Positive net change in carbon stock represents the ecosystem service of carbon sequestration because carbon dioxide is removed from the atmosphere and stored in a terrestrial ecosystem. The net carbon stock change is the balance between additions due to growth and reductions due to combustion, decomposition and removal of stocks from the area. The physical volume of this service is shown in Table 5.2a. Negative net change in carbon stock, or emission, represents a contribution of the land use activity to the national greenhouse gas emissions.

Gross additions to carbon stocks by plant growth are shown in Table 5.2b. This metric is sometimes used to represent the ecosystem service of carbon sequestration. In the current study, however, we have used net carbon stock change to represent the ecosystem service, because this is the metric used in the carbon accounting system for the Emissions Reduction Fund (Clean Energy Regulator 2015), which is equated to dollar values.

Table 5.2a. Physical volume of net annual change in carbon stock in the Central Highlands

Land Cover	Net annual change in carbon stock (MtC yr^{-1})				
	1991-95	**1996-00**	**2001-05**	**2006-10**	**2011-15**
Alpine ash	0.196	0.167	0.176	0.000	0.216
Bare	0.000	0.000	0.000	0.000	0.000
Built-up area	0.000	0.000	0.000	-0.001	0.001
Crop	0.000	0.000	0.000	0.000	0.000
Crop/pasture	0.000	0.000	0.000	0.000	0.000
Eucalypt plantation	0.000	0.000	0.000	-0.033	0.115
Horticulture	0.000	0.000	0.000	0.000	0.000
Montane woodland	0.003	0.003	0.003	-0.001	0.000
Mountain ash	0.330	0.304	0.261	0.198	0.694
Open mixed forest	0.154	0.158	0.171	0.110	0.170
Open water	0.000	0.000	0.000	0.000	0.000
Pasture/grassland	0.000	0.000	0.000	0.000	0.000
Pine plantation	0.000	0.000	0.000	-0.019	0.008
Rainforest	0.006	0.006	0.006	-0.001	0.003
Riparian shrubs	0.000	0.000	0.000	0.000	0.000
Shrub/heath	0.000	0.000	0.000	0.000	0.000
Swamp	0.000	0.000	0.000	0.000	0.000
Wet mixed forest	0.394	0.430	0.436	0.308	0.433
Woodland	0.001	0.001	0.001	-0.002	0.000
Total	**1.084**	**1.070**	**1.054**	**0.557**	**1.641**

Table 5.2b. Physical volume of gross annual additions to carbon stocks from growth

Land Cover	Annual additions to carbon stocks (MtC yr^{-1})				
	1991-95	1996-00	2001-05	2006-10	2011-15
Alpine ash	0.324	0.322	0.320	0.368	0.426
Bare	0.000	0.000	0.000	0.000	0.000
Built-up area	0.000	0.000	0.000	0.000	0.001
Crop	0.000	0.000	0.000	0.000	0.000
Crop/pasture	0.000	0.000	0.000	0.000	0.000
Eucalypt plantation	0.000	0.000	0.000	0.000	0.033
Horticulture	0.000	0.000	0.000	0.000	0.000
Montane woodland	0.003	0.003	0.003	0.002	0.000
Mountain ash	0.664	0.703	0.749	0.758	0.874
Open mixed forest	0.167	0.187	0.202	0.180	0.177
Open water	0.000	0.000	0.000	0.000	0.000
Pasture/grassland	0.000	0.000	0.000	0.000	0.000
Pine plantation	0.000	0.000	0.000	0.000	0.019
Rainforest	0.006	0.006	0.006	0.006	0.003
Riparian shrubs	0.000	0.000	0.000	0.000	0.001
Shrub/heath	0.000	0.000	0.000	0.000	0.002
Swamp	0.000	0.000	0.000	0.000	0.000
Wet mixed forest	0.427	0.474	0.497	0.465	0.461
Woodland	0.001	0.001	0.001	0.001	0.000
Total	**1.592**	**1.696**	**1.779**	**1.781**	**1.999**

5.3.2 Effects of land use

The effect of land use was considered as two components: (1) the change in carbon stock density and total carbon stocks in areas of different land use, and (2) carbon sequestration as a net change in carbon stock per year. The carbon stocks and net change over 5 year periods shown in Table 5.3 represent stocks accounted within the study area, as a total and disaggregated by areas logged and by areas burnt.

The difference in carbon stock density (tC ha^{-1}) due to the effect of land use was assessed by comparing stocks in the same forest type, that of montane ash forest (Mountain Ash and Alpine Ash), but under different land use activities. The difference in carbon stock density of montane ash forest between areas unlogged and logged in 2015 was an average of 143.2 tC ha^{-1}. This is the carbon stock loss due to logging, but alternatively, represents the carbon sequestration potential if logged forests were allowed to continue regrowing without repeated logging.

The difference in net change in carbon stock density between the area logged and the area unlogged but available for logging indicates the **carbon sequestration potential, which was 2.98 tC ha^{-1} yr^{-1} averaged over 1990 – 2015** (1. in Table 5.4). The area unlogged included areas that may have been logged before 1932, areas burnt and regenerated, and areas both available and unavailable for logging (2. in Table 5.4).

All forest areas sequestered carbon in each time period, except the area that had been logged, and the area that had been burnt in 2009. The area that had been logged consisted of all recorded cutover areas in the spatial data, which began in 1932 (2a. in Table 5.3). **Gross reduction in carbon stock due to logging was 14.2 MtC over the period from 1990 to 2015. Logging resulted in loss of carbon due to combustion and decomposition of waste material, and product removal. The net reduction in carbon stock (gain from growth minus loss from harvesting) was 0.83 MtC, or an average rate of 0.033 MtC yr^{-1}.**

The area unlogged but available area for logging (2b. in Table 5.3) had net sequestration of 10.7 MtC over the 25 years, with an average rate of 0.43 MtC yr^{-1}. This is public land zoned to permit timber production; it is not reserved, and has not been harvested since 1932 (but may have been harvested earlier before commencement of spatial records). This area would not necessarily all be harvested under future production plans. Net sequestration in all areas that have not been logged (since 1932) (available and unavailable for logging) was 28.3 MtC over 25 years (2b. and 2c. in Table 5.3).

Carbon stock loss from all fires within the study area over the 25 years was -3.4 MtC, and loss from the 2009 fire was -2.4 MtC. Carbon stock loss during the 2009 fire was re-gained over the subsequent 5 years through sequestration by the regenerating vegetation.

Some of the reductions in stocks reported for the areas logged were due to harvested timber products that were transported outside the region. These stocks in the products would be included in a national carbon account. However, even at the regional scale, it has been demonstrated that including these products in total carbon stocks does not increase the total stock above that in an unlogged forest (Keith *et al.* 2015).

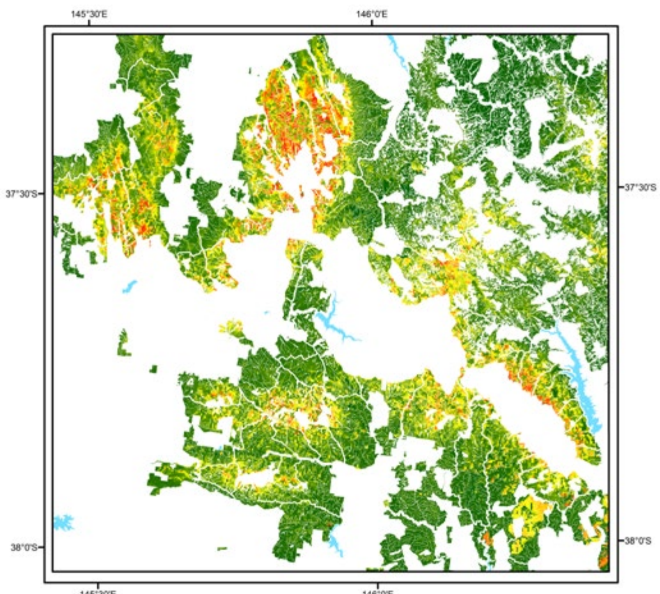
Table 5.3. Account of carbon stocks (MtC) and stock changes (MtC 5-yr^{-1}) for the study area over 5-year time periods, showing (1) total area, (2) total area disaggregated by logged area, and (3) total area disaggregated by burnt areas

	1991-95	1996-2000	2001-05	2006-10	2011-15
1. Total study area					
Opening stock (MtC)	119.05	124.47	129.82	135.09	137.85
Additions due to growth (MtC 5yrs^{-1})	7.96	8.48	8.89	8.91	10.00
Reductions due to fire (MtC 5yrs^{-1})	-0.07	-0.03	-0.05	-3.16	-0.06
Reductions due to harvesting (MtC 5yrs^{-1})	-2.47	-3.11	-3.58	-2.98	-2.07
Closing stock (MtC)	124.47	129.82	135.09	137.85	145.72
2.a) Area logged					
Opening stock (MtC)	32.37	32.02	31.27	30.42	29.67
Additions due to growth (MtC 5yrs^{-1})	2.13	2.36	2.75	2.97	3.16
Reductions due to fire (MtC 5yrs^{-1})	-0.01	0.00	-0.02	-0.74	-0.01
Reductions due to harvesting (MtC 5yrs^{-1})	-2.47	-3.11	-3.58	-2.98	-2.07
Closing stock (MtC)	32.02	31.27	30.42	29.67	30.75
2.b) Area available for logging					
Opening stock (MtC)	24.94	27.10	29.38	31.67	33.05
Additions due to growth (MtC 5yrs^{-1})	2.18	2.30	2.30	2.26	2.57
Reductions due to fire (MtC 5yrs^{-1})	-0.03	-0.02	-0.01	-0.88	-0.02
Reductions due to harvesting (MtC 5yrs^{-1})	0.00	0.00	0.00	0.00	0.00
Closing stock (MtC)	27.10	29.38	31.67	33.05	35.58
2.c) Area unavailable for logging					
Opening stock (MtC)	61.74	65.35	69.17	72.99	75.13
Additions due to growth (MtC 5yrs^{-1})	3.65	3.83	3.84	3.68	4.27
Reductions due to fire (MtC 5yrs^{-1})	-0.03	-0.01	-0.01	-1.54	-0.02
Reductions due to harvesting (MtC 5yrs^{-1})	0.00	0.00	0.00	0.00	0.00
Closing stock (MtC)	65.35	69.17	72.99	75.13	79.38
3.a) Area burnt 2009 and since					
Opening stock (MtC)	18.26	18.96	19.56	20.36	17.87
Additions due to growth (MtC 5yrs^{-1})	1.07	1.13	1.17	0.94	2.39
Reductions due to fire (MtC 5yrs^{-1})	0.00	0.00	0.00	-2.43	-0.06
Reductions due to harvesting (MtC 5yrs^{-1})	-0.37	-0.53	-0.37	-1.00	-0.37
Closing stock (MtC)	18.96	19.56	20.36	17.87	19.83
3.b) Area burnt 1940 - 2008					
Opening stock (MtC)	11.50	12.71	14.13	15.61	16.75
Additions due to growth (MtC 5yrs^{-1})	1.46	1.70	1.90	2.16	2.22
Reductions due to fire (MtC 5yrs^{-1})	-0.07	-0.03	-0.04	-0.73	0.00
Reductions due to harvesting (MtC 5yrs^{-1})	-0.18	-0.25	-0.38	-0.29	-0.14
Closing stock (MtC)	12.71	14.13	15.61	16.75	18.83
3.c) Area burnt in 1939					
Opening stock (MtC)	87.04	90.50	93.77	96.72	100.78
Additions due to growth (MtC 5yrs^{-1})	5.38	5.60	5.78	5.76	5.35
Reductions due to fire (MtC 5yrs^{-1})	0.00	0.00	0.00	0.00	0.00
Reductions due to harvesting (MtC 5yrs^{-1})	-1.92	-2.33	-2.83	-1.69	-1.55
Closing stock (MtC)	90.50	93.77	96.72	100.78	104.58
3.d) Area unburnt					
Opening stock (MtC)	2.24	2.30	2.35	2.40	2.45
Additions due to growth (MtC 5yrs^{-1})	0.06	0.05	0.05	0.04	0.04
Reductions due to fire (MtC 5yrs^{-1})	0.00	0.00	0.00	0.00	0.00
Reductions due to harvesting (MtC 5yrs^{-1})	0.00	0.00	0.00	0.00	0.00
Closing stock (MtC)	2.30	2.35	2.40	2.45	2.49

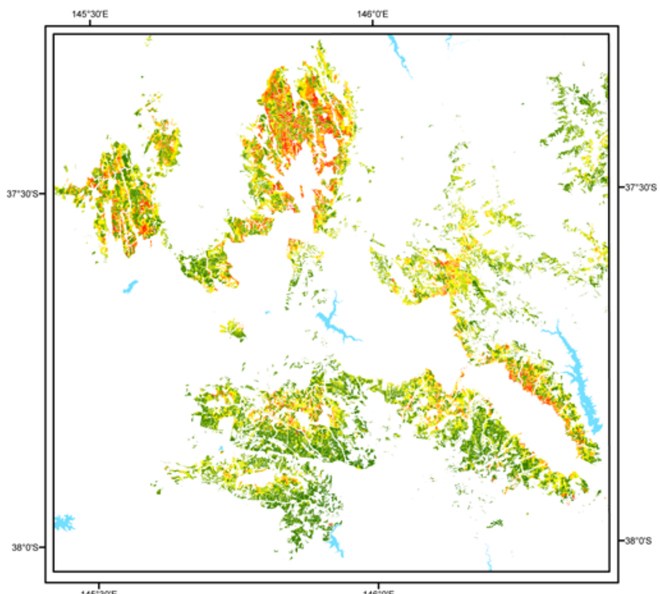
Table 5.4 Physical carbon sequestration by all forest types and areas available for logging averaged over 1990 to 2015, and carbon stock in montane ash forest in 2015.

	Area logged	Area unlogged	Difference
1. Carbon sequestration – all forest types			
Net change in carbon stock (MtC)	-1.62	10.65	
Area (ha)	115,421	176,186	
Net change in carbon stock density (tC $ha^{-1}yr^{-1}$)	-0.56	2.42	2.98
2. Carbon stock – montane ash forest type			
Carbon stock in 2015 (MtC)	22.58	73.43	
Area (ha)	61,341	143,718	
Carbon stock density (tC ha^{-1})	368.1	510.9	142.8

The spatial distribution of carbon stocks across the study region (Figure 5.1a) is shown for specific land use areas to differentiate the areas that are available for logging in all forest types (Figure 5.2a), and in montane ash forest that generally has high carbon stocks (Figure 5.2b), and the areas that have been logged (Figure 5.3). The effect of logging on changing the carbon stock is illustrated in Figure 5.4, which shows a zoomed in section of the study area so that the coloured grid cells can be observed. The number of red cells, designating high carbon stock density, decreased from 1990 to 2015, indicating that forest with high carbon stocks had been logged preferentially. The yellow area in the central lower part of the figure became a darker shade of yellow by 2015, indicating growth and accumulation of carbon stock. The small orange patches in 1990 had disappeared by 2015, suggesting that the high carbon stock areas had been logged.

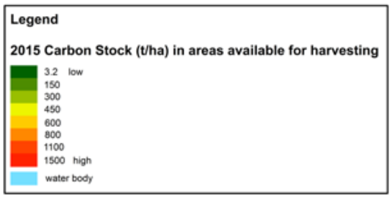


(a) All forest areas available for logging.



(b) Ash forest area available for logging.

Figure 5.2. Carbon stock (tC ha^{-1}) in 2015.



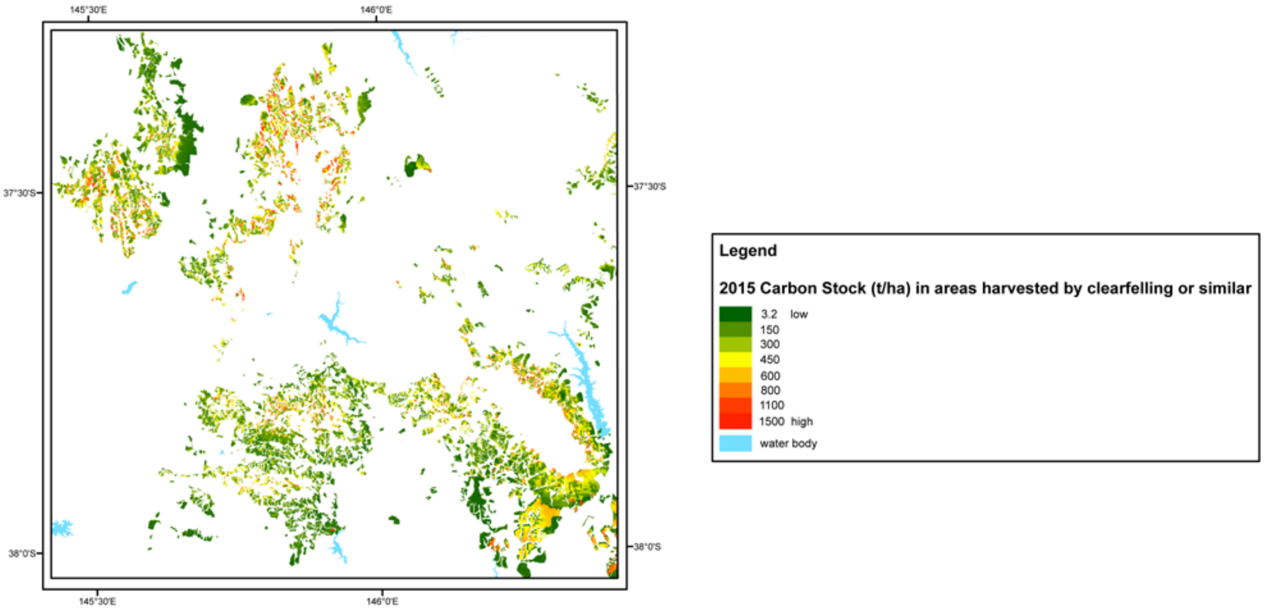
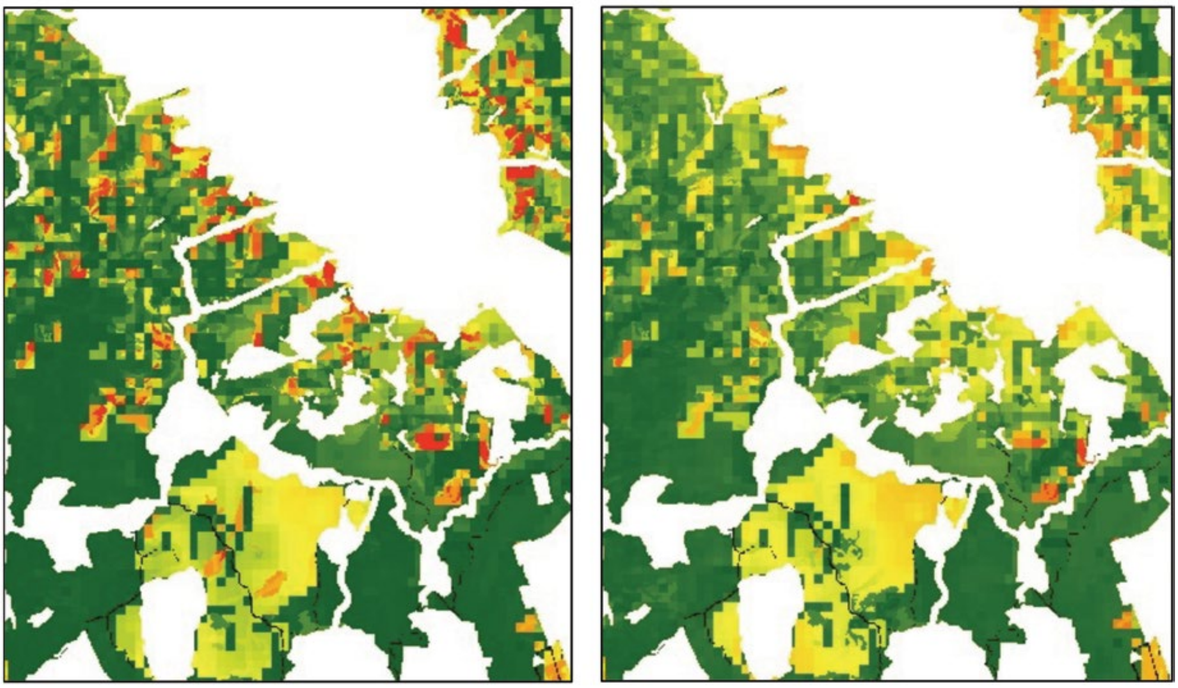


Figure 5.3. Carbon stock (tC ha^{-1}) in 2015 in the areas logged previously in all forest types by stand-replacing activities.



(a) 1990 *(b) 2015*

Figure 5.4. Carbon stock (tC ha^{-1}) in the area available for logging in (a) 1990, and (b) 2015, showing a zoomed in section of the study area to the south of the Baw Baw plateau. Legend as in Figure 5.2.

5.3.3 Valuation of carbon sequestration

The ecosystem service of carbon sequestration has a benefit for climate change mitigation both nationally and internationally. At a national level, the value of this service can be equated to the price of \$12.25 per tCO_{2_e} paid by the Australian Government in November 2015 for abatement projects under the second auction of the Emissions Reduction Fund (Clean Energy Regulator 2015) (see section 2.3). Using this price, which is paid on the basis of net annual changes in carbon stocks, the total value of carbon sequestration across the study area for 2010-15 was \$73.7 million yr^{-1} (Table 5.2a: 1.641 million tC yr^{-1} x 44/12 x \$12.25 $tCO_{2\_e}{}^{-1}$). This price for carbon abatement was applied to other years adjusted for inflation using the ABS Consumer Price Index (Table 5.5). It is acknowledged that the price of carbon was higher in earlier years, but there has not been a consistent national price over time. The potential range in values of carbon sequestration is shown in Table 5. 6, using national and international carbon prices.

Table 5.5. Value of carbon sequestration or net annual removal of CO_2 calculated as a change in carbon stock in the Central Highlands.

Land Cover	Value of carbon sequestration ($m yr^{-1})				
	1991-95	1996-00	2001-05	2006-10	2011-15
alpine ash	5.28	4.95	5.99	0.00	9.70
bare	0.00	0.00	0.00	0.00	0.00
built-up area	0.00	0.00	0.00	-0.05	0.05
crop	0.00	0.00	0.00	0.00	0.00
crop/pasture	0.00	0.00	0.00	0.00	0.00
eucalypt plantation	0.00	0.00	0.00	-1.32	5.17
horticulture	0.00	0.00	0.00	-0.01	0.01
montane woodland	0.08	0.09	0.11	-0.04	0.01
mountain ash	8.89	9.01	8.90	7.90	31.16
open mixed forest	4.14	4.70	5.83	4.38	7.63
open water	0.00	0.00	0.00	0.00	0.00
pasture/grassland	0.00	0.00	0.00	-0.02	0.02
pine plantation	0.00	0.00	0.00	-0.76	0.36
rainforest	0.16	0.18	0.21	-0.05	0.15
riparian shrubs	0.00	0.00	0.00	0.00	0.00
shrub/heath	0.00	0.00	0.00	0.00	0.00
swamp	0.00	0.00	0.00	0.00	0.00
wet mixed forest	10.61	12.74	14.87	12.32	19.44
woodland	0.04	0.04	0.05	-0.06	0.01
Total	**29.21**	**31.72**	**35.97**	**22.28**	**73.70**

Table 5.6. Range in the value of carbon sequestration for 2011-15 based on different carbon prices.

Carbon price	$ / tCO_{2_e}	$ million
Emissions Reduction Fund - auction 1	13.95	83.9
Emissions Reduction Fund - auction 2	12.25	73.7
Emissions Reduction Fund - auction 3	10.23	61.5
Global market – average for 2014	9.00	54.1
Verified Carbon Standard in Australia (2011)	10.00	60.2
Californian cap and trade program	10.68	64.3
Carbon Farming Initiative in 2014	23.00	138.4

Valuation of the ecosystem service of carbon sequestration to determine the effect of land use was based on the same two components: (1) the potential carbon stock density under a change in land use, and (2) carbon sequestration as a net change in carbon stock per year.

In montane ash forest, the potential to increase carbon stock density by 142.8 tC ha^{-1} (Table 5.4) if logging ceased and forests were allowed to re-grow, is equivalent to $6413 ha^{-1}. Over the area of montane ash forest that has been logged, this potential increase is 8.76 MtC, which is equivalent to $393 million.

The difference in carbon sequestration between the area logged and the area unlogged but available for logging, averaged over 1990 – 2015, was 2.98 tC ha^{-1} yr^{-1} (Table 5.4). At a carbon price of $12.25 per tCO_{2_e}, **the carbon sequestration potential of 2.98 tC ha^{-1} yr^{-1} by ceasing logging is equivalent to $134 ha^{-1} yr^{-1}**. The area available for logging includes public land with native forest types that are zoned to allow harvesting.

Currently, there is no market system for the valuation of carbon sequestration to quantify the potential economic activity in terms of IVA. This lack of market for the carbon sequestration in native forests is due to current government regulations. However, a price for carbon sequestration exists through the results of government auctions for permitted abatement activities ($12.25 per tCO_2). An indicative IVA was calculated based on the potential for abatement activities in native forests to be permitted in the changing of government regulations.

Potential revenue was the product of the amount of carbon sequestered and the price, which is equivalent to the ecosystem service of carbon sequestration. The expenses incurred for producing this revenue were assumed to be those required for managing a native forest, such as exists in national parks. Such expenses would include fire prevention and fighting, road maintenance, control of weeds and pests. The financial accounts from Parks Victoria were used to estimate these expenses (Parks Victoria 2013-14).

The time series of IVA for carbon sequestration (Figure 10.6) was derived from the calculated income from carbon sequestration annually (Table 5.5) and expenses in 2013-14 adjusted for inflation using the Consumer Price Index Calculator (ABS 2016b).

Table 5.7. Estimation of IVA for carbon sequestration for the Central Highlands study area based on potential revenue from the government carbon price for abatement activities and the expenses of managing native forest land from Parks Victoria. *(Source: Parks Victoria Annual Report 2013-14, p42).*

2013-14	Parks Victoria total	Parks Victoria per ha	Central Highlands study area
	($m)	($ ha^{-1})	($m)
Revenue ($m)			
Parks Victoria income	226.40		
Income from carbon sequestration		109.73	63.17
Expenses ($m)			
Employee benefits expenses	105.83	25.81	14.86
Depreciation and amortisation	11.83	2.89	1.66
Contracts and external services	77.83	18.98	10.93
Other operating expenses	24.75	6.04	3.48
Intermediate consumption	102.58	25.02	14.4
Total Expenses	220.24	53.72	30.93
Area (million ha)	4.10		0.5757
IVA ($m)			48.77

5.4 Trade-offs in carbon stocks and sequestration

The potential gain in carbon stocks by ceasing logging and protecting native montane ash forests is approximately double the current stock averaged across areas that have been harvested, including all stocks in living and dead biomass, wood products and landfill (Keith 2014a and b, 2015). This gain in carbon stock due to ceasing logging in ash forests is similar to that predicted for the catchments of the Goulburn River (ACF 2009). Reductions in carbon stocks due to wildfire are widespread but constitute on average only 10% of the biomass carbon stock, and this is regained within a decade (Keith et al. 2014b). Hence, maximising carbon stocks in forest biomass, which have the highest carbon density and highest longevity of stocks, should be priority activities for mitigation. Whether this value is recognised in the market depends on government regulations. Under current Australian Government regulations for carbon credits, avoiding harvest and protecting native forests to store carbon is not included under approved methodologies. The information exists to develop a methodology and the estimates of carbon stock change with a conversion of logged forest to protected forest from this study show the mitigation benefit.

The Carbon Credits Act (2011) (Carbon Farming Initiative) enables the crediting of greenhouse gas abatement from emissions reduction activities in Australia. Abatement is achieved by reducing or avoiding emissions or by removing carbon from the atmosphere through storage in vegetation and trees. Carbon credits are earned for each tonne of CO2 equivalent stored or avoided by a project. The credits may be sold to generate income, either to the Government through a Carbon Abatement Contract or on the secondary market where credits are treated as financial products. Emissions Reduction Fund (Commonwealth of Australia 2014) projects must be conducted according to a methodology approved by the Clean Energy Regulator (2016).

The price for carbon credits under the Emissions Reduction Fund represents the price the government is prepared to pay for abatement from approved methodologies and activities. The aim of the scheme is for the government to purchase emissions reductions at the lowest cost from reverse auction. The price does not necessarily represent a true value of the activity of carbon sequestration because markets are constrained by institutional regulations. Additionally, activities that reduce emissions typically deliver valuable co-benefits, for example economic benefits from energy efficiency and using waste products, improved productivity from revegetation and increasing soil carbon, and reducing environmental problems like erosion, water quality, salinity. These co-benefits reduce the level of funding required under the Emissions Reduction Fund to make projects viable, because they are included in the business case for projects (Commonwealth of Australia 2014).

A voluntary carbon market also exists, for example, the Verified Carbon Standard (VCS 2017). This standard provides rules and requirements for projects to verify that the emissions reductions generated by the project are actually occurring. Projects are certified and issued with Verified Carbon Units (VCUs) that can be sold on the open market.

The price of carbon sequestration in the market does not equate to the social cost of carbon, that is, the marginal damage costs caused by carbon dioxide emissions if they were not avoided. An average value of the social cost of carbon was estimated to be \$58 tC^{-1} (\$212 tCO_2^{-1}) based on a literature survey (Tol 2005). This social cost represents the trade-off between avoided impacts of climate change and the costs of emission reduction.

Additional benefits of carbon storage in old growth forests are the reduction in risk of wildfire, and the consequent emissions of carbon as well as damage to life and property. Evidence from the 2009 wildfire in the Mountain Ash forest showed that protected old-growth forests were less likely to burn at high severity (Taylor et al. 2014).

6. Timber

6.1 Introduction

A range of forest types in the Central Highlands of Victoria supply wood for timber and fibre. Native forest used for timber production is from the forest types of montane ash (118,349 ha), and open and wet mixed species (200,722 ha). Plantations of *Eucalyptus* (25,310 ha) and *Pinus* (11,025 ha) also occur in the region (Table 3.1).

Of the total area of native forest harvested in Victoria from 1990 to 2015, an average of 25% of the area was in the Central Highlands study area, with a range from 12% to 47% in different years. The study area included 93% of the area harvested in the Central Highlands Regional Forest Agreement (RFA) area from 2005 to 2014, excluding only a small area in the western part of the region (Figure 6.1).

There has been a long history of native forest logging in the Central Highlands, beginning in the 19th century with selective logging, but this was increasingly intensified in the 20th century. A wildfire in 1939 burnt most of the Central Highlands region and the forest was salvage logged for at least a decade (Noble 1977, Mould 1991). Most of the unburnt old growth montane ash forest available in State Forests had been logged by about 1990. Logging of the 1939 regrowth commenced in the mid-1980s and is currently continuing. The silvicultural system is mainly clearfelling, with clearfell salvage logging after wildfire, where all trees in a coupe are logged (Lutze et al. 1999, Flinn et al. 2007). Small areas are harvested to retain seed trees, that is, a few selected trees are left in a coupe. Areas cleared for roads are included in the logged area. Forests that have been thinned were not included in the logged area because these are relatively small areas, and the volume and products are highly variable.

Plantations in the region consist of either pine or eucalypt species and occur on private land. The pine plantations occur in large areas and are owned by the company HVP Plantations. The area of pine plantation has increased from 8,400 ha to 11,000 ha over the course of the land cover time series data from 2005 to 2015 (Figure 10.1). The eucalypt plantations occur in smaller areas with a wide range of private ownership. The area has increased from 3,000 ha to 25,300 ha from 2005 to 2015. Rotation length is up to 30 years and varies with the products of sawlogs or pulpwood. Trees are clearfelled at the end of the rotation and there may be thinning operations during the rotation.

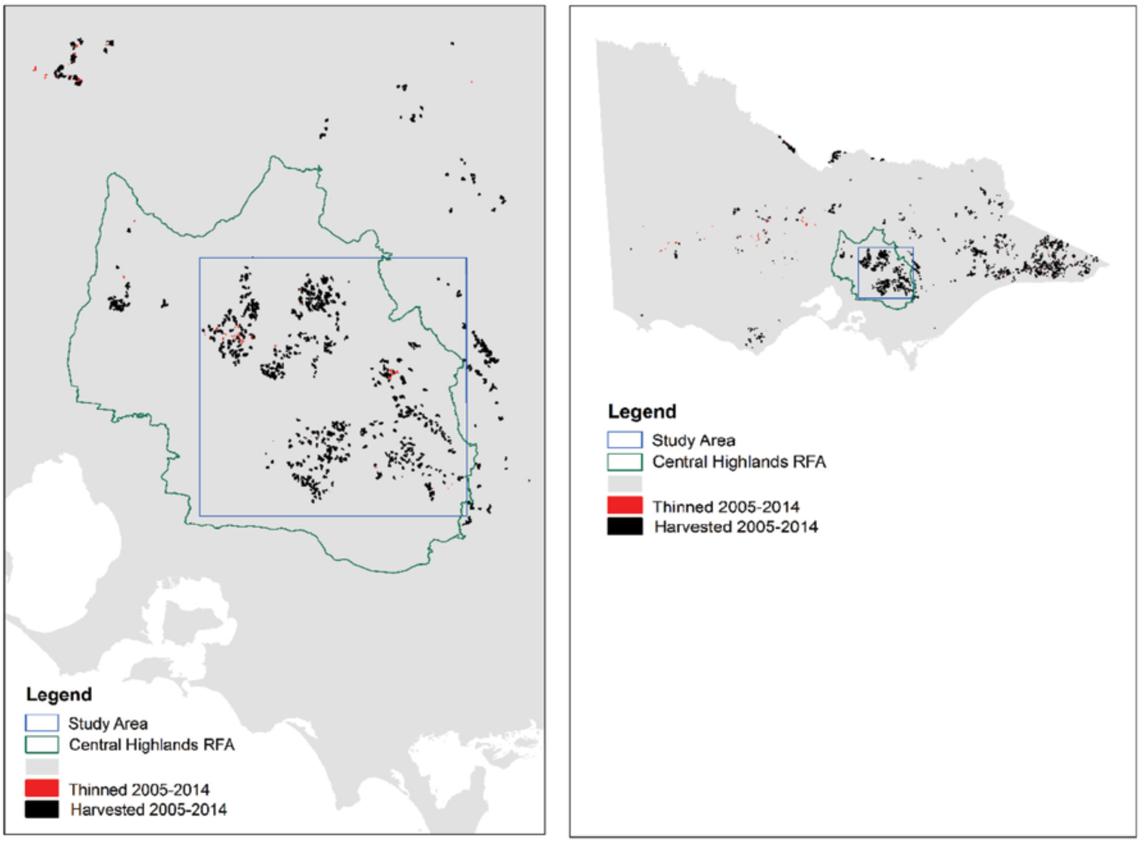


Figure 6.1. Map of the study area in relation to the boundary of the Central Highlands RFA, and the distribution of areas of native forest harvested across Victoria.

6.2 Physical wood stocks and flows

Harvested wood from the Central Highlands is derived from ash and mixed species native forest types, and pine and eucalypt plantations. Data input required for the accounts are the area harvested (ha), wood yield (m^3 ha^{-1}), and wood volume (m^3 yr^{-1}) for each forest and product type over time. Data were not available in a consistent format over the time required, so a range of data sources was used. Hence, a range of results is presented.

6.2.1 Data sources and methods

6.2.1.1 Native forest timber

Data about wood resources harvested from native forests were sourced from the government agency responsible for managing the resource. This agency has changed in structure and name over time, and is currently VicForests. Two sources of data are available: (A) reports, including the annual and sustainability reports of VicForests, and (B) spatial data on logging areas. Reports for the State of Victoria and individual Forest Management Areas provide data on areas harvested, volume and yield of sawlog and residual log (logs of inferior quality used for woodchip and pulp). Spatial data are for the areas harvested each year.

A. Reports

A range of data was collated from various reports to assess area harvested, volume and yield of logs. These data were assessed to determine the most useful to apply in the accounts.

1) Reports for Forest Management Areas

a) Reports on **Monitoring Annual Harvesting Performance (MAHP)** in Victoria's State Forests produced by the Victorian Government Department of Sustainability and Environment provided data from 1990-91 to 2004-05. These reports are produced each year for the state and each Forest Management Area (FMA). The reports contain information about the total area harvested (ha yr^{-1}), the volume of sawlog and residual log (m^3 yr^{-1}), and the yield (m^3 ha^{-1}) by forest type of ash or mixed species within the FMA for the year. In many of the MAHP reports, graphs are presented from the preceding 10 years of data. Data from these reports about sawlog yield are available for 1990-91 to 2008-09 and for residual log yield for 1990-91 to 2000-01. In the account tables, data up to 2004-05 were used. The Central Highlands study area consists of parts of four FMAs: Central, Dandenong, Benalla-Mansfield and Central Gippsland. The area logged in the study area was calculated each year as percentages of the total logged within each of the FMAs. These percentages were used to calculate the total volume harvested each year within the study area. Yield is calculated from specific coupe data by VicForests to give an average yield for each FMA. The estimated yield for the study area used a weighted average yield according to the volume harvested from each FMA per year.

The MAHP reports give the legislated sustained yield for each FMA for sawlogs based on modelled forest growth and yield and mapped landscape variables, the licensed yield commitments for sawlog, and residual log (DSE 2009), and the actual harvested volumes each year. The differences between sustained yield and licensed yield are various categories of non-economically accessible resource. The report of harvesting performance compares the licensed yield and the actual harvest for the year. Current sawlog commitments by VicForests are to 2017.

The area harvested is based on the information for the silvicultural systems of clearfell, clearfell salvage, seedtree and roading, where the majority of the trees are harvested in a coupe. Areas harvested by thinning have not been included in the assessment because there were not specific data for the comparable volumes and yield produced.

The data for sawlog volume usually includes D+ grade, but to be conservative and to be consistent with the later data from VicForests, all log grades A to E have been combined in the accounts. (Log grading is from A – highest quality, to E – lowest quality, which determine their use in a range of products). E grade logs have been used for either sawlog or residual in different times and places, and they can be used for pallets, poles and fencing and so are not necessarily used for woodchip. To calculate the time series of volume data, the average proportion of E grade logs in each FMA was added to the MAHP sawlogs and subtracted from the MAHP residual logs. Log grading and the distinction between sawlog and residual has varied due to market demand, species, FMAs and log sizes, as well as differences in the way products are described.

Methods of assessing volume harvested have changed over the 25 years, and hence the data are not a true time series and there are various sources of uncertainty. Timber volume is based on sales volumes with the data reconciled by a customer. Sales data are not necessarily an accurate metric of harvest volumes within an FMA because wood can pass through transit dumps or be sold in other FMAs.

Classifications of area and volume harvested differ. Area harvested is based on SFRI dominant forest type classification and calculated using a GPS after harvesting is complete. Volume harvested is based on the actual species of the log for sawlogs and forest type for residual logs. Therefore, area and volume by species may differ for some coupes if there were inaccuracies in the forest type mapping or both ash and mixed species occurred within the area harvested. This difference in classification means that calculations of yield based on total areas and total volumes may be inaccurate. Additionally, not all coupes have harvesting and log sales completed at the end of the season or financial year when yield statistics are calculated, and this can cause inaccuracies in yield based on total area and volume. The reported areas and volumes of harvested wood can vary from year to year depending on whether only completed harvesting in coupes are reported at the end of the season.

Yield data are calculated specifically by the forest management agency and reported. There are specific coupe candidacy rules for calculating yield: (a) only coupes with harvesting completed, and (a) there has to be 90% alignment between the forest type of the area harvested and the species of the harvested log volumes, for the coupe to be included in yield calculations. Yield is calculated after reconciling the forest type classifications for the area and harvested logs of each coupe.

Sawlog yield harvested for each forest type varies annually due to a range of factors. Sawlog yields are generally high during the early stages of salvage logging after wildfire, prior to the logs deteriorating. Coupes vary in their yield, and so the average yield for the year depends on the individual coupes harvested in that year. The proportions of sawlog and residual in the yield depend on the quality of the timber in the coupe, but also the prevailing market demand for the wood resources.

b) VicForests have produced reports for FMAs since 2004-05, and data for area, volume and yield harvested have been used in the accounts for the period 2005-06 to 2014-15. In 2008-09, a new LogTracker system was introduced to assess harvest volumes by following the supply chain for each log from forest to market. This meant that the system for calculating volume changed from sales volume used in the MAHP reports to harvest volume used in the VicForests reports. Using harvested volume is more accurate because the wood may not be sold, or not sold in the same FMA, and so not recorded. For example, after the 2009 fire, there was burnt harvested wood that was not sold. Volume data are sourced from multiple supply chain management systems, implemented at varying points of sale and operated under differing harvesting arrangements, which affect the consistency of the data over time. Data from the MAHP and VicForests reports do overlap for 5 years, but have not been shown on the same graph because they are not necessarily comparable due to the different methods for data collection.

Hence, the volume data from MAHP and VicForests are not necessarily comparable. MAHP data provides an indication of trends over time within the dataset, but there is uncertainty in the quantitative volume and yield data. The VicForests data for volume and yield since 2008-09 are considered more accurate than earlier records. Aggregated data over the 5-year time periods used MAHP data for 1990-94, 1995-99, 2000-04, and VicForests data for 2005-09 and 2010-14. These two sets of data were combined to produce the time series from 1990-91 to 2014-15 of area harvested, volume and yield of sawlogs and residual logs to use in the accounts, but cognizant of the assumptions and uncertainties involved.

2) Coupe data

Data for individual coupes harvested during the year were presented in the MAHP Central FMA reports from 2003-04 to 2008-09. Data for area harvested, forest type and sawlog volume were used to calculate the average sawlog yield for each year. These results for yield were compared with the data presented in graphs of yield as the average for the FMA in the report (Figure 6.2). These yield data are similar in some years for ash, but differ in other years, and are always higher for the coupe data from mixed species. The reason for these differences in yield data derived from these two sources within the same report is not known. It may be related to the fact that harvesting was not complete in all the coupes at the end of a season and reporting year, and this was not noted in the table of coupe data. However, there must be additional reasons for the higher yield from mixed species from the coupe data. The comparison of yield data from these two sources is shown in Figure 6.2 and Table 6.1.

Data from the MAHP Central FMA reports for total area harvested and volume of residual product was used to calculate yield of residual by forest type. Data were annual for the period 2002-03 to 2008-09 and shown in the summary in Table 6.1.

In the timber account table (Table 6.3), the graphs of 10-year time series of sawlog yield data presented in the body of the MAHP reports have been used, rather than the results from calculating the coupe data.

3) NCAS Technical Report 32

Historical data and expert opinion were used to derive estimates of timber yields in forestry regions of Australia by forest type and silvicultural type over 5-year time periods up to 2000 (Raison and Squire 2007). Sawlog yield was calculated as the volume divided by area of clearfell harvest. Residual yield was calculated as volume divided by area of clearfell plus thinning harvest.

4) FullCAM model

Yield was calculated using the Australian Government's forest carbon model, FullCAM, which is used in the National Carbon Accounting System (NCAS) (Richards and Evans 2004, DotE 2015a, DotE 2015b). The representative plot for harvested native forest comparable to the forest types in the Central Highlands is Tall Dense Eucalypt Forest (TDEF). The model calculates the biomass in the forest, debris and products at the end of a rotation, from which an average yield of products can be estimated across forest types and years.

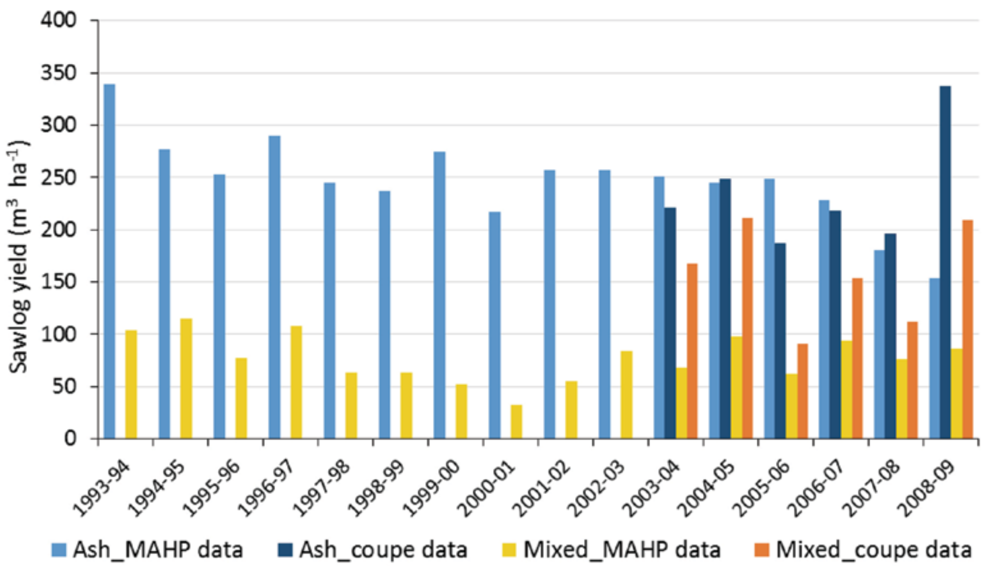


Figure 6.2. Sawlog yield (m^3 ha^{-1}) from ash and mixed species forest, and comparing sources of data from MAHP reports and coupe data.

B. Spatial data

The area (ha) harvested each year was calculated from the logging history spatial data since 1932, assessed by forest type and silvicultural system. Forest types were ash and mixed species. Silvicultural systems included were clearfell and clearfell salvage, seed tree, gap selection, shelterwood, reforestation and majority biomass removal in thinning. Silvicultural treatments that have a lesser proportion of the biomass harvested were not included: single tree selection and thinning from below.

Annual area harvested was multiplied by the yield (m^3 ha^{-1}) of sawlog and residual log for each forest type, from the data in the MAHP and VicForests reports (Figure 6.5). The result is the volume of sawlog and residual product harvested per year (m^3 yr^{-1}).

These various sources of data were analysed and compared in an attempt to determine the most realistic numbers to represent the timber asset and the change over time. Both sources of data, from reports and spatial data, are publically available from the government agency managing the timber resource. Reported data were used in preference to the coupe data, because the reports are the annual information presented by the agency. The differences in these sources of data, and the difficulty in accurately quantifying the timber asset, are noteworthy. Data have been used as a time series because this is needed for the accounts, however, the different sources and potential differences are noted in the results.

6.2.1.2 Plantation timber

Estimates of wood product volume and yield were derived from three sources.

1. Outputs of the FullCAM model (DotE 2015a) using representative forest plots for the region for pine and eucalypt plantations. Output data were used for the wood product mass at end-of-rotation, wood density for the species, proportion of different products, rotation length, and total area of plantations in the study area. Pulplogs were classified by their products of pulp and paper, wood packaging and fibreboard. Sawlogs were classified by their products of furniture, poles and construction.
2. Data from ABARES (2016) for hardwood and softwood plantation statistics for the state of Victoria. Data for the study area were derived from the ratio of each type of plantation area within the study area compared with the state.
3. Data from HVP Forest Management Plan (2016), the company that owns the softwood plantations in the study area. Data for the company plantations in Victoria were scaled to the study area based on the ratio of areas.

6.2.2 Results

6.2.2.1 Native forest timber

Two sets of results are presented for area and volume harvested, based on the data sources from FMA reports and spatial data. Both the area and volume harvested reported for the FMAs (Figures 6.3a and 6.4a) were mostly lower than the spatial data (Figures 6.3b and 6.4b) during the 1990s, but more similar since the 2000s. Discrepancies of generally less than 10% are indicative of the improved spatial referencing of areas harvested and their silvicultural systems.

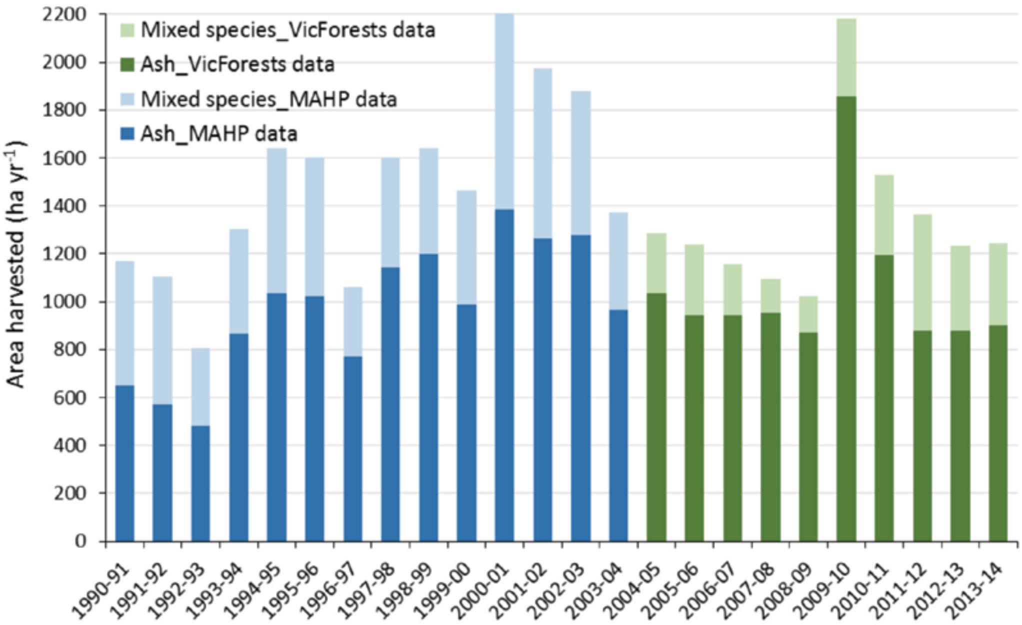
The comparison of yield from different sources (Table 6.1) demonstrates a range of data, with the average reported data for FMAs (1. a and b) generally lower than specific coupe data (2.), and average data for the forest type (3. and 4.) both higher and lower than the FMA data. The time series of yield (Figure 6.5) is based on the data in MAHP and VicForests reports.

Results for area, volume and yield harvested were aggregated for each 5-year period for accounting purposes (Table 6.2). Differences in the results from the data in MAHP and VicForests repots (a), and results derived from the spatial area data (b), reflect inconsistencies and methodological differences in the data recorded, differences in coding of locations of logging within FMAs, and changes over time in the methods used. In the early decades of recorded logging, particularly 1932 to 1962, locations within FMAs were not recorded. This difference in the reported compared with spatial data produces a different result for the proportion of logged areas in FMAs that occur within the study area.

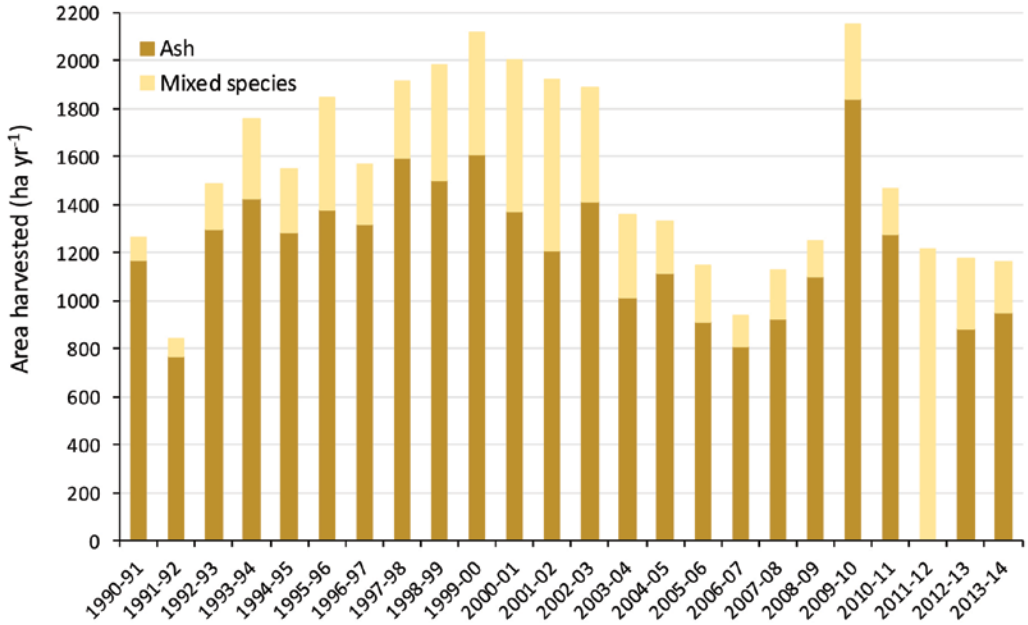
Data used in the accounts integrating asset and financial information (Section 6.3.2), included the spatial data for area harvested each year in the study area and the yield reported by VicForests for their timber production.

Table 6.1. Comparison of yield data from different data sources

		Sawlog yield (m^3 ha^{-1})					Residual yield (m^3 ha^{-1})				
Data source	Forest type	1990-94	1995-99	2000-04	2005-09	2010-14	1990-94	1995-99	2000-04	2005-09	2010-14
1. a) MAHP FMA reports	Ash	195	212	222	178						
	Mixed sp.	45	56	68	70						
	Total						440	457	255	421	
1. b) VicForests FMA reports	Ash				230	268				426	433
	Mixed sp.				81	131				272	311
2. MAHP Central FMA coupe data	Ash			235	262						
	Mixed sp.			189	150						
	Total								484	410	
3. NCAS Tech. Rep. 32	Ash	223	181				275	320			
	Mixed sp.	72	69				49	68			
4. FullCAM output for TDEF	Average			132					384		

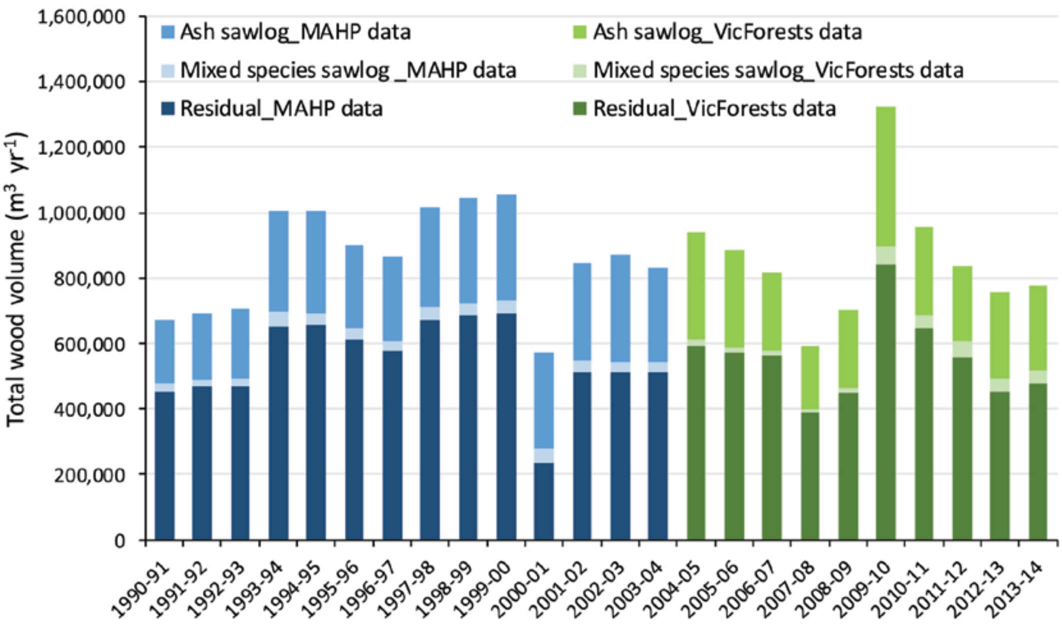


(a)

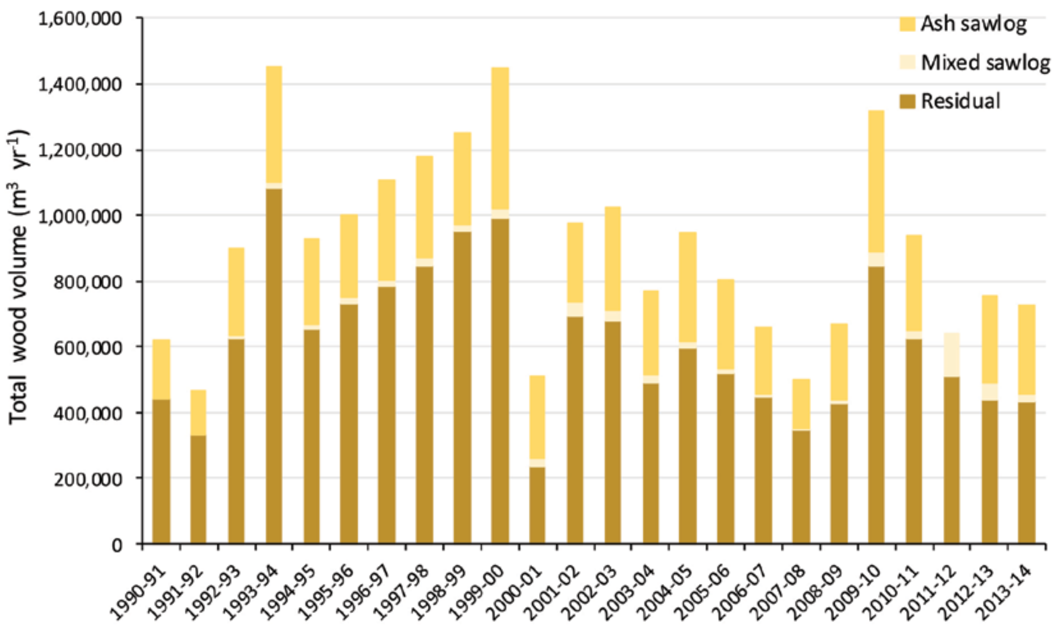


(b)

Figure 6.3. Annual area harvested (ha) from ash and mixed species forest types within the study area. Data from different sources are compared: (a) data from reports from MAHP (1990-91 – 2003-04), and VicForests (2004-05 – 2013-14), and (b) spatial data from VicForests (1990-91 – 2013-14).



(a)



(b)

Figure 6.4. Annual volume of sawlog and residual log harvested (m^3 yr^{-1}) from ash and mixed species forest types within the study area. Data from different sources are compared: (a) data from reports from MAHP (1990-91 to 2003-04), and VicForests (2004-05 to 2013-14), and (b) spatial data from VicForests (1990-91 to 2013-14). [residual log volume data were not available for 2001-02 to 2003-04 in (a) and estimated.]

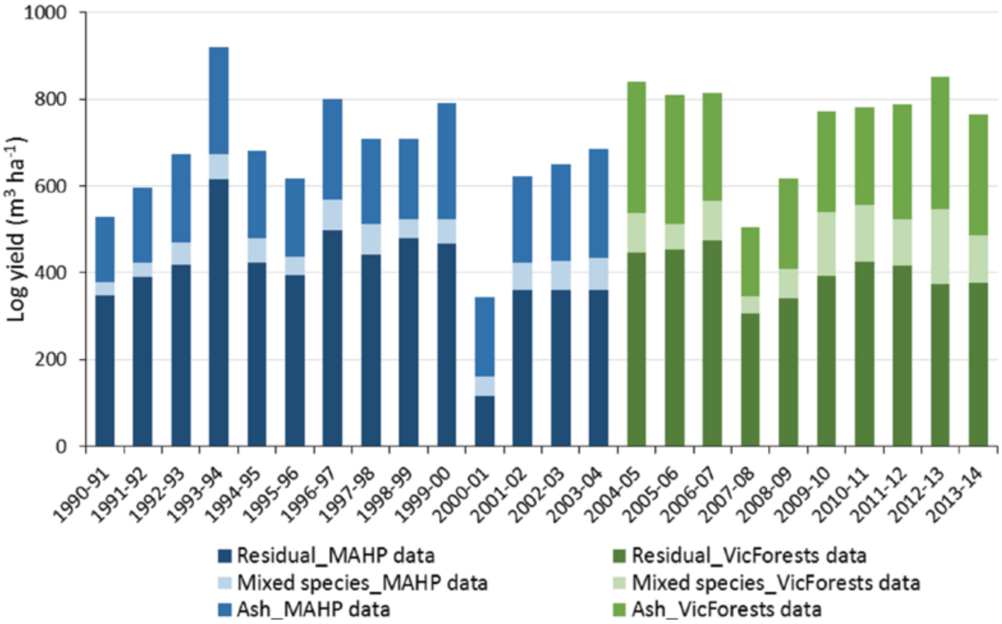


Figure 6.5. Annual yield of sawlog and residual log harvested from ash and mixed species forest types within the study area; data sourced from MAHP (1990-91 – 2003-04) and VicForests (2004-05 – 2013-14) reports. [residual log volume data were not available for 2001-02 to 2003-04 and estimated.]

Table 6.2. Total area, yield and volume harvested over 5-year time periods

(a) Data sourced from MAHP and VicForests reports.

	1990-94	1995-99	2000-04	2005-09	2010-14
Area (ha 5yr^{-1})					
Ash	3,603	5,125	5,864	5,563	4,820
Mixed	2,422	2,246	2,823	1,130	1,888
Yield (m^3 ha^{-1})					
Ash sawlog	195	212	222	230	268
Mixed sawlog	45	56	68	81	131
Residual	440	457	255	394	398
Volume (m^3 5yr^{-1})					
Ash sawlog	1,232,201	1,469,679	1,523,761	1,397,681	1,280,717
Mixed sawlog	155,153	178,056	185,942	111,326	200,368
Total sawlog	1,387,355	1,647,735	1,709,704	1,509,007	1,481,085
Residual	2,693,699	3,236,332	1,978,521	2,813,898	2,674,140
Total	4,081,054	4,884,067	3,688,224	4,322,905	4,155,225
Volume (m^3 yr^{-1})					
Ash sawlog	246,440	293,936	304,752	279,536	256,143
Mixed sawlog	31,031	35,611	37,188	22,265	40,074
Total sawlog	277,471	329,547	341,941	301,801	296,217
Residual	538,740	647,266	395,704	562,780	534,828
Total	816,211	976,813	737,645	864,581	831,045

(b) Data sourced from the spatial data of area harvested and yield from the reports

	1990-94	1995-99	2000-04	2005-09	2010-14
Area (ha 5yr^{-1})					
Ash	5,949	7,397	6,120	5,588	3,882
Mixed	954	2,037	2,374	1,023	2,391
Yield (m^3 ha^{-1})					
Ash sawlog	195	212	222	230	268
Ash residual	440	457	329	426	433
Mixed sawlog	45	56	68	81	131
Mixed residual	440	457	329	272	311
Volume (m^3 5yr^{-1})					
Ash sawlog	1,183,051	1,570,373	1,399,722	1,278,284	1,024,755
Mixed sawlog	48,468	109,747	149,294	89,628	286,737
Total sawlog	1,231,519	1,680,120	1,549,016	1,367,913	1,311,492
Residual	3,132,369	4,305,359	2,687,152	2,581,292	2,508,744
Total	4,363,888	5,985,480	4,236,168	3,949,204	3,820,236
Volume (m^3 yr^{-1})					
Ash	236,610	314,075	279,944	255,657	204,951
Mixed	9,694	21,949	29,859	17,926	57,347
Total sawlog	246,304	336,024	309,803	273,583	262,298
Residual	626,474	861,072	537,430	516,258	501,749
Total	872,778	1,197,096	847,234	789,841	764,047

6.2.2.2 Plantation timber

Estimates of wood product volumes and yields from the three data sources are shown in Table 6.3.

Table 6.3. Wood product volume and yield from the study area in 2015

	FullCAM output			ABARES data			HVP
	Hardwood	Softwood	Total	Hardwood	Softwood	Total	Softwood
area (ha)	25,305	11,010	36,315	25,305	11,010	36,315	11,010
pulplog volume (m^3 yr^{-1})	389,697	46,242	435,939	340,900	68,900	409,800	135,000
sawlog volume (m^3 yr^{-1})		63,858	63,858	7,300	122,500	129,800	115,000
total volume (m^3 yr^{-1})	389,697	110,100	499,797	348,200	191,400	539,600	250,000
yield (m^3 ha^{-1})	460	300			435		609

The data from ABARES was subsequently used in analyses because there were sufficient data to create a time series and the data were consistent for volumes and values. Estimates from different sources provided an indication of the possible range in data. These data are general, for a region or the state. Hence, they are likely to underestimate the yield and volume for the study area because it is generally more productive land than the state average. The data for pine plantation yield and volume from HVP were higher than the other sources, and is likely to be more specific to the pine plantations in the study area, although the estimate is still based on a ratio of the areas of all HVP plantations in the state.

6.3 Timber provisioning service and timber supply

6.3.1 Data sources and methods

6.3.1.1 Native forest timber

The total volume and value of the timber supplied by VicForests is reported in Annual Reports and other publications. This includes a stumpage value, which is the revenue from forest products less harvesting and haulage costs. The stumpage value was taken to be the value of the ecosystem service of timber provisioning. Data on the area and volume of wood production from the Central Highlands study area (Figures 6.3 and 6.4) was used to scale financial information for the state in the Annual Reports of VicForests. Estimates of the value of timber supplied from the study area were generated, based on the stumpage value, as well as a calculation of profit (loss) and industry value added.

The physical ecosystem service was taken to be the volume of timber harvested in each year. This is not a true reflection of the timing of the growth of the timber. The provisioning service used by VicForests is recorded in the year that VicForests harvest the timber and is assumed to be supplied into the market in the same year. The effect is that ecosystem services are only used when VicForests supplies to market.

An alternative accounting treatment would be to record the use of the timber provisioning service as year-on-year increments to volume of timber that could be harvested by VicForests. A value for the biological assets, which is the value of timber, is also recorded in the balance sheet of VicForests. This value represents the "Estimated standing timber available for harvest for the next eighty years", and is calculated using a net present value approach and a discount rate 7.98% (a market rate).

6.3.1.2 Plantation timber

Data for the gross value of hardwood and softwood products were used from ABARES (2016) for the state of Victoria, and scaled to the study area based on the ratio of areas of each type of plantation within the study area and state. Data include total gross value, sawlog and pulplog volumes and price index for hardwood and softwoods, from which values for each component were calculated. ABARES (2016) data for Australia was used to provide the ratio of IVA to gross value in the forest product industry for forestry and logging from 2004 to 2015. Using this ratio, the IVA for the plantation industry in the study area was calculated.

The value of ecosystem services was derived for the use of services in the production of plantation timber, because the plantation is within the production boundary of the market (CICES 2016). Unit resource rent was calculated from the ABS data (available on request) for the Australian industry production for the subdivision of forestry and logging, based on the gross operating surplus and mixed income, consumption of fixed capital and return on fixed capital. Resource rent as a percent of gross operating surplus was multiplied by IVA to estimate the value of the ecosystem services contributing to production (Appendix Tables A6.1 and A6.2).

6.3.2 Results

6.3.2.1 Native forest timber

Summary information on the operations of VicForests across all of Victoria is shown in Table 6.3, including the revenue, costs, profit (loss) and industry value added (IVA) calculations for all VicForests activities within the state. The area and volume harvested in the study area of the Central Highlands were used to calculate the percentage of the state total contributed by the study area. Table 6.4 shows the results estimated for industry value added, timber supply and timber provisioning service that result from activities within the study area.

The industry value added is only for the native forest logging undertaken by VicForests and relates to the area available for timber production in native forests within the Central Highlands study area, as shown in Table 3.1. **This IVA represents the annual contribution of the native forest timber industry to GDP, which was $12.2 million in 2013-14. This value corresponds to $46 ha^{-1} for the area available for harvesting, and $38 ha^{-1} for the area managed for the timber industry. The value of ecosystem services in the study area used by VicForests was $18.7 million in 2013-14, corresponding to $71 ha^{-1} or $58 ha^{-1} for the two areas, respectively.**

Estimates of employment in the native forest timber industry were based on data from two sources. VicForests annual report gives a total of 525 employees and contractors in the state in 2012, which would **represent 205 jobs in the Central Highlands** based on the proportion of area harvested. Data from the ABS and forest industry survey (Schirmer et al. 2013) give 391 jobs in forest growing, silviculture, harvesting and haulage in 2012 for Victoria. Data for the Central Highlands were estimated from the area harvested within the study area as a proportion of the whole state. This **represents 152 jobs in the Central Highlands**. Although there are differences in these estimates of employment, they are the same order of magnitude and useful for comparison across industries. The data from VicForests indicates that only 20% of those employed in managing, harvesting and haulage of native timber are employees. **The other 80% are contractors, many of whom could also be employed in other industries.**

Table 6.3. Summary financial data for all Victorian operations by VicForests, 2005-06 to 2014-15

	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16
Revenue ($m)											
Revenue from forest products	37.2	99.1	125.8	125.3	131.6	131.4	116.7	104.5	104.3	107.7	112.005
Other revenue	1.8	4.3	7.0	5.0	13.2	7.9	2.7	1.8	1.5	3.8	5.2
Total Revenue	**39.0**	**103.4**	**132.8**	**130.3**	**144.8**	**139.3**	**119.4**	**106.3**	**105.8**	**111.5**	**117.2**
Forest products as % of total	95.4%	95.8%	94.7%	96.2%	90.9%	94.3%	97.7%	98.3%	98.6%	96.6%	95.6%
Expenses ($m)											
Operating and other expenses	(15.3)	(84.3)	(117.2)	(117.6)	(124.3)	(117.9)	(100.4)	(86.2)	(84.5)	(88.9)	(91.0)
Wages, employee benefits	(13.3)	(14.4)	(13.7)	(13.7)	(13.3)	(14.1)	(13.8)	(13.9)	(13.7)	(13.0)	(13.8)
Amortisation	(5.0)	(4.0)	(0.3)	(3.8)	(3.8)	(3.4)	(2.9)	(3.4)	(4.1)	(4.4)	(4.5)
Depreciation	(0.3)	(0.6)	(0.7)	(0.9)	(1.1)	(1.0)	(1.0)	(1.0)	(0.8)	(0.8)	(0.9)
Financial expenses	-	-	(0.1)	(0.1)	(0.5)	(0.8)	(0.8)	(0.8)	(0.5)	(0.3)	(0.2)
Total expenses	**(33.9)**	**(103.2)**	**(132.0)**	**(136.1)**	**(143.0)**	**(137.2)**	**(118.9)**	**(105.3)**	**(103.6)**	**(107.4)**	**(110.4)**
Operating result ($m)											
Operating result before tax	**5.1**	**0.2**	**0.8**	**(5.8)**	**1.8**	**2.1**	**0.5**	**1.0**	**2.2**	**4.1**	**6.8**
Tax (expense)/benefit	(0.9)	-	(0.2)	1.9	(0.5)	(0.6)	0.0	(0.2)	(0.7)	(1.3)	(2.0)
Operating result after tax	**4.1**	**0.2**	**0.5**	**(3.9)**	**1.3**	**1.5**	**0.5**	**0.8**	**1.5**	**3.0**	**4.7**
Other economic flows net taxes	(2.0)	(0.1)	-	(1.1)	2.3	0.8	(0.5)	-	1.9	1.7	(1.3)
Net result	**2.1**	**0.1**	**0.5**	**(5.0)**	**3.6**	**2.3**	**(0.1)**	**0.8**	**3.4**	**4.7**	**3.4**
Estimated IVA ($m)	**23.7**	**19.2**	**15.5**	**12.6**	**20.0**	**20.6**	**18.2**	**19.3**	**20.8**	**22.3**	**26.0**
Assets ($m)											
Total assets	35.0	38.0	55.4	54.2	73.7	88.7	93.9	80.0	94.7	94.7	98.7
Total biological assets	-	-	7.1	10.9	10.9	16.2	30.0	29.5	48.6	48.7	46.2
Total liabilities	11.8	16.9	26.6	23.4	36.8	42.5	48.4	36.1	37.4	32.7	32.9
Net assets	**23.2**	**21.1**	**28.9**	**30.7**	**36.9**	**46.3**	**45.5**	**43.9**	**57.3**	**61.9**	**65.8**
Number of employees (FTE)		139.9	143			128	115	112	98	107.3	110.9
Number of contractors engaged		500-600					376	413	438	400	
Stumpage ($m)	**35.5**	**28.4**	**28.5**	**29.5**	**24.5**	**31.8**	**29**	**30.8**	**31.4**	**34.8**	**36.3**
Area harvested (ha)											
Total VicForests	4900	5628	6427	5579	5047	4979	4296	3327	2972	3017	
Central Highlands	1148	937	1127	1246	2153	1469	1218	1172	1159		
Central Highlands (% of total)	23	17	18	22	43	30	28	35	39		
Volume harvested (m^3)											
Total VicForests	1,833,923	1,674,172	1,963,997	1,686,540	1,856,352	1,695,079	1,426,626	1,259,719	1,213,904	1,287,155	
Central Highlands	805,283	658,591	499,479	666,561	1,319,290	938,479	637,526	755,883	724,301		
Central Highlands (% of total)	44	39	25	40	71	55	45	60	60		

Table 6.4. Financial estimates for VicForests operations in the Central Highlands study area, timber supply and use of ecosystem services

	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14
Financial estimates									
Profit/(loss)after tax ($m)	0.9	0.0	0.1	(1.9)	2.3	1.2	0.0	0.5	2.0
Estimated IVA ($m)	9.9	7.2	3.7	4.8	12.9	10.8	7.9	11.4	12.2
Timber supply									
Volume supplied (m^3)	805,283	658,591	499,479	666,561	1,319,290	938,479	637,526	755,883	724,301
Revenue from supply ($m)	16.3	39.0	32.0	49.5	93.5	72.7	52.2	62.7	62.2
Timber provisioning services*									
Volume used (m^3)	805,283	658,591	499,479	666,561	1,319,290	938,479	637,526	755,883	724,301
Value used ($m)	15.6	11.2	7.2	11.7	17.4	17.6	13.0	18.5	18.7

**This is stumpage value for the Central Highlands study area.*

6.3.2.2 Plantation timber

Estimated volume of sawlogs and pulplogs supplied by hardwood and softwood plantations, based on their area within the study area as a proportion of the plantation area in Victoria, together with the gross value of the wood volume supplied, based on data from ABARES (2016) (Table 6.5). The industry value added and the timber provisioning service were estimated from ABS (2016) data for Australian plantation forestry and logging, and the proportion of the industry gross value derived from the study area (Table 6.6). The values for the provisioning service and IVA are combined for hardwood and softwood sawlogs and pulp logs. Area of hardwood plantations has increased by 10-fold over the last 5 years. Hence, the relationship between harvested wood volume and area of plantations will not be stable for some years, depending on rotation length.

The **IVA** represents the annual contribution of the plantation timber industry to GDP, which was **\$29.9 million in 2013-14**. As a value of the industry per ha of land used, this corresponds to \$823 ha^{-1}. The value of **ecosystem services used in plantation production was \$9.1 million in 2013-14, or \$250** $\mathbf{ha^{-1}}$.

Estimates of employment in the plantation industry were based on data for Victoria for hardwood and softwood plantations in 2012 from the ABS and a forest industry survey (Schirmer et al. 2013). Data for the Central Highlands were estimated from the area harvested within the study area as a proportion of the whole state. Within Victoria, there were 1684 jobs in plantation industry for growing, silviculture, harvesting and haulage. Within the Central Highlands, there were estimated to be 56 jobs.

Table 6.5. Volume and value of plantation wood products in the study area, based on ABARES (2016) data for Victoria

Change in area of plantations each year was interpolated from the years with spatial land use data.

	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15
Hardwood											
Area (ha)	3,059					2,265					25,305
Sawlog volume ('000 m^3)	2.4					0.2					7.3
Pulplog volume ('000 m^3)	3.6					7.0					340.9
Gross value of sales ($m)	0.33	0.36	0.38	0.76	0.85	0.56	6.17	11.58	14.65	19.81	25.84
Softwood											
Area (ha)	8,356					8,500					11,010
Sawlog volume ('000 m^3)	101.6					90.0					122.5
Pulplog volume ('000 m^3)	55.8					44.0					68.9
Gross value of sales ($m)	8.88	9.11	8.96	7.91	8.55	8.35	9.07	8.13	11.26	12.65	13.18
Total plantations											
Gross value of sales ($m)	9.21	9.47	9.34	8.67	9.41	8.91	15.24	19.72	25.92	32.46	39.02

Table 6.6 Estimated output from plantation production, IVA and provisioning of ecosystem services for plantation timber production, based on ABS (2016) data* for Australia

	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14
Output from plantation production ($m)	16.8	16.1	17.9	18.7	27.5	39.6	52.0	64.1
Industry value added ($m)	4.4	4.1	5.0	6.3	14.0	16.5	23.3	29.9
Provisioning services for plantation production ($m)	0.2	0.3	0.4	0.9	3.3	4.7	7.1	9.1

**Data available from ABS on request*

6.4 Trade-offs for timber production from native forests or plantations

Several reports have been commissioned over the last decade that investigate the feasibility, opportunities, impediments, costs and benefits of structural adjustment in the timber industry to increase wood production from plantations in order to eliminate demand for wood from native forests. Studies have outlined how the Victorian forestry and wood products sector can transition towards total reliance on plantation forestry for pulp and solid wood products, thus allowing protection of native forests (VFA 2006; ACF 2009; NIEIR 2010; PWC 2016), and the need for renewed development in plantations (FWPA 2012, 2013), although other reports identify constraints and challenges for the transition to plantations (MBAC 2006; Pöyry 2011; Deloitte 2015).

Currently, 81% of the volume and value of Victoria's wood products are derived from plantations and 19% from native forests (ABARES 2015). Volume and value of production from plantations has increased over the last decade, while that of native timber production has declined (ABARES 2016a). The increase in plantations is mostly from native hardwood plantations for pulpwood (ABARES 2016b). On a state basis, the hardwood plantation industry in Victoria has been expanding and providing an increasing economic contribution to the state (PWC 2016). Evidence of this expansion is also seen in the study area, particularly for hardwood plantations (Figure 10.1a).

The main downstream user of the native forest timber by volume (830,000 m^3 of wood products with 65% as pulplogs) is the Maryvale Pulp Mill. Alternatives to supply from native forest timber are available from plantation timber and recycled paper. These alternatives are presumably more expensive than the native timber but the impact on profitability of operations cannot be determined as separate financial accounts for the Maryvale Pulp Mill are not publically available. Financial information on the Maryvale Pulp Mill is included in the reporting by Nippon Paper, which is a profitable company (Nippon Paper Industries 2015).

Protection of native forests and transition to plantations depends on many factors, including economics of the industries, available land, transport, quality and quantity of wood products, processing facilities, employment, markets, management of the forest, and co-benefits. Opinions differ about the substitutability of different timber sources (VFA 2006, Pöyry 2011, Deloittes 2016, PWC 2016).

(i) Economic –The stumpage price for plantation sawlogs is higher than for native forest timber because of the higher investment involved with purchase of land, payment of rates, and establishment costs (MBAC 2006). In contrast, the costs of land and rates are not accounted for in the government-owned native forest industry (NIEIR 2010). Thus, the Industry Rate of Return is lower for native forests than plantations. For native forests, the owner is the State of Victoria, which means that the public are not receiving the same returns as commercial companies for the use of their land (NIEIR 2010). This means that prices do not reflect the true market, investments in the sector will not be efficient, and limited segments of the forestry sector gain a cross-subsidy (PWC 2016). The issue is whether this form of subsidy is the best way to support the forestry industry and regional areas of Victoria, and provide the greatest benefit to the public. Analyses of the commercial return for the Victorian state government and public from the native forest timber industry, however, have resulted in different conclusions (PWC 2016, Deloittes 2016).

Government commercial agencies do not pay for the use of public land and its forests and thus are not operating under conditions of competitive neutrality in the market-place (TWS 2006). In this way, sale of wood products by state agencies are not complying with the National Competition Policy that aims to remove from government commercial entities any unfair competitive advantage arising from public ownership to achieve competitive neutrality with private sector competition. Current activities of state agencies have an anti-competitive advantage because of the free use of public land for forestry and the very low return on investment for use of the timber resource. Removing this distortion to the supply side to provide price parity between wood products sourced from private and public land would allow a functioning market place that would encourage more private investment in forestry (VPA 2006).

In general, economic analyses based on financial statements show net profit after tax based on operations, but do not account for the cost associated with the loss of economic value of the ecosystem asset (PWC 2016).

(ii) Transport - Costs of transport for wood from plantations is higher in many cases because the plantation areas are further away from the pulp mill in eastern Victoria, particularly for the plantations in the west (Deloitte 2016). However, establishing a processing plant in the west has been proposed (NIEIR 2010). Additionally, timber volumes from plantations are transported more efficiently, with the harvest and haulage costs is approximately \$10 m^{-3} cheaper for plantation logs than for native forest logs (MBAC 2006).

(iii) Trade – Investments in plantation pulpwood in western Victoria were designed for the export market, and so their use for the domestic paper industry would create competition, and potentially increase prices (Deloittes 2016).

(iv) Quality – Different wood qualities are required for different product types, and each product type has a differing capacity to transition to plantation sources. Low quality wood products, such as woodchips, pallets and poles, are currently supplied by hardwood plantations and have the capacity to be supplied entirely by plantations. High quality sawn timber products are currently partly supplied by softwood plantations, and there is capacity for greater supply (PWC 2016), but the time for transition is likely to take longer. Additionally, investment is required in different sawing technologies, management of existing and new long rotation hardwood plantations for sawlogs, and development of new production capabilities. Trees grown in plantations require specific silvicultural treatments, such as thinning and pruning, to produce timber suitable for sawlogs.

(v) Quantity – Sufficient quantity of wood for different product uses needs to be assured to support industry. Currently, the majority of hardwood plantations are managed for pulplogs, both silviculturally and economically. Structural grades of timber are produced by softwood plantations. Appearance grade hardwood sawlogs are more difficult to produce in plantations. Plantations are better suited to achieve high levels of productivity with increases in the scale of output and more consistent quality. Current hardwood plantations in the Central Gippsland and Dandenong FMAs supply about 280,000 m^3, of which 34,000 m^3 yr^{-1} are D+ sawlogs. Plantations are not currently supplying A and B grade sawlogs. Hence, existing plantations in the region do not currently have the capacity to supply the quantity or quality of sawlogs to replace those produced from native forests. Establishment of new hardwood plantations have the potential to produce A and B grade sawlogs suitable for appearance grade sawn timber or surface veneer products if they are specially managed, including thinning and pruning and a rotation of 25 – 35 years (MBAC 2006). Sawmills would need to be new or reconfigured with different sawing technologies to suit the smaller and faster grown timber from plantations.

(vi) Security of supply – Industries require security of supply of raw materials to allow investment, particularly in improving technology. Plantations that have their main purpose as wood production provide a greater security of supply (NIEIR 2010).

(vii) Employment - Scenarios of changes in employment as a result of protection of native forests and increase in plantations suggest an overall increase in jobs due to security of wood supply from plantations. Security allows investment in new processing technologies and value-added products from the plantations. Additional jobs would be created for maintaining protected forest areas and new opportunities in tourism and recreational use of public forests (NIEIR 2010). Evaluation of opportunities for industries to provide economic development for the State's regions showed that native forestry provided a poor investment in terms of economic return or employment. The average net profit margin was 1.4% over the last 10 years (PWC 2016).

Native forestry is a primary production industry consisting of growing and harvesting trees (defined by the ABS, see appendix A2.3). Employment in this industry within the study area is estimated to be 200 – 300 people, based on the proportion of either area or volume harvested within the study area compared with the whole of VicForests (see Table 6.3), or 152 people based on state statistics (Schirmer et al. 2013). **On a state basis, the softwood and hardwood forestry industry (growing, harvesting and haulage) employs more than twice as many people as the native forestry industry** (Schirmer et al. 2013).

The forestry industry, as defined by the ABS, does not include processing as this is a manufacturing industry. Most primary and secondary processing occurs outside the study area, with the main destination being the Maryvale Pulp Mill. However, some primary processing occurs in three small to medium sawmills (20 to 55 employees each, total of 107) within the study area at Yarra Junction, Noojee and Powelltown.

(viii) Co-benefits - Carbon storage can be increased if stocks are accounted in protected native forests and newly established long rotation plantations on previously cleared land, thus contributing to state and national abatement targets.

(ix) Management of the forest estate – Land requires a certain level of management to maintain ecosystems, irrespective of the land use. Such management includes road maintenance, fire management, visitor facilities, and weed and pest management. Investment for these management activities needs alternative sources, for example from tourism and carbon abatement. Proposals for investment in tourism in the region have been developed (VFA 2006).

Detailed proposals for a transition strategy for the forest industry have been developed that provide a secure source of wood, transition of employment, and on-going management of the forest. The proposal for a protected area network in eastern Victoria would protect old-growth forest, water catchments, habitat for species, and connectivity for species within reserved areas (VFA 2006). There are precedents, at previous times and locations in Australia and overseas, when supply of native forest timber has been reduced and plantation timber has filled the gap. It has been concluded that commercially viable plantations could fill the gap in the Central Highlands and would provide positive economic returns for the region (PWC 2016).

Hardwood plantations have not yet provided a sawlog resource of sufficient size or quality to significantly reduce demand on native forests, and the industry for solid hardwood products is not yet operated in a profitable and sustainable manner (Nolan et al. 2005). Investment in research and development to support a hardwood plantation industry for high-value timber has been slow, but this is required to reduce dependence on native forest timber (Brown and Beadle 2008). Plantations for high-value timber require different management to those producing pulp; longer rotations, different species, selection for wood properties, more sophisticated stand management, wood drying techniques and processing facilities. Research on hardwood sawlog processing has demonstrated that drying and sawing of plantation-grown eucalypts managed with various silvicultural strategies is technically feasible with a range of sawing equipment currently used for either softwood or hardwood processing (Washusen and Innes 2008). Hence, solid wood products produced from new hardwood plantations should support a profitable industry, focussed on supplying high quality and high value appearance grade timber. However, investment in these longer rotations does attract greater risk (Nolan et al. 2005).

7. Agriculture

7.1 Introduction

The study area contains a significant area (96,041 ha) used for agricultural production (Table 3.1). Agricultural production relies on a variety of inputs: labour, land and other capital assets, energy and fertilizers. In addition to these inputs, which are already accounted for in standard economic statistics, agricultural production relies on a range of ecosystem services.

The SEEA Experimental Ecosystem Accounts (UN *et al.* 2014b) identifies "food provisioning" as one of the ecosystem services, but this is related to gathering of wild foods (for example, picking of wild berries or hunting wild animals), not those grown in commercial agriculture. Commercial agriculture, however, does use ecosystem services. These are identified in the Common International Classification of Ecosystem Services (CICES 2016) as, "Provisioning services for crop production" and "Provisioning of fodder for livestock". The ecosystem services used for crop production and fodder for livestock include pollination, abstraction of water, soil nutrient uptake, and nitrogen fixation (UN *et al.* 2014b, p. 62). Some of these services would have been generated on the land used for agricultural production (soil water and nutrient uptake), whereas others may have been generated elsewhere (for example, pollination). For this account, all ecosystem services produced (supplied) were allocated to the agricultural land cover and all use was allocated to the agricultural industry.

Where the value of ecosystem services to crop production have been estimated in other regions, it has been large, for example:

- In the United Kingdom, the value of pollination to agriculture was £600 million in 2010 (Hanley et al. 2013).
- In the Netherlands, for the province of Limburg, the value of ecosystem services used for fodder and crop productions was over €40 million (Remme and Hein 2016).
- In Australia, in the Great Barrier Reef region, the value of ecosystem services for agriculture was $1,344 million in 2012-13 (ABS 2015a).

The current study used the resource rent approach (see Section 2.3) to valuing the ecosystem services used in agricultural production, which was the approach used by the ABS (2015a). To estimate the value of ecosystem services to agriculture using the resource rent approach, a variety of data are needed, including information on the physical volume of production and costs of production. Information about the physical volume of agricultural production is available for ABS statistical areas (ABS 2012). The value of agricultural production is available for Victoria as a whole, and by using the physical volume data, an estimate for the value was made for the study area. Information on the costs of production at a national level is available from the ABS from the national accounts.

Presented below are the data sources, methods and estimates of the physical volume of agricultural production, the gross value of agricultural production, and the value of the contribution of ecosystem services to the gross value of agriculture production.

7.2 Data sources and methods

Agricultural production and costs were obtained from the ABS sources:

- ABS (2016) Value of Principal Agricultural Commodities Produced, Australia, 2010-11. ABS cat. no. 7503.0
- ABS (2011). Agricultural Commodities, Australia, 2010-11. ABS cat. no. 7501.001 – physical volume of commodities produced by Statistical Areas Level 2 and Level 4 (SA2 and SA4)
- ABS (2011). Value of Principal Agricultural Commodities Produced, Australia, Preliminary, 2010-11. ABS cat. no. 7501.001 – value of agriculture for Victoria as whole.
- ABS unpublished data on the costs of production and calculation of resource rent (see Appendix 7)

The physical boundaries of the ABS SA2 and SA4 (statistical areas) are shown in Figure 7.1. The SA2 boundaries are nested within SA4 boundaries. The study area was mapped against the ABS boundaries and the area of the SA2 within this was calculated (Table 7.1, Figure 7.1).

The value of production in monetary terms for the years 2010-11 to 2014-15 was calculated by multiplying the production from each SA4 by the proportion of each SA4 within the study area and summing to get a value for the study area.

The resource rent from agricultural production for all Australia was used as the starting point for calculations for the Central Highlands. A simple proportion of the gross value of agricultural production in the Central Highlands compared to total Australian production was multiplied by the total Australian resource rent (ABS data is given in Appendix Table A7.1). This calculation assumes that the percentage of the gross value of agricultural production from the Central Highlands compared to Australia is a useful scaler, and that the level of resource rent generated from the Central Highlands is not different from the rest of Australia. Neither assumption is likely to be accurate but is probably broadly indicative of the level of services provided.

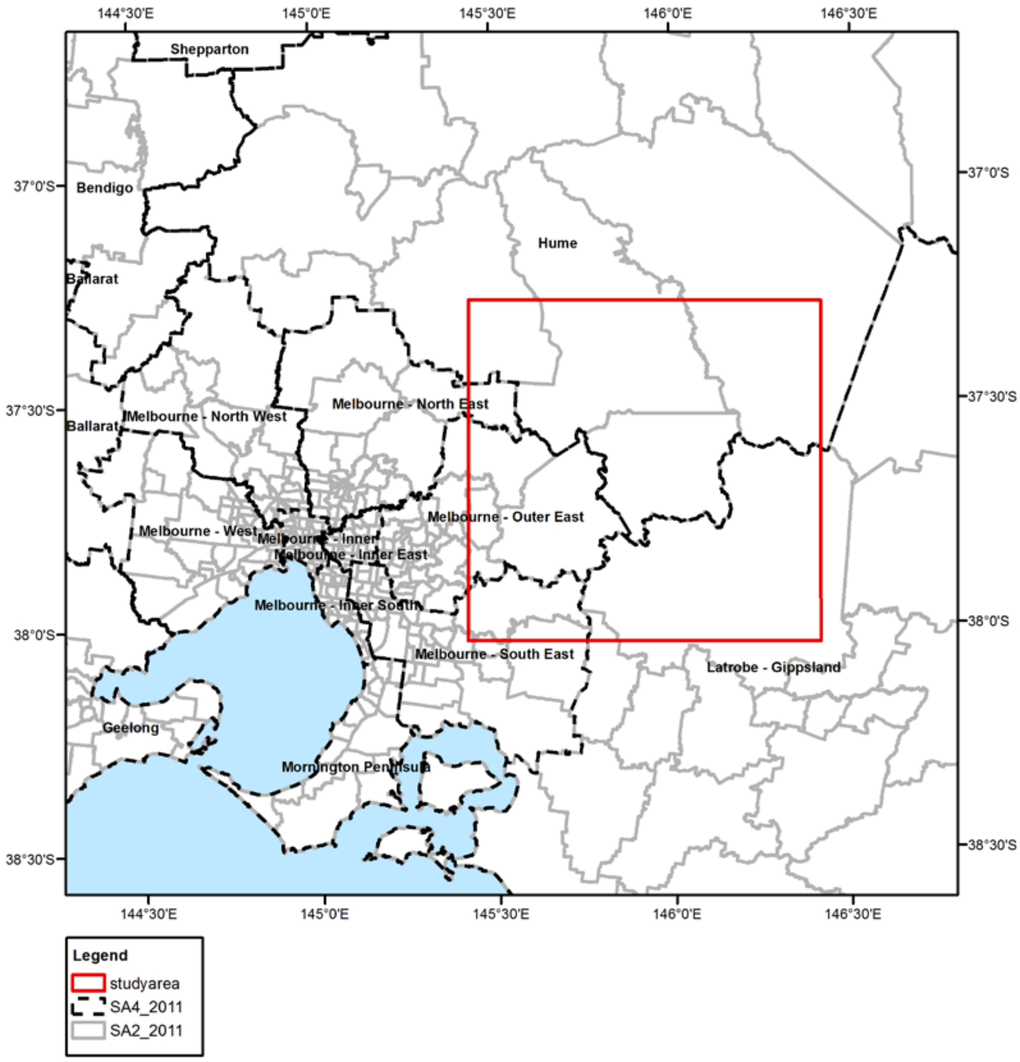


Figure 7.1 Map of ABS Statistical Areas 2 and 4 within the study area

Table 7.1 ABS Statistical Areas: percentage within study area

SA4	SA2_Name11	Total Area SA2 (ha)	Area of SA2 inside study area (ha)	Area of SA2 inside study area (%)
Hume	Alexandra	211,788	126,573	59.8
Melbourne-South East	Beaconsfield - Office'	4,171	252	6.0
Melbourne-Outer East	Belgrave - Selby	5,562	2	0.0
Melbourne-South East	Bunyip - Garfield	37,294	9,632	25.8
Latrobe-Gippsland	Drouin	32,659	3,706	11.3
Melbourne-South East	Emerald - Cockatoo	37,053	34,218	92.3
Melbourne-Outer East	Healesville - Yarra Glen	36,939	27,549	74.6
Melbourne-North East	Kinglake	31,940	13,917	43.6
Melbourne-Outer East	Lilydale - Coldstream	10,935	1,715	15.7
Hume	Mansfield (Vic.)	392,530	96,626	24.6
Melbourne-Outer East	Monbulk - Silvan	6,853	5,831	85.1
Latrobe-Gippsland	Mount Baw Baw Region	275,497	204,603	74.3
Melbourne-Outer East	Mount Dandenong - Olinda	8,188	447	5.5
Melbourne-South East	Pakenham - North	3,671	936	25.5
Hume	Upper Yarra Valley	85,852	85,428	99.5
Melbourne-Outer East	Wandin - Seville	11,170	10,278	92.0
Melbourne-Outer East	Yarra Valley	73,367	72,846	99.3
Hume	Yea	147,370	41,098	27.9
Total		**1,412,840**	**737,072**	

7.3 Results

The gross value of agricultural production in the Central Highlands was calculated for 2010-11 to 2014-15 (Table 7.2). The value of production has increased from $435.7 million in 2010-11 to $494.6 million in 2014-15. In contrast, production from the Central Highlands as a percentage of production for Australia has decreased slightly over the same period from 0.95% to 0.92%. The value of the ecosystem services used by agriculture and the value of the products has fluctuated with the value of the agricultural production (Table 7.3).

Table 7.2 Gross value of agricultural production ($m) for Australia, Victoria and the Central Highlands

	2010-11	2011-12	2012-13	2013-14	2014-15
	($m)	($m)	($m)	($m)	($m)
Australia	46,020	46,687	48,048	50,866	53,625
Victoria	11,618	11,324	11,631	12,683	13,144
Central Highlands	435.7	449.9	410.3	474.1	494.6
Central Highlands as % of Australia	0.95%	0.96%	0.85%	0.93%	0.92%

Table 7.3 Central Highlands, estimated IVA, supply of agricultural products and use of ecosystem service by agriculture.

	2010-11	2011-12	2012-13	2013-14	2014-15*
	($m)	($m)	($m)	($m)	($m)
Output from agricultural production	511.6	604.5	571.1	658.6	663.1
Industry value added#	241.7	282.6	261.7	311.9	297.3
Regulating services used by agriculture‡	58.4	84.9	100.1	120.5	103.5

** Calculation for 2014-15 used an average Resource Rent as a % of Total industry output from previous years (Table A7.1), because data were not available for that year from the ABS.*

 # IVA equals Gross operating surplus & mixed income (Table A7.1) multiplied by Central Highlands as % of Australian Gross value of agricultural production (Table 7.2).

‡ Provisioning service equals Resource Rent (Table A7.1) multiplied by Central Highlands as % of Australian gross value of agricultural production (Table 7.2).

8. Tourism

8.1 Introduction

The Central Highlands are used for various recreational purposes. The region includes national parks and other reserves, as well as wineries and other tourist attractions. As an example, visitation to national parks in the study area was approximately three-quarters million in 2010-11 (Varcoe et al. 2015). The SEEA EEA and CICES define tourism and recreation as a cultural service (UN 2014b p. 68). The use of these services by people can be assessed as part of the value to the area of the consumption by tourists. This consumption relies not just on the ecosystem services, but also capital, labour and other inputs from the industries supporting tourists (for example, restaurants and accommodation).

Tourism is not defined as an industry in the SNA or SEEA but is an activity associated with the consumption of a particular range of goods and services. Internationally, there is a framework for Tourism Satellite Accounts (TSA) based on the SNA concepts and there is an annual Tourism Satellite Account for Australia (ABS 2014b) as well as for the States (TRA 2015). A SEEA for tourism is in development. In 2013-14, the direct contribution of tourism in Victoria to GDP was $8.5 billion (TRA 2015, p. 10).

8.2 Data sources and methods

The State of Victoria has produced regional tourism satellite accounts (Tourism Victoria 2015a). The accounts provide information for each of the regions defined by Tourism Victoria. These regions are based on local government areas and built from ABS SA2 boundaries. The tourism regions that overlap with the Central Highlands study area include, Yarra Valley and Dandenong Ranges (53.3% within the study area), Gippsland (11.1%) and High Country (5.7%). The output and IVA for the Central Highlands was estimated by applying the fraction of the area from these regions to the data from the regional tourism accounts.

The cultural and recreational ecosystem services were estimated using the resource rent approach, which was used by the ABS in the ecosystem accounts for the Great Barrier Reef (ABS 2015a). The ABS estimates were built up from lower level spatial data. A top-down approach was used in the current study, as the lower level data were not available. Individual coefficients of Resource Rent to Industry Value Added from the Great Barrier Reef account for the years 2006-07 to 2012-13 were applied to the data from the Central Highlands. An average of the coefficients from these years, 2006-07 to 2012-13, was used for the year 2013-14 (as this time period is after the reference period of the ABS account). It is understood that the nature of tourism, and hence the resource rents, in the Great Barrier Reef is likely to be different in the Central Highlands. As such, the results presented for the ecosystem services of culture and recreation are indicative only. Use of lower level spatial data could be used to refine the estimates of these ecosystem services.

8.3 Results

The contribution of tourism to industry value added was $260 m in 2013-14 and accounted for 3,500 jobs (Table 8.1). The total output associated with tourism activity (that is, the goods and services consumed by tourists) in the study area in 2013-14 was $485 million. The value of the cultural and recreational ecosystem service in the same year was $49 million.

Table 8.1. Tourism related IVA, output and ecosystem services in the Central Highlands, 2006-07 to 2013-14.

	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14
Tourism economic indicators								
Estimated IVA ($m)	111	123	114	127	133	136	257	260
Employment ('000s)	2.7	2.9	2.9	2.9	3.3	3.2	3.3	3.5
Tourism goods and services supplied								
Output ($m)	361	402	374	416	433	443	479	485
Cultural and recreational services								
Value used ($m)	15	16	18	19	22	28	48	49

The IVA for tourism was generally depressed in Australia for the period 2006-07 to 2010-11 owing to a range of factors including the Global Financial Crisis and the mining boom (TRA 2013), which lowered demand from within Australia and from overseas. Since 2011-12, the value of tourism in Australia has increased due largely to more international tourists, particularly from China and the United Kingdom (TRA 2015). This general pattern is seen in the Yarra Valley and Dandenong Ranges, with large increase in tourism employment (8.3%) and gross regional product (9.2%) between 2011-12 and 2012-13 (Tourism Victoria 2015c), and these increases are mirrored in the study area.

9. Biodiversity

9.1 Introduction

Biological diversity is defined as the variability among living organisms from terrestrial, aquatic and marine ecosystems, and the ecological interactions of which they are part. This includes a hierarchy of diversity from genes, within species, between species, and of ecosystems (see Convention of Biological Diversity, CBD 2014a). The biodiversity of a region consists of populations of organisms, which can be considered in terms of the total number of organisms, identified threatened species that should be specially considered for conservation, and indicator species that are used to represent groups of organisms and general ecosystem condition.

A particular imperative for accounting of biodiversity arises from the Aichi Biodiversity Target 2 under the Convention on Biological Diversity (CBD 2014b) and the Sustainable Development Goals 15.5 and 15.9 (UN 2015). The aim of these targets is to place biodiversity into mainstream information systems for policy-makers (Rode *et al.* 2012). The target states that benefits from biodiversity should be included as part of national accounting or the System of National Accounts, which produces the indicator of GDP. By integrating biodiversity information into the System of National Accounts, biodiversity can be considered in economic policy, resource allocation and planning tools used in decisions of governments and the private sector. Hence, developing systems to incorporate information about biodiversity into the same accounting concepts and structures of the System of National Accounts via ecosystem accounts provides a mechanism to include the benefits of biodiversity in decision-making.

Biodiversity *per se* is not included as an ecosystem service in the SEEA Experimental Ecosystem Accounting, although habitat provisioning services are identified in some investigations (Varcoe *et al.* 2015) and conceptual frameworks (Mace *et al.* 2012). Under the CICES (2016) classification, there is a regulating service that includes maintenance of biological condition, and includes lifecycle maintenance, habitat and gene pool protection. In this report, the contribution of species level diversity to ecosystem services is clear for the tree species used for timber provisioning and carbon sequestration services (Sections 5 and 6). There are also cultural and recreational services provided by particular species, such as the iconic Leadbeater's Possum, which is the animal emblem of Victoria, and the Helmeted Honeyeater, which is the bird emblem. However, quantifying the cultural and recreational services provided by these species has not been attempted in this report.

In addition to the biodiversity accounts for species, biodiversity is also included in the SEEA ecosystem extent and ecosystem condition. Biodiversity is one of the characteristics used in the ecosystem condition accounts, while the number of types and extent of ecosystems shown in the ecosystem extent account also could be a type of biodiversity account at the ecosystem level (Vardon *et al.* 2015).

Biodiversity accounts quantify the stock of species or ecosystems at a particular point in time in terms of properties described by their type, quantity and quality, for example, the ecosystem composition, structure and function. Composition of the ecosystem refers to taxonomic grouping of species occurring within the region. Structure of the ecosystem, in the case of the forests in the Central Highlands, includes the number of vegetation layers within the forest, the size distribution of trees, and the age distribution of areas of forest due to disturbances. Function of components of the ecosystem includes abundance of large trees with hollows for nesting by cavity-dependent species, old trees with decorticating bark that affords habitat for insects and other arthropods, and occurrence of particular plant species such as *Acacia* as food sources. Using these properties of ecosystems, the objective of biodiversity accounting is to apply consistent classifications over time to identify change in condition of populations and their habitat, threatening processes, and extinction risk.

In accounting for biodiversity, it is not practically possible to measure all components of biotic composition, structure and function of ecosystems and to quantify change over time. Identifying the critical components of the ecosystem, in terms of species and their relationship with habitat attributes, is key to obtaining information about the status of biodiversity and its change over time.

In developing biodiversity accounts for the Central Highlands, data on the following components of the ecosystem were used to assess condition and change over time in biodiversity.

1. Total number of species listed as occurring in the study area.
2. Threatened species assessed by identifying species listed under different threat classification systems, and change in their classified threat status.
3. Species abundance and richness assessed in ecosystems of different types and condition, and monitored to assess change over time.

In an initial assessment of species level biodiversity in the Central Highlands, we have concentrated on the group of arboreal marsupials in the montane ash forests. The selection of a group of species to indicate condition and change in biodiversity was based on the following criteria:

- species that can be monitored repeatedly over many years,
- species that have defined relationships with habitat variables,
- populations that change in response to disturbance events,
- species that are indicative of other components of ecosystem condition,
- species may be specialists that indicate a specific component of ecosystem condition, or generalists that are representative of many other species.

For the current study, species status, as determined by State, national and international criteria and procedures, has been used to create tables indicating the general condition of biodiversity at the species level within the study area. In addition, site level information has been used to show the relationship between the abundance of arboreal marsupials and the time since disturbance by either fire or logging events.

9.2 Total number of species

An estimate of total number of species in the region was determined from records documented in the Atlas of Living Australia (ALA 2015). Total species richness was determined from the area of the study region drawn in the Atlas of Living Australia and the total species list extracted for this area (Table 9.1). This is not a complete inventory of all species, particularly lower order taxa of plants and animals, and microorganisms. Hence, quantifying change over time of all species in their entirety is not possible with the available data. For this reason, components of biodiversity need to be selected that provide information about ecosystem condition across temporal and spatial scales.

Table 9.1. Total number of species in each taxon within the Central Highlands study area, as recorded in the Atlas of Living Australia

Taxon	Number of species
Mammals	74
Birds	319
Reptiles	47
Amphibians	23
Invertebrates	2,758
Plants	2,269
Fungi	643
Bacteria	9
Protozoans	11

9.3 Threatened species list

9.3.1 Data sources and methods

Species identified in various categories of threat and under different State, national and international systems were catalogued. The list was collated from the species listed in:

1. VicForests Sustainability Report 2014-15 and VicForests Operating Procedures Regulatory Handbook 2014, which cover Victorian land under the jurisdiction of VicForests (VicForests 2014-15, 2014).
2. Parks Victoria Plan of Management for Yarra Ranges National Park (Parks Victoria 2002).
3. Atlas of Living Australia for the defined area of the study region, with species filtered by threat category (ALA 2015).

All species found in these tables were checked against occurrence in the study area based on the Atlas of Living Australia. The conservation status of each species was checked in the Atlas, and included if they were listed under any of the following threat classification systems:

1. International: IUCN Red List of Threatened species, based on global criteria for assessment of species status, trends and threats (IUCN 2015). Criteria are specific to assessing risk of extinction.
2. National: Australian Government Environmental Protection and Biodiversity Conservation Act (EPBC Act 1999) lists of Threatened Fauna and Flora (DotEE 2016), with the criteria for listing defined in the EPBC Regulations 2000 (DotE 2000). This is a national scheme for environment protection and biodiversity conservation, especially protection of matters of national environmental significance. Legislated listings include threatened fauna, flora, ecological communities, critical habitat, and key threatening processes.
3. State: Victorian Government Flora and Fauna Guarantee Act (1988) (FFG), and the Victorian Advisory Lists for Threatened Vertebrate Fauna and Flora (Victorian Government 2015b). The FFG provides the legislated listing of threatened species and communities, and threatening processes. The process of listing involves nomination of a species by the public, assessment against criteria for eligibility by a scientific committee, public comment, recommendation by the committee, decision by the Minister, and publication of an Order in the Victorian Government Gazette. The Threatened Species Advisory Lists are based on technical information and advice from experts, and are reviewed periodically. This is not a statutory listing and does not involve legal requirements. The information in these lists is used in planning processes for national park management, local government, regional catchments, and setting priorities for actions to conserve biodiversity.

Records for each species were checked for the dates of new listings and changes in status of the listed category over time under the IUCN Red List and EPBC regulations, which provide historical information about listings. From these data, a table of change over time in the threat categories was constructed. Historical information is not provided for the Victorian Fauna and Flora listings.

9.3.2 Results

Condition of biodiversity was assessed in terms of the number of species classified as threatened, the threat categories, and the change in categories over time. The full list of threatened species, in each of the international, national and State classification systems, and their threat category is given in Appendix Table A9.1. A summary of the numbers of species listed as vulnerable, endangered or critically endangered in each classification system is shown in Table 9.2.

Major differences occurred between the classification systems in number of species listed in each category of threat status, and these differences are due to several reasons:

1. Criteria for listing under each category differ between the systems.
2. Assessment of threat status differs depending on the spatial scale of regional, State or national extent of the species.
3. Assessments for each system occur at different times and some are updated more frequently than other systems.
4. Not all species have been assessed for each system, in particular, the IUCN have not assessed all plants and invertebrates, and thus total number of species listed differs.
5. Listing is based on nomination and so is not necessarily comprehensive or representative.

These differences result in different species being listed in each of the systems. Hence, there are more species in the 'Total' column in Table 9.2 than in any of the classification systems columns.

The change over time in the listing of the threat categories indicates change in the conservation status of the species. This may be indicative of the direction of change in the overall status of biodiversity. Change in status of each species was analysed over 5-year periods for the IUCN and EPCB classifications (Table 9.3).

The species listed as extinct by the IUCN is the Dandenong Freshwater Amphipod (*Austrogammarus australis*), which was first listed as extinct in 1994, but then was found in 2014 and listed as critically endangered. The species listed by the EPBC as regionally extinct are the Eastern Bettong (*Bettongia gaimardi*) and the Eastern Quoll (*Dasyurus viverrinus*) that no longer occur as wild populations on the mainland.

Table 9.2. Number of species listed as vulnerable, endangered or critically endangered in 2015 in the Central Highlands study area under each threat classification system

	International	National	State		Total number of
	IUCN	EPBC	FFG	Advisory List	species listed*
Mammals	4	6	15	14	16
Reptiles	1	1	4	5	5
Amphibians	3	4	5	6	6
Fish	4	4	4	6	6
Birds	4	4	27	28	33
Invertebrates	7	1	14	26	29
Plants	0	16	37	69	71

**Total number of species listed includes all species that are listed in at least one threat classification system. Note that species can be listed under each classification system and hence the total is not a sum of the columns.*

Table 9.3a. Change over time in the numbers of species listed under the IUCN Red List of threatened species categories in the Central Highlands study area

	Extinct	Critically Endangered	Endangered	Vulnerable	Near Threatened	Least Concern	Lower Risk	Total
1990	0	0	0	2	2	0	12	16
1995	1	0	6	10		0	10	27
2000	1	1	7	15	1	1	14	40
2005	1	3	8	13	5	8	2	40
2010	1	4	7	10	11	8	0	42
2015	0	8	6	9	9	12	0	44
Net change 1990 to 2015	0	8	6	7	7	12	-12	28

Table 9.3b. Change over time in the numbers of species listed under the EPBC Act list of threatened species categories in the Central Highlands study area

	Regionally Extinct	Critically Endangered	Endangered	Vulnerable	Total
2000	2	0	12	14	28
2005	2	1	13	15	31
2010	2	1	13	18	34
2015	2	5	14	17	38
Net change 1990 to 2015	0	5	2	3	10

9.3.3 Discussion

The trend over time of increasing numbers of species added to the list has three likely causes. First, with increasing work on inventorying species, more are identified as being threatened. However, there are also the cases where more individuals of listed species have been found, such as the Dandenong Freshwater Amphipod. Second, criteria for the classifications and methods of inventorying may have changed over time. Third, numbers of individuals of species are declining due to loss of habitat and competition from introduced species, so that their threat status has increased. It is difficult to distinguish these causes in terms of the total number of species listed. The process of listing by nomination from the general and scientific community does are not necessarily provide comprehensive or representative lists of species.

The change in category of species, however, is more likely to be due to increased threat. This process is illustrated by the increase in the number of critically endangered species by 2015. In the last 5 years, the following species had their threat classification increased to critically endangered: Leadbeater's Possum, Regent Honeyeater, Yellow-tufted Honeyeater, Round-leaf Pomaderis, and Mount Donna Buang Wingless Stonefly. In the previous 15 years, the following five species also had their threat category increased to critically endangered in either the IUCN or EPBC classifications: Golden Sun Moth, Barred Galaxia, Baw Baw Frog, Spotted Tree Frog, and Mountain Pygmy Possum. In the other threat categories, some species have remained in the same category, while others have increased their threat category and thus species are moving through the classification system as population numbers decline.

9.4 Site data from the Central Highlands

9.4.1 Introduction

Estimating change in the status of biodiversity in the Central Highlands study area is possible for one taxonomic group because research data exists from long-term monitoring. The abundance of arboreal marsupials has been monitored in the montane ash forests for 28 years (Lindenmayer 2009). This group of animals is important because they are highly vulnerable to changes in condition of the forest, such as composition and structure, which result from both human and natural disturbance events. Monitoring data also exists for birds at the same sites that could be analysed to produce similar accounts.

The key habitat requirement for arboreal marsupials is the presence of hollow-bearing trees (HBTs) to provide nest or den sites; the animals cannot survive in forests without these old trees. The abundance of HBTs depends on the age of the forest, the type of stand-replacing disturbance event – either logging or fire, the previous stand structure, and environmental variables like slope and topographic wetness. Logging is the main form of human disturbance in the wet forests of the Central Highlands, using the common practice of clearfell harvesting and slash-burning. The number of residual trees is highly variable and has changed over time as harvesting practices have changed. Different species of arboreal marsupials select different morphological forms of trees with hollows as den sites, ranging from intact, living trees through to highly decayed, dead trees (Lindenmayer 1991b). Animals regularly swap between dens in different trees, but rarely co-occur in the same trees. Thus, sites with numerous and varied hollow-bearing trees are required to meet the behavioural and resource requirements of arboreal marsupials (Lindenmayer *et al.* 1991a).

Arboreal marsupials require a complex forest structure for their habitat, including large old trees and multiple layers of vegetation in the mid-storey and understorey to provide transport routes for movement horizontally and vertically within the forest, and a range of food sources. Species have different requirements for food sources, but generally include a range of understorey plants, insects and sap from acacia and eucalypt trees. The critically endangered species, Leadbeater's Possum, requires a specific habitat of montane ash forests with large decayed trees with hollows to provide den sites, and a dense understorey of *Acacia spp.* for food (Lindenmayer 2009). The other species of arboreal marsupials have broader resource and habitat requirements and occur in a wider range of environments throughout eastern Australia. The characteristics of complex forest structure also provide the most diverse habitat for a large range of other species, and hence are indicative of other components of biodiversity.

We analysed the site data of animal occurrence to investigate the abundance of animals and species in relation to forest age class and change over time. The relationship between abundance of animals and hollow bearing trees was assessed. Change over time of this key habitat attribute was indicative of the effect of disturbance events on the condition of the forest as habitat for arboreal marsupials.

9.4.2 Data sources and methods

A total of 161 sites have been monitored for arboreal marsupials in the Central Highlands study area since 1987-88. Sites were located in a stratified random design according to forest age and other environmental factors. In the current analysis, forest age was categorised into old growth (Old Growth), 1939 regrowth (Fire 1939), mixed age (Mixed), logged (Logged), and young regrowth since the 2009 fire (Fire 2009). Old growth had minimal signs or records of human disturbance and trees were assumed more than 100 years old. Regrowth after the 1939 fire was identified from maps of the fire extent and the presence of trees approximately 75 years old. The mixed age category consisted of sites with variable proportions of trees of different ages, with some sites having old growth elements. The logged age category consisted of sites where the majority of trees were harvested in 15 to 40 ha coupes in a single operation, under the silvicultural practices of clearfell, clearfell salvage, seed tree or road construction. Subsequent high-intensity burning of slash on-site removed debris after harvesting and created an ash bed for regeneration, which was often achieved by artificial re-seeding (Flint and Fagg 2007). Within harvested coupes, a few trees were retained as seed trees, habitat trees or left because they were unmerchantable. The logged sites selected for monitoring did have some HBTs to ensure some likelihood of animals occurring, and as such were not necessarily representative of all logged areas. Young regrowth since the 2009 fire consisted of sites from any of the initial age categories where high severity fire in 2009 killed the majority of trees and resulted in regeneration.

The sites cover a wide range in environmental conditions, in slope (inclination: 2 – 38°), elevation (220 – 1040 m), topographic position (gully, midslope, ridge), and aspect (north-westerly and south-easterly). Sites are monitored on a rotating schedule with a subset of sites selected (n = 19 to 85); these were not necessarily the same sites each year, nor the same number of sites per forest age category.

The seven species of arboreal marsupials recorded in the monitoring programme are Leadbeater's Possum (LBP), Feathertail Glider (FTG), Greater Glider (GG), Yellow-bellied Glider (YBG), Sugar Glider (SG), Mountain Brushtail Possum (MBP) and the Common Ringtail Possum (RP). Numbers of animals were recorded at each site using the stag-watching method. This involves counting the number of individuals of each species emerging from every tree with an identified hollow on a 1 ha site (Lindenmayer et al. 1991a). All hollow bearing trees at a site are monitored simultaneously by a team of observers for 1 hour at dusk to ensure the detection of both small- and large-bodied species that have different emergence times. Data used are for 'On Site', that is the specific 1 ha site, and not observations of animals in the surrounding forest.

A hollow bearing tree (HBT) was defined as any tree greater than 0.5 m diameter at breast height and containing an obvious cavity, which is determined by visual inspection with binoculars. The suitability of an observed cavity for a particular species related to its internal characteristics is not known, and this will change over time. Therefore, the actual number of trees available for nesting by different species of arboreal marsupials is less than the number of trees identified and monitored as HBT. HBTs are classified by their form according to the condition of the tree. Classes 1 to 8 refer to standing trees containing cavities, with increasing degree of senescence, and form 9 refers to a collapsed tree. Surveys of the HBTs at each monitoring time identified transitions in form classes of the trees and the number of trees per site lost due to collapse or gained by recruitment. HBTs were considered to provide habitat if they were form 1 to 8. Trees of form 9 were functionally collapsed and no longer have viable hollows, and so were considered lost from the population.

Analysis of the abundance of animals and HBTs at sites showed that there were more animals than HBTs at some sites. This meant that a binomial function could not be used because the occurrence of an animal was not simply presence / absence for each HBT. Some HBTs had more than one animal. Therefore, the analyses used a Poisson distribution so that the mean number represented the probability of occurrence of an animal within the 1 ha site.

Differences in the abundance of animals and HBTs between sites and forest age categories were tested using a generalized linear mixed model with a Poisson distribution and log link function to give a geometric mean for each site or age category (Genstat 18th edition 2015). These data include all sampling years at each site, that is, repeated measures at sites, but there are different numbers of sampling years at each site and they occur at different times. Therefore, site was included in the model as a random effect to remove confounding between the abundance of animals and forest age. Forest age at each site was defined by two types of factors: (i) an assigned age category with five levels; and (ii) age calculated at the year of sampling for each site and year, that is, age of a site changing continuously. Both age category and age at a sampling time were included in the model as fixed effects. This assumed that sampling time was related to previous sampling time and so removes the effect of variation over time due to the year of sampling within sites. Mean numbers refer to the probability of occurrence of an animal at a 1 ha site. The relationship between the abundance of animals and numbers of HBTs was based on data from the same sites and sampling years in the monitoring schedule.

The dynamics of the measured population of HBTs was based on data from the same set of sites in the monitoring programme but trees were assessed for hollows at times additional to the animal monitoring schedule. Numbers of HBTs were considered as independent trials not affected by sites and were analysed as the change over time in the presence or absence of trees each year. Loss in HBTs was analysed as relative to the number of HBTs at the site, that is, the population from which loss could occur. Gain in HBTs could not be calculated as a proportion because there were no information about the total population of trees at a site that potentially could form hollows.

9.4.3 Results

9.4.3.1 Abundance of animals and species

Abundance of animals, in terms of the total number of individuals of all species of arboreal marsupials per 1 ha site, averaged over all sampling times, ranged from 0 to 6 with a mean of 2 animals. Sites had significantly different numbers of animals (deviance ratio = 3.92; $\chi^2_{prob} < 0.001$; df = 160, 747).

Abundance of animals was assessed in relation to age of the forest, as this is a major determinant of their spatial variation and an indicator of how arboreal marsupials are influenced by stand-replacing disturbances. Results show that old growth had significantly higher abundance of animals and species, and young regrowth had significantly lower abundance (Table 9.4).

Changes over time in abundance of animals and species were modelled from the year of sampling of each site and the assumed year of regeneration for each age category: 1900 for old growth; 1939 for Fire 1939; 1960 for Mixed; 1980 for Logged; and 2009 for Fire 2009 (Table 9.5, Figure 9.1). The year for old growth is probably an underestimate of age for some stands, and the mixed aged stands are highly variable but a mean age had to be assumed. The highest abundance of animals and species occurs in old growth forest, shown by the mean height of the curves. Change over the years of sampling shows a decline in abundance of animals and species, illustrated by the slope of the curves. Slopes of the curves were not significantly different between the forest age categories for animals or species.

Other factors, in addition to forest age, that may affect species occurrence and animal abundance are the forest type (Mountain Ash, Alpine Ash and Shining Gum) and land use (Conservation or Production forest).

- Forest type had a significant effect on number of species, number of animals and LBP only in old growth forests, with significantly higher ($P < 0.01$) numbers of animals in Mountain Ash compared with Alpine Ash or Shining Gum.
- The Greater Glider was the only species that was significantly ($P<0.05$) more abundant in Mountain Ash forest of all age categories than in Alpine Ash or Shining Gum.
- The numbers of HBTs were significantly higher ($P < 0.01$) in Mountain Ash than in Alpine Ash in 2009 regrowth, and were significantly lower ($P < 0.01$) in Shining Gum in 1939 regrowth.
- Land use did not have a significant effect on numbers of animals.

Conditions in which particular species do not occur include:

Leadbeaters' Possum (LBP) – young 2009 regrowth, Alpine Ash old growth forest

Feathertail glider (FTG) – young regrowth from logging or 2009 fire

Yellow-Bellied Glider (YBG) – young 2009 regrowth, rare in regrowth from logging

Ringtail Possum (RTP) – young 2009 regrowth

Sugar Glider (SG) – rare in young 2009 regrowth

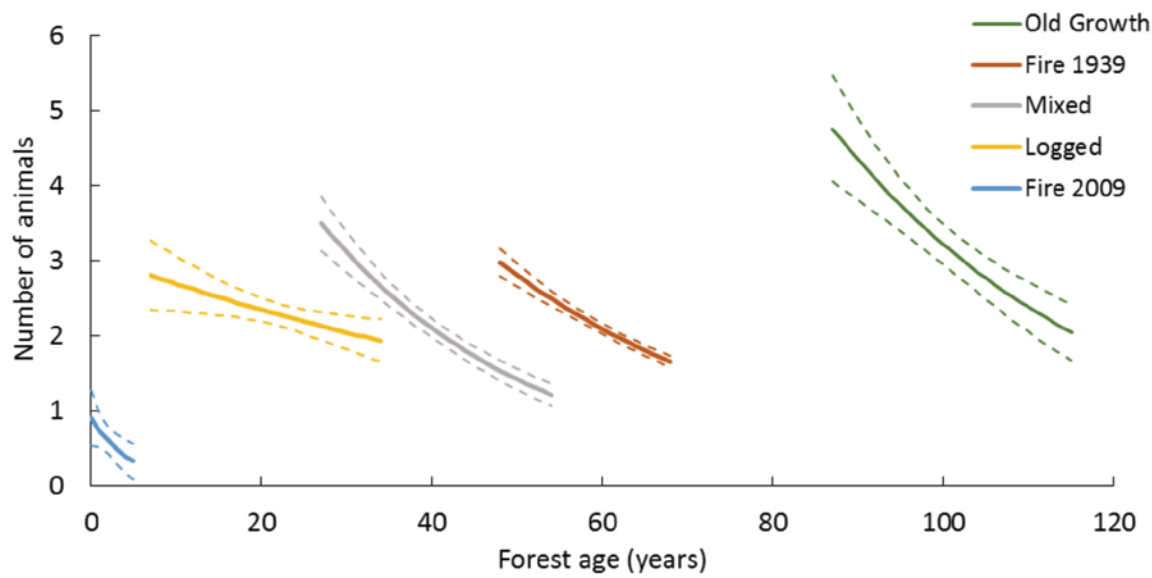
Table 9.4. Summary of mean abundance of animals, species and individual species in forest age categories and statistical differences between categories (calculated as a geometric mean for the middle year of the sampling time, and based on logarithmically transformed data).

Age	Animals	Species	FTG	GG	LBP	MBP	RTP	SG	YBG
OG	3.11_{a}	1.98_{a}	0.108_{a}	1.07_{a}	$0.45_{a,b}$	0.78_{a}	$0.060_{a,b}$	0.18_{a}	0.360_{a}
Fire39	1.99_{b}	1.29_{b}	0.043_{a}	0.61_{b}	0.27_{b}	0.73_{a}	0.019_{b}	0.18_{a}	0.094_{b}
Mixed	1.99_{b}	1.28_{b}	$0.031_{a,b}$	0.72_{b}	0.25_{b}	$0.65_{a,b}$	$0.033_{a,b}$	0.18_{a}	0.062_{b}
Logged	2.28_{b}	1.42_{b}	$0.0026_{b,c}$	0.36_{c}	0.62_{a}	0.96_{a}	0.11_{a}	0.15_{a}	$0.043_{b,c}$
Fire09	0.60_{c}	0.56_{c}	0.0002_{c}	0.21_{c}	0.00_{c}	0.37_{b}	0.0002_{b}	0.0005_{b}	0.0005_{c}
df	4, 298	4, 288	4, 328	4, 300	4, 279	4, 319	4, 283	4, 311	4, 200
Fstat	14.15	8.15	2.65	9.71	8.27	3.47	3.41	n.s.	3.56
Fprob	<0.001	<0.001	0.034	<0.001	<0.001	0.01	0.01	n.s.	0.01

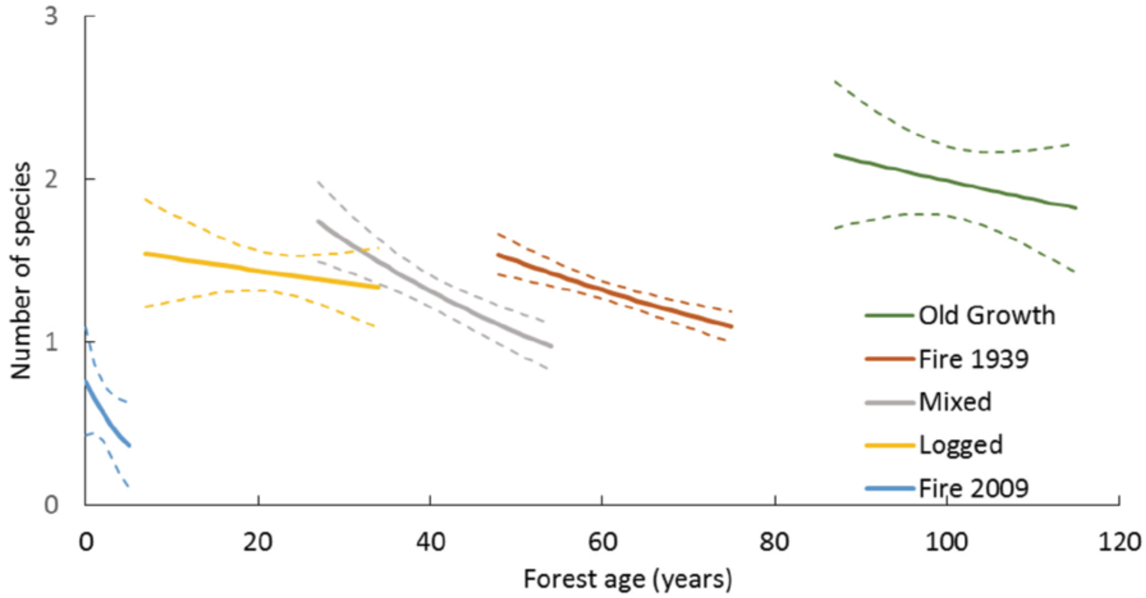
Subscript letters ($_{a, b, c, d}$) after the numbers within columns indicate significant differences between mean numbers at P<0.01.

Table 9.5. Numbers of animals significantly decreased over time for all forest age categories

Number	Fstat	df	Fpr
animals	70.98	1,648	<0.001
species	21.49	1,642	<0.001
LBP	28.33	1,240	<0.001



(a) Number of animals



(b) Number of species

Figure 9.1. Change over time in numbers of animals per 1 ha site within each forest age category

Solid lines represent the mean number and dashed lines are the upper and lower confidence limits.

9.4.3.2 Relationship between arboreal marsupials and habitat attributes

The main habitat attribute influencing the presence of arboreal marsupials is the occurrence of hollow bearing trees (HBTs). Based on average numbers of animals present at sites and the number of HBT monitored, only 25 – 62% of trees were occupied across the sites and sampling years.

The number of animals was significantly positively related to the number of HBTs at a site (df = 1, 445; Fstat = 196.5; Fprob = < 0.001) (Figure 9.2). The relationship was analysed for sites that had HBTs and so the minimum was 1 and the curves were drawn for the range in number of HBTs observed in the forest age category. Logged sites were the only age category that had a significantly different slope for the relationship (P<0.001). The number of animals was significantly lower for a given number of HBTs in Alpine Ash forest (P < 0.001) for all forest age classes, and there was no effect of land use type within forest areas.

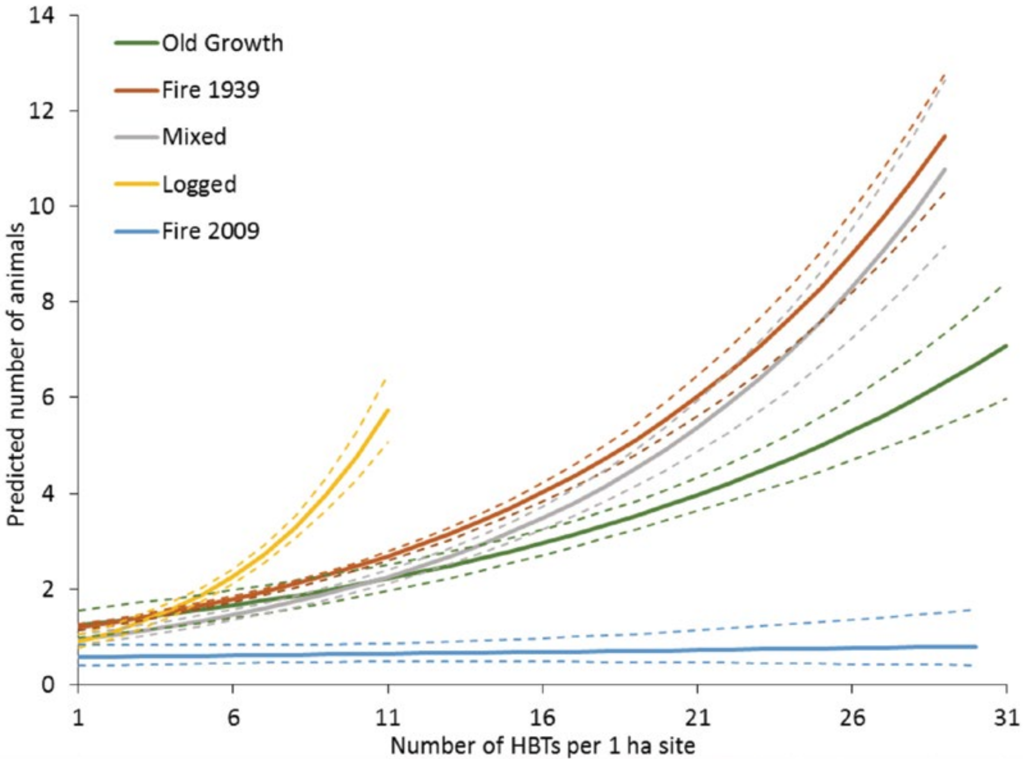


Figure 9.2. Relationship between the predicted number of animals and the number of HBTs at sites, assessed by the forest age category.

Solid lines refer to the modelled mean number and dashed lines are the upper and lower confidence limits.

9.4.3.3 Distribution of hollow-bearing trees

Numbers of HBTs increased with forest age, with old growth forest having 2 – 3 times the number of HBTs than regrowth forests. Regrowth from the 1939 fire had significantly higher numbers of HBTs than younger regrowth from logging (Table 9.6). This result is consistent with the disturbance history where the 1939 stands regenerated from wildfire, as well as salvage logging in some areas. Regrowth stands from the 1960s to 2000s regenerated from clearfell logging or wildfire plus salvage logging. Fewer large trees remained after these more recent disturbance events. Logging practices have become more intensive and regeneration burns more intense with the use of aerial ignition, so that fewer trees are retained and subsequently survive. Many of the retained trees collapse after a short time due to wind-throw of exposed trees or damage during the regeneration burns (Lindenmayer *et al.* 2012, 2016).

Numbers of HBTs were significantly different in each age category, in terms of the number of standing trees, number of trees lost, trees lost as a percentage of the number standing at the beginning of each year, and number of trees with hollows gained (Table 9.6). The loss of HBTs in regrowth forest was four times the rate in old growth forest, and even higher at the sites burnt in 2009. Regrowth forests post-logging have lost more than half of the retained large trees within a few decades. The gain in HBTs in old growth forest was about three times higher than in regrowth forest, and logged forest had the lowest number of new HBTs.

Table 9.6. Number of HBTs per 1 ha site and rate of loss and gain per year in forest age categories over the 17 year monitoring period.

Age class	Number of HBTs			
	Number in 2015	Loss	% loss	Gain
OG	12.1 $_a$	0.128 $_a$	1.06 $_a$	0.128 $_a$
Fire 1939	5.5 $_d$	0.233 $_b$	4.20 $_c$	0.049 $_b$
Mixed	7.1 $_b$	0.166 $_a$	2.35 $_b$	0.058 $_b$
Logged	3.6 $_e$	0.160 $_a$	4.25 $_c$	0.034 $_c$
Fire 2009	6.5 $_c$	0.424 $_c$	6.48 $_d$	0.153 $_a$
df	4, 3115	4, 3106	4, 2874	4, 3111
Dev. ratio	395.7	11.73	29.91	8.99
χ^2pr	<0.001	<0.001	<0.001	<0.001

Subscript letters ($_{a, b, c, d, e}$) after the numbers within columns indicate significant differences between mean numbers at P<0.01.

The dynamics of HBTs across all sites is shown in Table 9.7, with the numbers of standing trees, lost and gained over different time periods before and after the 2009 fire. Number of HBTs lost over the whole time period of 1998-2015 was 585 trees, or 47% of the population. During the pre-fire time period from 1997 to 2008, 111 trees were lost, that is, 8.9% of the population or 0.81% per annum. Post-fire from 2009-15, 474 trees were lost, that is, 42% of the population or 6% per annum. By 2015, 17% of sites no longer supported any HBTs. Of the HBT population in 2015, 15% were trees that had developed cavities and become new HBTs after the 2009 fire.

The loss of HBTs each year was analysed as a proportion of the population of HBTs at the beginning of the year (Figure 9.3). The analysis revealed that 2009 was the only year with significantly higher loss than other years (df = 18, 2838; deviance ratio = 68.53; χ^2pr <0.001). All sites burnt at high severity in 2009, where the majority of trees were killed, were assigned to the Fire 2009 age category. Hence, the sites remaining in the other age categories were those where the trees were not killed, but loss of HBTs occurred because of low severity fire as well as severe drought conditions. A higher proportion of HBTs were lost in the regrowth sites from the 1939 fire and logging, than in the old growth sites over all years.

Table 9.7. Population dynamics of hollow-bearing trees (HBTs) across the monitoring sites

	Monitoring period	Pre-fire	Post-fire
	1998 – 2015	1998 - 2008	2009 - 2015
Number of sites monitored	156	156	156
Initial number of HBTs	1244	1244	1128
Number of HBTs lost	585	111	474
% of population lost	47.0	8.9	42.0
% per year of population lost	2.77	0.81	6.0
Number of HBTs lost per ha	3.75	0.71	3.04
Number of HBTs s lost per year	0.22	0.06	0.43
Number of HBTs in 2015			770
Number of sites with no HBTs			26
% of sites with no HBTs			16.7
Total new HBTs gained			118
% of HBTs new in 2015			15.3

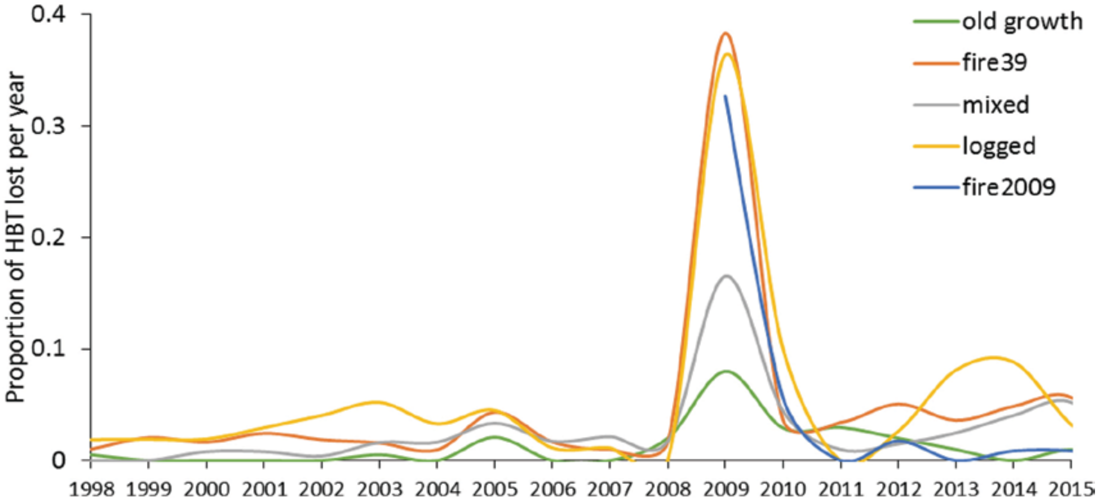


Figure 9.3. Proportion of HBTs lost per year over the sampling period from 1998 to 2015.

The frequency distribution of HBTs in relation to forest age category shows the pattern of change in this habitat resource as areas of forest were disturbed and regrew (Figure 9.4). Old growth has the greatest mean and maximum numbers of HBTs per site. Fire 2009 has a great range in numbers of HBTs, from 1 to 30, probably because a range of forest age categories was burnt and new trees with hollows were formed due to fire damage. Logged forest is distinct with low numbers of HBTs, both as a mean and maximum.

Analysis of HBTs at each site and sampling year showed that numbers have decreased significantly over time in all forest age categories (df = 4,3106; deviance ratio = 648.9; χ^2pr <0.001), but the decrease was significantly faster in the logged and 1939 regrowth categories (df = 4,3106; deviance ratio = 36.5; χ^2pr <0.001) (Figure 9.5). The decrease in numbers of HBTs over time is only significantly different from 2009 to 2010 after the fire, with an increase in the rate of loss and an increase in the rate of gain of HBTs, but an overall reduction in the total number of HBTs.

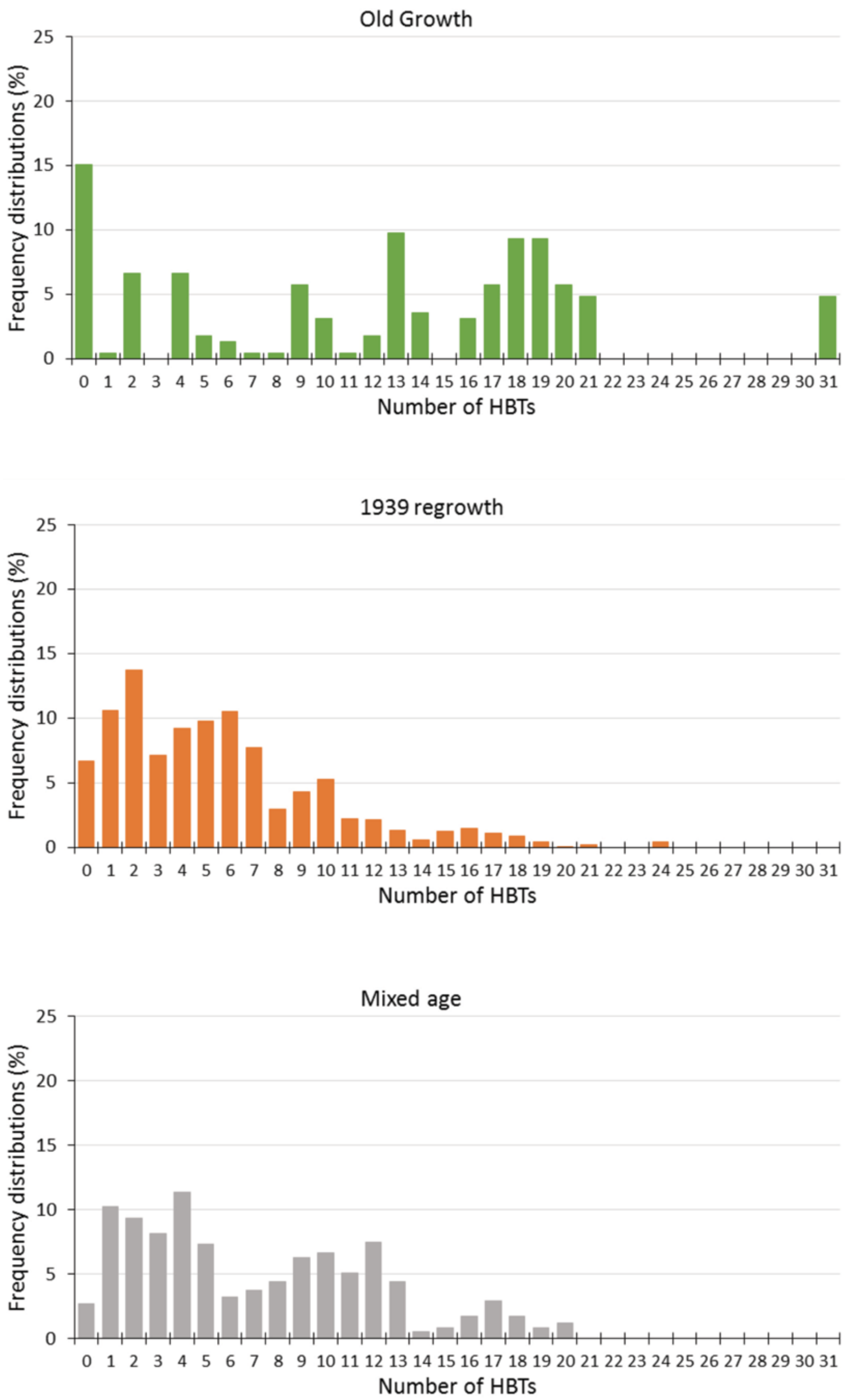
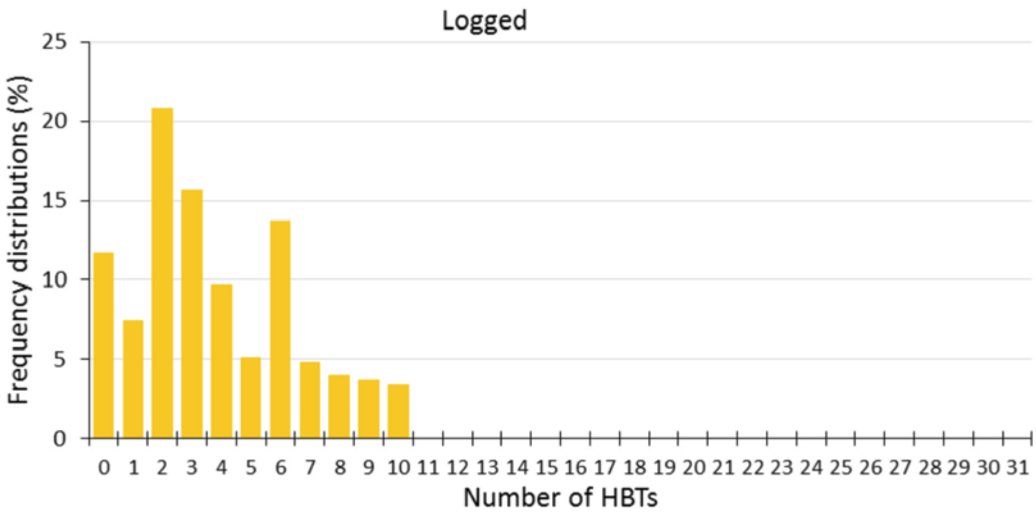


Figure 9.4. Frequency distribution of numbers of HBTs at sites according to forest age categories.



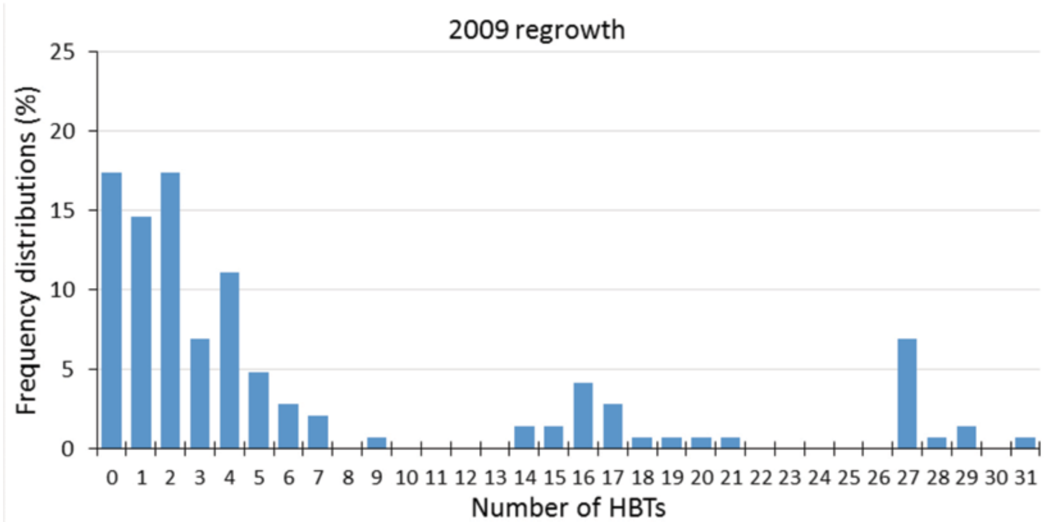


Figure 9.4 (continued). Frequency distribution of numbers of HBTs at sites according to forest age categories.

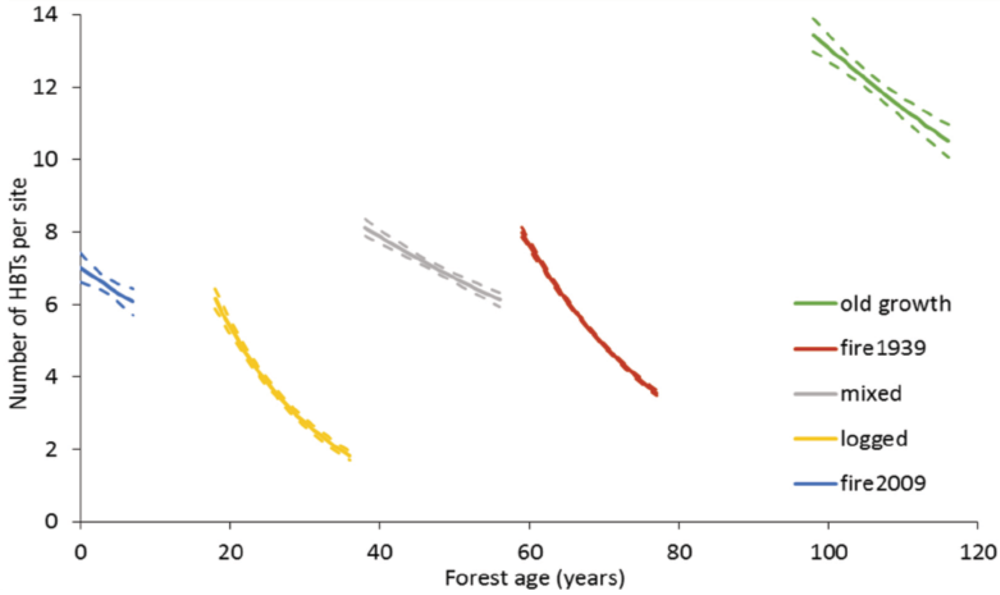


Figure 9.5. Change over time in number of HBTs in each forest age category.

Solid lines represent mean numbers and dashed lines are the upper and lower confidence limits.

The existing monitoring sites were not representative of all montane ash forests. There are some data, however, that provide an estimation of the frequency of HBTs across the landscape. An assessment of 529 sites in montane ash forest selected randomly provides an example of the range in numbers of HBTs: 28% of sites had no HBTs, 65% of sites had $\leq$ 4 HBTs, and hence only 7% of sites had > 4 HBTs (Lindenmayer *et al.* 1990). Additionally, surveys of HBTs at nine sites of young regrowth (12 – 22 years old) post clearfelling and slash burning in Mountain Ash showed that only three sites had HBTs remaining. Two sites had one tree, and one site had eight trees. Living HBTs were all resprouting species; such as *Eucalyptus cypellocarpa, E. obliqua, E. nitens*; which had a greater chance of survival from the slash burns (Brenton von Takach Dukai 2016 pers. comm.).

9.4.4 Discussion

The analysis of abundance of arboreal marsupials over 28 years demonstrated the importance of: (i) the relationship between animal occurrence and the habitat attribute of HBTs, and (ii) the effect of forest age and disturbance type on the provisioning of HBTs. The egeneral trend has been a decline in the numbers of animals over time, which is related to the reduction in numbers of HBTs. The difference in numbers of animals between forest age classes is due to the effect of past disturbances on maintaining trees that can form hollows, as well as other habitat factors such as food sources. Additionally, the marginal benefit of each HBT varies. Where few HBTs occur but food sources are high, such as in young regrowth forests, higher density of animals occurs per tree (Lindenmayer *et al.* 2017). However, this is not a sustainable system because of the high rate of tree loss (Lindenmayer *et al.* 2016).

Numbers of HBTs have declined over the last few decades because disturbance by logging and wildfire have created a greater loss with trees collapsing, than gain in trees developing new hollows. The number and distribution of HBTs remains the key habitat attribute that defines potentially suitable habitat for arboreal marsupials and is more tractable to monitor spatially and temporally than animal numbers. Thus, defining the processes controlling recruitment and loss of HBTs across the landscape is key to predicting change in habitat condition and impacts of management activities and disturbance events.

Trees begin to form hollows after about 120 years of age through processes of damage and decay in the trunk and limbs. These hollows continue to provide nest sites in living trees for 250 or more years, and then a further time after tree mortality as the dead trees remain standing (Ambrose 1982). The probability of occurrence of cavities, and number of cavities, increases with increasing tree age. Hollow bearing trees are identified as having an observable cavity, but the internal characteristics of the cavity and hence its suitability for nesting by different species are unknown (Lindenmayer *et al.* 1990). Therefore, the actual number of trees available for nesting by different species of arboreal marsupials is less than the number of trees identified and monitored as HBTs.

The impact of fire on HBTs is highly variable depending on fire severity and state of the original old trees. Fire in an old growth forest often produces HBTs that are either large dead trees after a high-severity fire, or fire-scarred living trees after low- to moderate–severity fire. These large trees mostly remain standing for decades, first as living trees and then as dead standing trees. Some old trees are combusted and collapse, and hence no longer provide hollows. Fire in young regrowth stands results in few HBTs because dead small trees are susceptible to rapid collapse and lack the volume to support large cavities (Gibbons and Lindenmayer 2002).

Logging impacts abundance of HBTs by only retaining a few large, old trees to provide seed for regeneration, or to provide habitat, or as streamside buffers, or the tree was decayed and not commercial to harvest. The number of residual trees is highly variable depending on site condition, silvicultural practices and markets for products, which have changed over time. Residual trees within regrowth, derived from logging or the 1939 fire, had the highest rates of loss of HBTs. It is likely that residual trees within regrowth are subject to higher rates of wind-throw. Additionally, residual trees within a cleared area after logging are subject to damage from slash burns and subsequent loss. Sites in the 'Logged' age category were clearfelled and slash burnt from the late 1960s to 1980s. Only three sites were logged and regenerated during the monitoring period from 1997 to 2015. Hence, monitoring of HBTs at logged sites began some years after the clearfell and slash burn, and so it is likely that residual trees damaged during these processes had already collapsed, and so their loss was not recorded during the monitoring program. The result is that loss of HBTs from logged sites was probably greater than the monitoring results indicate.

The impacts of natural and human disturbances interact when burned forests are subject to salvage logging, which aims to recover some of the economic value of fire-damaged trees (Lindenmayer *et al.* 2008). Extensive salvage logging occurred after fires in 1939, 1983 and 2009 (Noble 1977, Lindenmayer and Ough 2006, Lindenmayer *et al.* 2010). Here, regeneration of the forest, its structure and the abundance of HBTs depend on the combined effects of fire and logging. Abundance of HBTs is less in forests subject to clearfelling or salvage logging after fire, than in burnt forests, as shown by the comparison of the 'Logged' and 'Fire 2009' forest age categories (Table 9.6).

At the current rate of loss of HBTs shown in Figure 9.5, the average number of HBTs in logged forest will be < 1 tree ha^{-1} in under 9 years. The density of HBTs of < 1 tree ha^{-1} was suggested by Burns *et al.* (2015) as being the critical threshold of the habitat attribute to cause ecosystem collapse, as defined by the IUCN Red List of Threatened Ecosystems (Keith *et al.* 2013).

Recruitment is the key issue for maintaining HBT populations. It is unlikely that new HBTs will be recruited in the next 40-50 years in the montane ash forest because most of the forest extent is regrowth from the 1939 fire (trees currently 75 years old). Regrowth from the 1939 wildfire contains some large, old trees as remnants that survived the fire. Some of these remnant trees can be retained when the 1939 regrowth is harvested to provide habitat as HBTs, but would be subject to a high rate of loss as residual trees. Continuing harvesting on rotations of less than 120 years, however, means that there will be no recruitment of HBTs. Thus, the key threatening process for arboreal marsupials is the accelerated loss of existing HBTs and the impaired recruitment of new cohorts of HBTs.

Estimation of the spatial distribution of biodiversity is not possible based on the existing site data. The sites covered a range of forest age classes, disturbance history and environmental conditions within montane ash forest. However, some sites were selected to be potential habitat for arboreal marsupials and each site had at least some HBTs. Therefore, this range in sites cannot be considered representative of all conditions of the montane ash forest across the landscape, nor other forest types, and hence it is not appropriate to scale up the site data spatially.

The site data is useful for identifying areas of suitable habitat, based on the relationships between animal abundance and site characteristics. The relationship presented between animal abundance and HBTs was based on numbers of HBTs, but did not account for the quality of these trees in terms of the specialised nest requirements of particular species. Leadbeater's Possum, for example, prefers short, large diameter trees with many holes and surrounded by dense vegetation (Lindenmayer *et al.* 1991a). Only 25 – 62% of trees identified with hollows were occupied. Occupancy of trees is influenced by a range of characteristics and spacing of the trees and surrounding vegetation (Lindenmayer *et al.* 1991b). Models of the probability of occurrence of a species, in this case LBP, based on site characteristics of the number of trees with hollows and the basal area of *Acacia* spp showed that animals were absent from 40% of sites where they were predicted to occur (Lindenmayer *et al.* 1991a). Habitat attributes that influence occurrence of species have been modelled in detail and over a range of scales, including the bioclimatic domain, landscape context of sites, patch, stand, tree and microhabitat level factors (Lindenmayer *et al.* 1993, Lindenmayer 2009). These models identify areas of suitable habitat, but do not provide quantitative information about abundance of animals spatially. There are many additional factors, as well as habitat suitability, which determine the occurrence and abundance of animals at regional scales.

These factors include dispersal distance, reproductive capacity, population dynamics, competition, and impacts of seasonal weather conditions. Hence, it is likely that areas of forest are suitable for a particular species, such as LBP, but in fact, the animals do not occur, possibly because of the generally low number of animals, lack of capacity to colonise, and fragmentation of habitat areas.

Predictions of future changes in numbers of HBTs and animals require different types of data. Data on HBT loss and recruitment over time, as a long-term background rate and in relation to specific disturbance events, is currently not adequate to make these predictions spatially. When relating loss of key habitat attributes to loss of species, the timeframe of processes needs to be considered. Loss of habitat accurately predicts species loss in regions where the habitat loss occurred a long time ago, but there can be a time lag between the occurrence of habitat loss and subsequent species loss. Additionally, feral animals and weed species can increase the rate of loss of endemic species (Brooks *et al.* 2002).

9.5 Quantifying the ecosystem service of biodiversity

Biodiversity is more difficult to quantify in absolute terms than other ecosystem assets like water, carbon and timber. Translating the benefit of biodiversity as an ecosystem asset or determining its contribution to ecosystem services is difficult. Estimating monetary values for biodiversity were not attempted in the current study, although they have been reported elsewhere. For example, a value for Leadbeater's Possum was calculated to be in the range of $40-84 million in 2001 by Jakobsson and Dragun (2001) using the contingent valuation method (using the CPI tool from the ABS, this is approximately $58-121 million in 2015 dollars, ABS 2016b). This estimate of the value of the critically endangered species was based on welfare economics, and hence was not compatible with the exchange values of SEEA and the System of National Accounts.

Habitat services, and particularly those for threatened species such as Leadbeater's Possum, are specifically identified by Varcoe *et al.* (2015) as a service from parks. Physical measures of these services were presented by Varcoe *et al.* (2015) but no monetisation was attempted. Species occurring within the study area clearly have value, as evidenced by the efforts made to conserve many of them, for example, listing as endangered under various laws and the expenditure on their protection. However, methods for measuring and recording this in ecosystem accounting is not yet clear in the SEEA.

9.6 Discussion

The biodiversity accounts show that the extinction risk of species in the Central Highlands has increased, as determined by their status in various threat classifications systems. While only a small fraction of the species in the area have been assessed, those that are listed show an increasing risk of extinction over time.

Specific monitoring and analysis of populations of arboreal marsupials demonstrated that animal abundance is significantly related to the habitat attribute of hollow bearing trees (HBTs), and these habitat trees are affected by forest age. Numbers of animals and species were significantly higher in old growth forest than in regrowth forest. The numbers of animals have decreased over time in all forest age categories. **Logging rotations of less than 120 years mean that there will be no recruitment of HBTs. The key threatening process for arboreal marsupials is the accelerated loss of existing HBTs and the impaired recruitment of new cohorts of HBTs.**

In addition to the specific group of arboreal marsupial animals monitored at the Central Highlands sites, at least 98 animal species throughout Victoria require tree hollows for shelter and breeding (Traill 1995). Logging of native forests in general is removing the older age classes of trees greater than 100 years that have the potential to form hollows.

The accounts of biodiversity and habitat attributes in this study contribute to the mounting evidence of the impacts of declines in biodiversity on the integrity of the biosphere and functioning of ecosystems (Newbold *et al.* 2016). This trend is counter to the Sustainable Development Goals (UN 2015) that aim to improve human well-being by protecting, restoring and sustainably using ecosystems.

10. Synthesis of ecosystem accounts

10.1 Introduction

Ecosystem accounting consists of accounts for assets and the ecosystem services flowing from these assets. Ecosystem assets are spatial areas containing a combination of biotic and abiotic components and other characteristics that function together. Ecosystem assets are measured in terms of ecosystem extent and ecosystem condition. The capacity of an ecosystem asset to generate ecosystem services can be understood as a function of the extent and condition of that ecosystem (UN *et al.* 2014b). The impact of human activity on ecosystem assets may be immediate or may not become apparent in terms of changes in ecosystem condition for some time. Because of this potential time lag, it is important to assess changes in ecosystem extent and condition over time, as well as ecosystem services and the links to economic benefits.

It is not practically possible to assess all stocks and flows within ecosystems, and therefore it is recommended in the SEEA-Experimental Ecosystem Accounts (UN *et al.* 2014b) that the most relevant components of ecosystem assets be identified to provide aggregated information for measuring trends and comparisons. Selection of relevant characteristics to assess forest condition depends on the capabilities of the forest ecosystem to provide ecosystem services. These ecosystem characteristics and suitable indicators for evaluation are region-specific and reflect the priorities and sensitive issues of the region (Castañeda *et al.* 2017).

For this report on the Central Highlands study area, ecosystem extent is described by the land cover account (Figure 3.1 and Table 3.1), while the age of forests is used as the measure of ecosystem condition. The condition of other native vegetation types has been estimated by DEPI/DELWP for the year 2005 (Eigenraam *et al.* 2013). The condition of urban areas and agricultural lands was not assessed in this report.

The age of forests is determined by the time since stand replacing disturbance events, which in this case are fire and logging (section 3.6). Forest age is useful for describing ecosystem condition because it determines vegetation structure and composition and animal habitat attributes, which in turn influence stocks and flows of carbon, timber, water and biodiversity, and related ecosystem services. Forest condition differs depending on the type of disturbance (that is, logging or fire). For example, more hollow-bearing trees remain after fire than after logging.

10.2 Data sources and methods

10.2.1 Ecosystem extent and condition

Changes in ecosystem extent and condition were assessed using three comparisons. The first comparison was to a reference state, which was considered to be the ecosystem existing pre-European settlement, with a nominal age of 1750. These data were available from the Victorian Ecological Vegetation Classes (EVCs) that are mapped for an indicative age of 1750 based on an assumed distribution of natural vegetation classes. Impacts of Aboriginal occupation on ecosystems are recognised, although this was less in the dense, wet montane forests than other vegetation types. However, a reference state needed to be set for the analysis of ecosystem types and their extent.

The second comparison was the change over time during the 10-year period from 2005 to 2015 for which spatial data about ecosystem extent were available. Change in ecosystem extent was assessed from changes in area of each land cover class.

The third comparison to assess change in ecosystem condition was derived from changes in the area of each forest age class, based on a single classification of forest type. This approach was taken to ensure that change was attributed to a disturbance activity, and not attributed spuriously due to changes in classification systems. Forest age was estimated from the time since last stand-replacing disturbance event of clearfell logging in all forest types plus wildfire in ash forests. The impact of the 2009 wildfire was considered stand replacing only for areas of high severity fire. This distinction was not possible for previous fires where there was insufficient information about fire severity. Areas of forest changed their age class over time due to increasing age and the effects of stand-replacing disturbance events.

10.2.2 Spatial distribution

Spatial distributions of ecosystem services for carbon, water and timber were derived from their physical metrics in relation to land cover, land use and the environmental conditions across the landscape. Sufficient data for these services existed for spatial analysis. Additionally, use of these ecosystem services creates conflict in the forest lands of the study area.

The value of the timber provisioning service was derived from the forest age weighted by forest type. Forest age was calculated from the last regeneration event (section 3.6) and range-normalised to an index between 0 and 1. The forest age index was multiplied by a weighting for forest type (ash = 1; wet, mixed species = 0.667; open, mixed species = 0.333). The physical metrics for carbon storage (Figure 5.1) and water yield (Figure 4.5b) are continuous variables that were range-normalised to indices between 0 and 1. The interaction of the values of ecosystem services was derived from the product of these three component indices. This interaction index showed the areas of relatively highest value, or 'hotspots', and hence potential for conflict.

The indices are continuous from 0 to 1, but are displayed on the maps (Figures 10.10 to 10.14) as 5 classes for ease of comparison. Classification used the Jenks natural breaks optimization function in ARC GIS. This is a data clustering method designed to reduce the variance within classes and maximise the variance between classes. Because the data are highly skewed, this classification produced more even classes than using equal class sizes.

10.3 Results

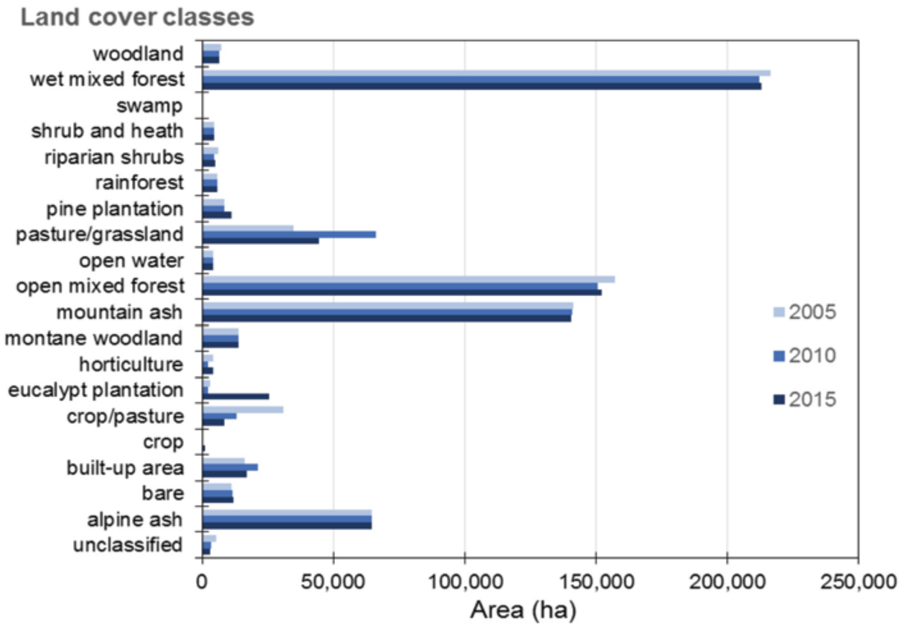
10.3.1 Ecosystem extent

The land cover change from 1750 to current refers to clearing of the original land cover or vegetation type and replacement with a different ecosystem type (Table 10.1). The greatest change has occurred in the open mixed forest, which exists in the foothills of the study area. This area has been extensively cleared for other land uses, such as cropping, grazing, horticulture, plantations and built-up areas. Three-quarters of the area of riparian shrubs has been changed and this would likely have a large impact on water supply and quality.

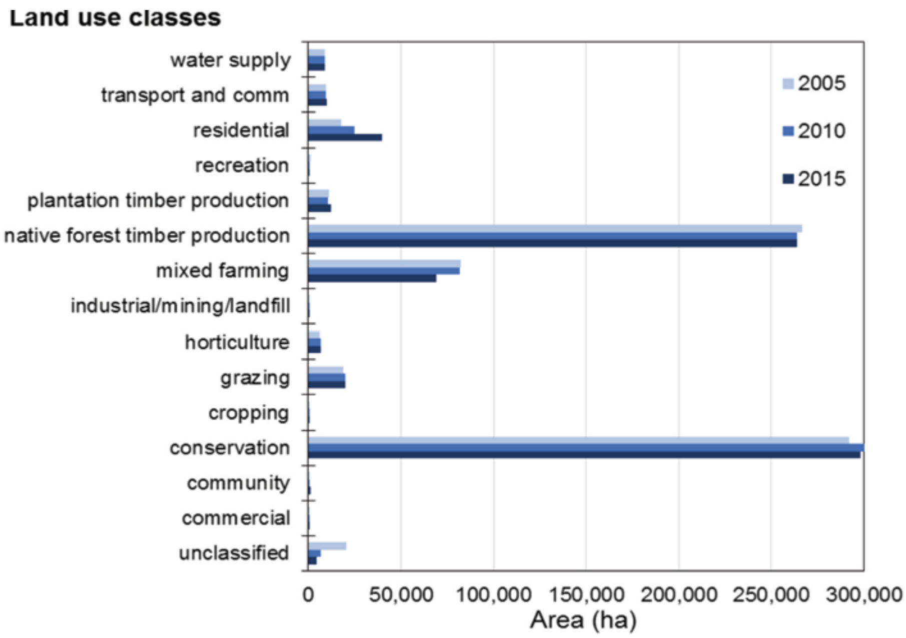
Over the 10-year period from 2005 to 2015, the extent of different ecosystems has been reasonably stable (Figure 10.1 and Table 10.2). The main changes have been due to changes in land use and the consequent vegetation type, mainly non-native vegetation. Wet mixed and open mixed forests have decreased by small areas. Areas of private land have changed in land use depending on markets, weather conditions, and land ownership. Areas of cropping and pasture for grazing often change, and some areas are used for both, so that a combined crop/pasture category was appropriate. Areas of plantations, mainly hardwood but also softwood, have increased in the last 5 years and this coincides with a decrease in crop/pasture areas. The increase in built-up area in 2010 and then decrease in 2015 is considered to represent an anomaly in the classification of land cover types between years, rather than an actual recent decrease in built-up area (see examples of anomalies in Appendix A3.5). By contrast, the area of the residential land use class has increased over the three time periods. Areas of public land have had little change in land tenure over the last 50 years and hence little change in extent and spatial distribution of land cover classes.

Table 10.1 Change in ecosystem extent from 1750 to 2015 (based on Ecological Vegetation Classes and SFRI forest types)

Area (ha)	Opening stock (1750)	Additions	Reductions	Closing stock (2015)
Alpine Ash	64,820		-344	64,476
Bare	19	11,802		11,821
Montane woodland	13,955		-120	13,835
Mountain Ash	144,688		-4,105	140,583
Open mixed forest	219,382		-67,431	151,951
Rainforest	5,688		-42	5,646
Riparian shrub	19,466		-14,655	4,812
Shrub and Heath	6,136		-1,739	4,397
Swamp	4			4
Wet mixed forest	245,567		-32,486	213,081
Woodland	15,926		-9,349	6,577
Unclassified	3	2,915		2,918
Total	**735,655**	**14,718**	**-130,272**	**620,100**



(a)



(b)

Figure 10.1. Ecosystem extent, change in areas of (a) land cover, and (b) land use classes from 2005, 2010 and 2015.

Table 10.2. Change in ecosystem extent (ha): 2005, 2010 and 2015

Land cover	2005	net change 2005 to 2010	2010	net change 2010 to 2015	2015
Unclassified	5,397	-2,122	3,276	-357	2,918
Alpine Ash	64,484	15	64,499	-23	64,476
Bare	11,166	363	11,529	292	11,821
Built-up area	16,209	5,146	21,355	-4,470	16,885
Crop	171	101	271	859	1,131
Crop/pasture	30,939	-17,760	13,179	-4,771	8,407
Eucalypt plantation	3,059	-795	2,265	23,041	25,305
Horticulture	4,125	-2,064	2,060	1,996	4,056
Montane woodland	13,833	9	13,842	-7	13,835
Mountain Ash	141,388	-609	140,779	-196	140,583
Open mixed forest	157,104	-6,513	150,591	1,360	151,951
Open water	4,361	0	4,361	0	4,361
Pasture/grassland	34,695	31,306	66,001	-21,602	44,399
Pine plantation	8,356	143	8,500	2,511	11,010
Rainforest	5,643	2	5,646	0	5,646
Riparian shrubs	6,236	-1,535	4,701	111	4,812
Shrub and heath	4,655	-227	4,428	-32	4,397
Swamp	4	0	4	0	4
Wet mixed forest	216,495	-4,480	212,015	1,066	213,081
Woodland	7,336	-981	6,355	222	6,577

10.3.2 Ecosystem condition - forests

Changes in areas of forest type by age class from 1990 to 2015 are shown in Figure 10.2 and Table 10.3. The spatial distribution of these forest age classes is shown in maps for each 5-year time period (Figure 10.3). Older age-classes are associated with higher condition for biodiversity, timber provisioning, carbon stocks, water provisioning and water filtration. The main features and patterns of change in the age class of forests over time include:

- General trend of reduction in area of older age classes and increase in area of younger age classes in all forest types.
- The area of Mountain Ash regenerated in 1939-59 (aged 56-75 years old) decreased from 115,233 ha to 79,753 ha between 1990 and 2015, a 31% reduction in area in 25 years, and young forest increased by a similar area.
- The area of Alpine Ash forest regenerated in 1939-1959 (aged 56 – 75 years old) decreased by 22,747 ha or 38%, and increased in areas of younger forest in the 7 – 32 years by 13,775 ha due to logging, and the ≤ 6 years class by 11,071 ha due to fire and/or logging.
- Areas of rainforest aged 56 – 75 years old decreased by 985 ha or 18%.
- No areas of rainforest or Alpine Ash older than 75 years were recorded in the spatial data, and only a very small area of Mountain Ash (~200 ha).
- Areas of wet mixed and open mixed forest older than 55 years decreased steadily over time, by 1.6% and 1.1% respectively, and areas of younger forest increased, reflecting the change in age structure due to logging.
- Areas of woodland and montane woodland had stable age classes because there has been limited logging in these forest types, and trees regenerate after fire.

In interpreting the data, it needs to be understood that most of the study area was burnt in 1939 and the resolution of mapping of this event was not sufficiently accurate to show the areas that were not burnt or to show differences in fire severity. As such, areas of wet mixed and open mixed forest, woodland and montane woodland that are classified as older than 75 years may have been burnt in 1939 and regenerated, but the fire was not considered stand-replacing in these forest types. Small areas of ash and rainforest that appear to be undisturbed have been observed in the study area, but are not recorded in the spatial data, probably because of the resolution of the mapping process.

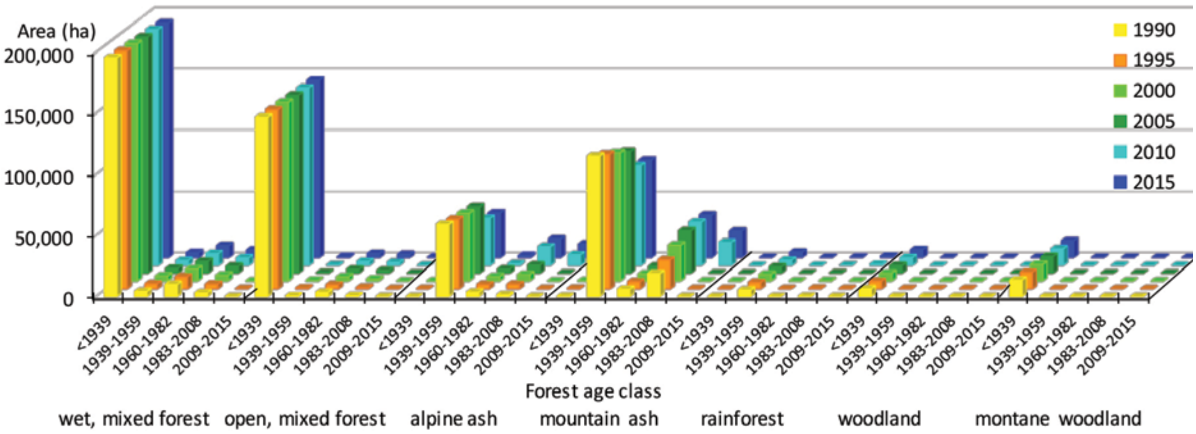


Figure 10.2. Change in area of each forest type and age class over time from 1990 to 2015.

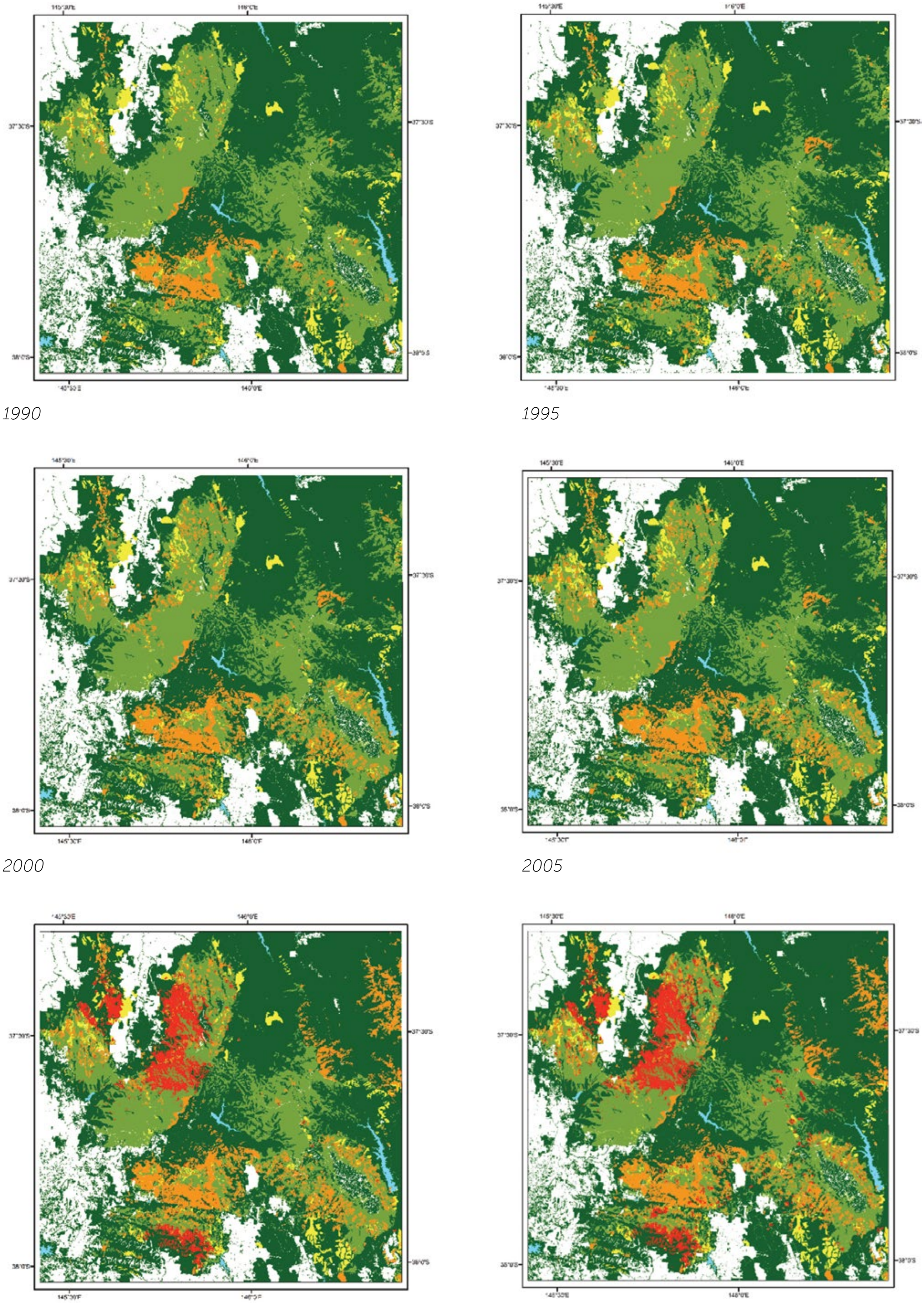


Figure 10.3. Maps of forest age class derived from regeneration time at 5-year time intervals from 1990 to 2015
Age classes 0: non-forest; 1: before 1939; 2: 1939-1959; 3: 1960-1982; 4: 1983-2008; 5: 2009-2015.

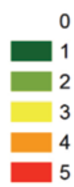


Table 10.3. Account of the change in area for each forest type and age class from 1990 to 2015

Land Cover class	Age	1990	change	1995	change	2000	change	2005	change	2010	change	2015
Wet mixed forest	< 1939	195,693	-679	195,014	-681	194,333	-934	193,398	-328	193,070	-931	192,139
	1939-59	4,261	-59	4,202	-75	4,127	-6	4,121	-122	3,999	-41	3,957
	1960-82	10,069	-6	10,063	-125	9,938	-137	9,801	-22	9,779	-24	9,755
	1983-08	3,058	744	3,802	882	4,683	1,078	5,761	412	6,173	-11	6,162
	2009-15								60	60	1,007	1,067
Open mixed forest	< 1939	147,113	-307	146,806	-450	146,356	-636	145,720	-320	145,400	-202	145,198
	1939-59	640	-32	608	-25	583	-7	576	-4	572	-21	551
	1960-82	3,460	0	3,459	-71	3,389	-64	3,324	-30	3,295	-18	3,277
	1983-08	739	339	1,078	546	1,624	706	2,330	279	2,610	-35	2,575
	2009-15								74	74	276	350
Alpine Ash	< 1939											
	1939-59	59,373	-2,128	57,244	-1,517	55,728	-1,531	54,197	-15,508	38,689	-2,063	36,626
	1960-82	3,609	-43	3,566	-21	3,545	-54	3,491	-1,945	1,546	-36	1,510
	1983-08	1,494	2,171	3,665	1,538	5,203	1,584	6,788	8,648	15,435	-166	15,269
	2009-15								8,805	8,805	2,266	11,071
Mountain Ash	< 1939	216	0	216	0	216	0	216	0	216	0	216
	1939-59	115,233	-4,749	110,483	-5,374	105,109	-5,262	99,847	-18,068	81,780	-2,027	79,753
	1960-82	6,044	-106	5,937	-124	5,813	-125	5,688	-1,587	4,101	-53	4,048
	1983-08	19,091	4,856	23,946	5,499	29,445	5,386	34,831	728	35,559	-684	34,875
	2009-15								18,927	18,927	2,764	21,691
Rainforest	< 1939											
	1939-59	5,344	-1	5,343	-1	5,342	0	5,342	-985	4,357	0	4,357
	1960-82	37	0	37	0	37	0	37	-15	23	0	23
	1983-08	265	1	266	1	267	0	267	-1	265	0	265
	2009-15								1,002	1,002	0	1,002
Woodland	< 1939	6,415	0	6,415	0	6,415	0	6,415	0	6,415	0	6,415
	1939-59	43	0	43	0	43	0	43	0	43	0	43
	1960-82	96	0	96	0	96	0	96	0	96	0	96
	1983-08	23	0	23	0	23	0	23	0	23	0	23
	2009-15											
Montane woodland	< 1939	13,712	-1	13,711	0	13,711	0	13,711	-1	13,710	0	13,710
	1939-59	23	0	23	0	23	0	23	0	23	0	23
	1960-82	92	0	92	0	92	0	92	0	92	0	92
	1983-08	8	1	9	0	9	0	9	0	9	0	9
	2009-15											

The proportion of the area in each forest type that has been logged, within the forest management zone available for logging, indicates the overall change in condition in terms of age structure of the forest. Table 10.4 shows the four land cover classes of forest types that are subject to logging, and the areas within these forest types that have been logged over the period of historical records (1932 – 2015), the area available for logging but has not yet been logged, and the percentage of area logged. Although the forest management zone is classified as available for logging, not necessarily all the area would actually be logged under future harvesting plans. Mountain Ash and Alpine Ash have had the highest percentage of area logged.

Table 10.4. Areas (ha) that have been logged and are available for logging for each forest type

Area (ha)	**Land Cover class**			
Land management	Open mixed forest	Mountain Ash	Wet mixed forest	Alpine Ash
Logged	13,251	44,611	37,745	16,730
Available	43,702	33,241	78,372	16,765
% logged	23.3	57.3	32.5	49.9

The proportion of the montane ash forest area that was old growth in 1750, or a 'natural' condition, was estimated to range from 30 to 60% (McCarthy and Lindenmayer 1998; Lindenmayer *et al.* 2013). Within the study area, the area of montane ash forest in 2015 that has no recorded history of disturbance by fire or logging is 216 ha or 0.11% of the total extent of montane ash. This area is considered old growth forest because there are no records of stand-replacing disturbance events. Across all forest types, there are 5,580 ha with no records of fire or harvesting, which represents 1% of the total forest area. However, there are many reasons why the records may not represent the current state of the forest, and the forest would need to be assessed on the ground to check characteristics of structure and composition that comply with the old growth status. Additionally, spatial analysis of these small areas has high uncertainty because the areas are based on polygons of coupe logging history and fire history. There may be small areas within polygons that were not logged or burnt.

Another source of information is the Victorian Government defined boundaries of modelled old growth in forest regions throughout the state (Victorian Government 2014a). Old growth was defined under the Code of Practice for timber production (DSE 2007b) as forest that contains significant amounts of its oldest growth stage in the upper stratum, usually senescing trees, and has not been subjected to any disturbances, and if so the effect is now negligible. The spatial data contains modelled old growth forest, which has been updated since 2009 to account for timber harvesting and fire disturbances. The original definition of old growth forest was based on a set of modelling criteria, rules and input datasets. The modelled old growth within the study area consists of 1,978 ha of montane ash forest and 7,571 ha of mixed species forest. However, based on analysis of the spatial data, all these areas are designated as being burnt in 1939 or disturbed at some time during the historical records. Thus, it is difficult to reconcile areas of old growth forest from spatial data without ground-truthing.

The overall change in forest age over time is illustrated by the proportion of the total forest area in each forest age category, showing the result for each 5-year period (Figure 10.4). More than half the area is shown as forest older than 75 years because the wet mixed and open mixed forests were assumed not to be killed by fire. The proportion of area in the two oldest age categories has declined in each 5-year interval, and the area in the youngest two age categories has increased. Thus, the ecosystem condition, as described by forest age, has declined over the last 25 years.

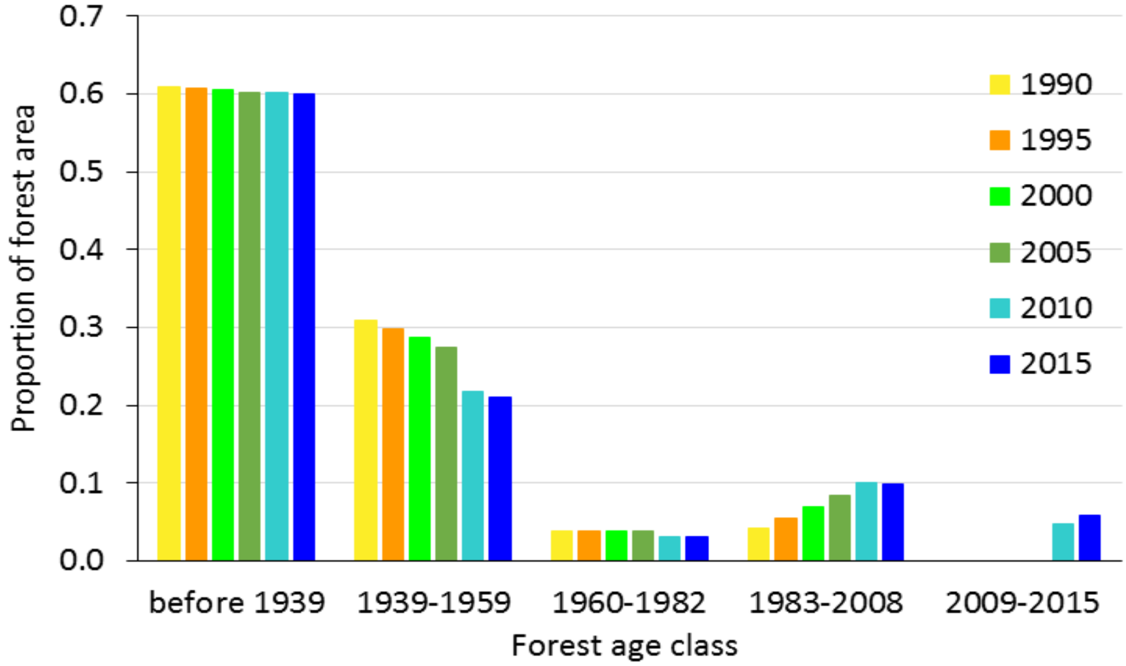


Figure 10.4. Proportion of total forest area in each forest age category from 1990 to 2015

10.3.3 Synthesis of ecosystem accounts

A set of ecosystem service supply and use tables were developed for the study area, and disaggregated by land cover type (see Appendix Table A10.1.). Table 10.5 shows the ecosystem extent (grouped by land cover types) and the physical services generated. Table 10.6 shows the value of the ecosystem services used by industry and households in 2013-14.

Only limited change has occurred in the extent of ecosystems over the study time period (Figure 10.1, Table 10.2). Changes in non-native vegetation land cover types have occurred due to changes in land use activities, particularly agricultural and plantation vegetation, and built-up areas. Some difficulties arise from using these changes in land cover types due to anomalies in the spatial data that produce spurious changes (see section 3.5 and Appendix A3.5). Change over time in the physical levels of ecosystem services are related to the disturbance history of logging and fire, which affect ecosystem condition and hence water, timber and carbon assets. There have been significant changes in condition as measured by forest age (Table 10.3, Figure 10.4).

Table 10.5. Supply of ecosystem services in the Central Highlands study area, average annual supply for the period 2010 to 2015

2010-2015		Land cover						
Ecosystem service	Units	built[a] /bare	open water	crops / pasture/ horticulture	plantations	native open vegetation	native forest	total
Area	Ha	31,624	4,361	57,993	36,316	29,624	575,737	735,655
	%	4.3	0.6	7.9	4.9	4.0	78.3	100.0
Provisioning services								
Water	ML yr^{-1}	0.99	0.14	0.14	0.12	0.22	3.39	3.97
Timber - sawlogs	m^3 yr^{-1}				129,800		304,920	
Timber - pulplogs	m^3 yr^{-1}				409,800		524,045	
Regulating services								
Agricultural production[b]	t			1,281				
Carbon sequestration[c]	MtC yr^{-1}	0.00	0.00	0.00	0.12	0.00	1.52	1.64
Cultural and recreational services								
Tourism[d]								

a built includes low-density and semi-rural residential, parks and gardens

b the physical volumes of production of different crops, fruit, vegetables and livestock and livestock products are available for ABS statistical areas and can be estimated for the study area, but they have not been presented because the utility of adding these to a single measure in tonnes is doubtful. Monetary estimates of this service were generated

c carbon sequestration is equated with net carbon stock change because this is the metric that is valued in the Australian Government abatement scheme

d physical estimates of the tourism services were not made but monetary estimates were made

Table 10.6 Use of ecosystem services in the Central Highlands study area by industry and households, 2013-14

The year 2013-14 is used for comparison across industries because data for 2015 were not available for tourism and native timber.

	Industry						Households	Total
Ecosystem service	Agriculture	Forestry	Water supply	Tourism*	All other industries	Subtotal industry		
	$m	$m	$m	$m	$m	$m	$m	$m
Provisioning services								
Water			101			101		101
Timber – native		19				19		19
– plantation		10				10		10
Regulating services								
Agricultural production	121					121		121
Carbon sequestration							63	63
Cultural and recreational services								
Tourism				42		42		42
Total	**121**	**29**	**101**	**42**		**293**	**63**	**356**

** Tourism is a collection of activities, not an industry*

The value of ecosystem services over time is shown in Figure 10.5. For most of the time, water was the most valuable ecosystem service from the study area, but highly variable in relation to climate. For example, the decline in water provisioning service from 2012-15 was due to lower rainfall and hence lower inflows. Since 2014, the regulating services used in agricultural production have been greater. The trend in carbon sequestration reflects only changes in net carbon stocks because a constant carbon price, adjusted for inflation, was applied. Decreases in carbon sequestration occurred after fires in 2007 and 2009 due to emissions from combustion, but then increased in the following years.

Change over time for IVA for each of the industries is shown in Figure 10.6. The decrease in IVA for water supply from 2012 to 2013 was due to the expenses associated with constructing the desalination plant. Although construction of this plant did not directly impact the volume of water supplied by the Central Highlands, it did cause a change in the price of water supplied by Melbourne Water and this reflected in the rising value of IVA for the subsequent two years. The IVA for tourism has increased since 2012 due mainly to increased numbers of international visitors, aided by the declining exchange rate post the global financial crisis and mining boom. IVA for plantation forestry is greater than that for native forestry, even though the area of land managed for plantations is 14% of the area of native forest available for harvest, indicating substantially greater intensity of land use in the plantation sector.

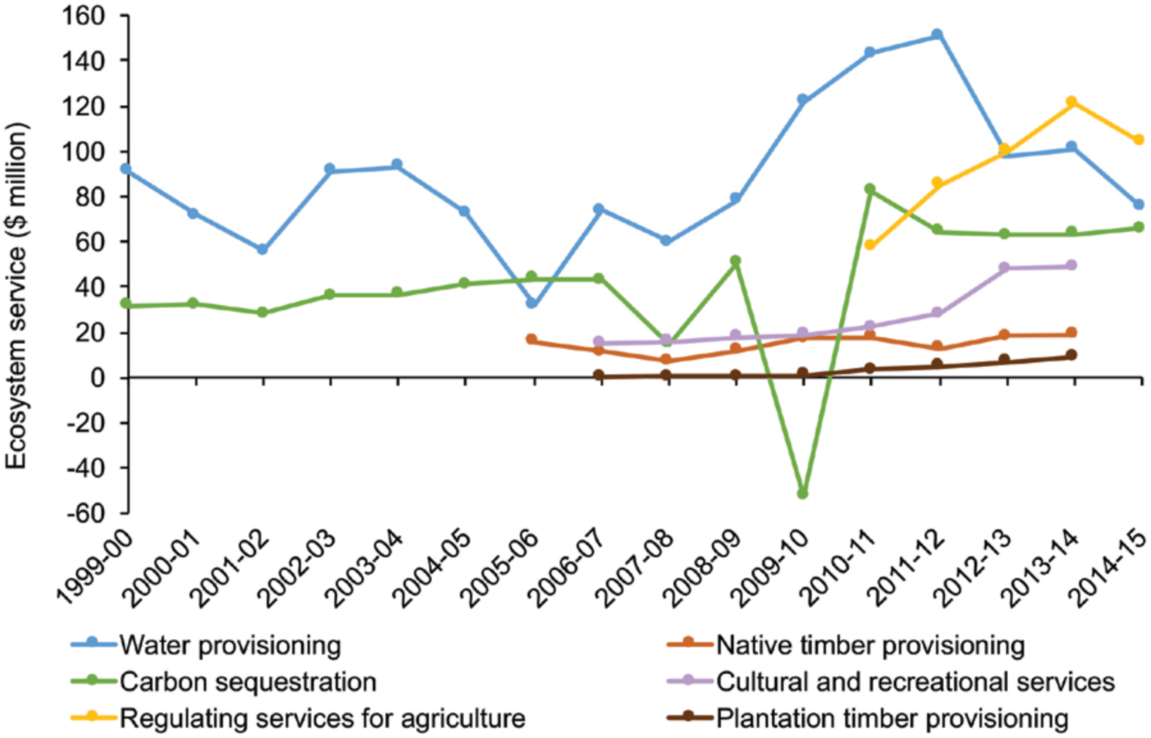


Figure 10.5. Value of ecosystem services generated in the Central Highlands study area.

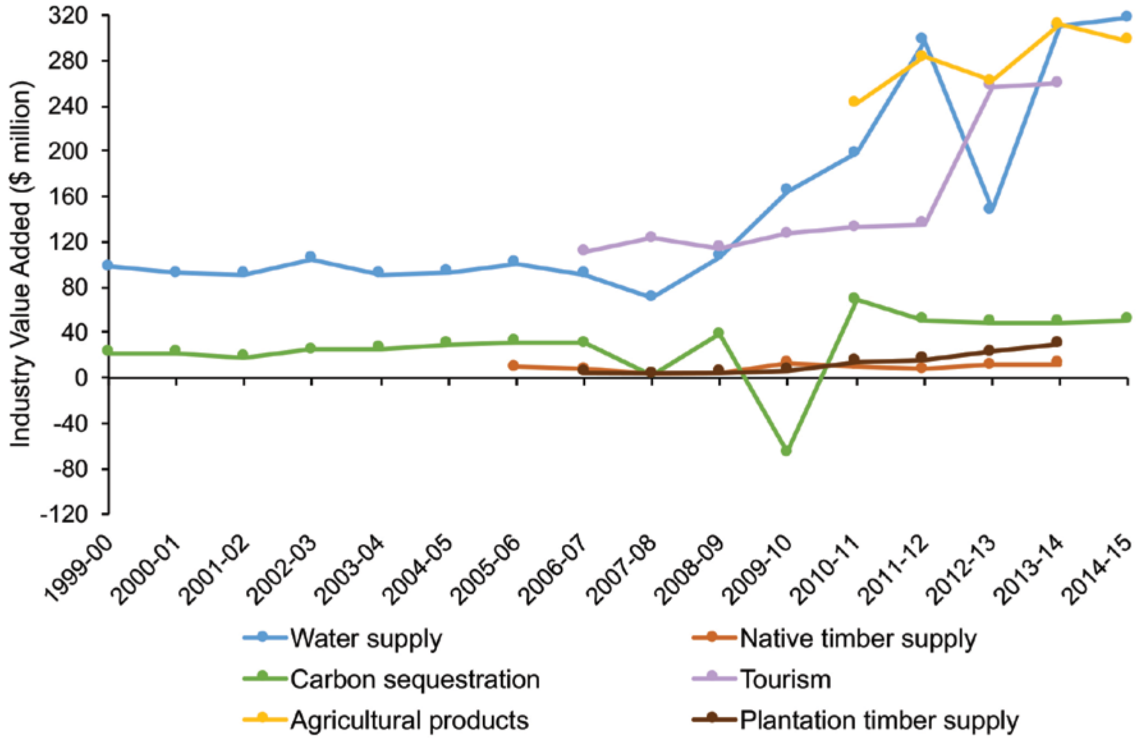


Figure 10.6 IVA contribution of industries in the Central Highlands to the national economy.

A summary of economic information for industries shows that agriculture and water supply were an order of magnitude greater than native forestry for all measures for the study area and per hectare of land use: sale of products, IVA and ecosystem services (Table 10.7). The low per hectare values for tourism are partly explained by the large area used, which was assumed to be the entire study area, thus making the largest denominator. The per hectare values for native forestry are conservative because the area used in the denominator is only that available for harvesting; the total area managed for timber production is 323,715 ha.

Table 10.7. Summary economic information for industries in the study region, 2013-14

Data for 2013-14 were used for comparison across industries because not all 2014-15 data were not available.

	Industries					
	Agriculture	Native Forestry	Plantation forestry	Water supply	Tourism	Carbon
Area of land use (ha)	95,813 [a]	264,154 [b]	36,316	115,149 [c]	735,655 [d]	735,655 [d]
Revenue from products ($m)	659	62	64	911	485	63
IVA ($m)	312	12	30	310	260	49
Ecosystem service ($m)	121	19	9	101	49	63
Revenue from products ($ha^{-1})	6874	235	1765	7913	659	86
IVA ($ha^{-1})	3256	46	823	2693	353	66
Ecosystem services ($ha^{-1})	1258	71	251	877	67	86

[a] *area of agricultural land use*
[b] *area available for native forest timber production*
[c] *area of water catchments*
[d] *total area of study region*

The different values associated with each stage in the ecosystem accounting model and the contribution of ecosystems services to each industry, and then the contributions of the industries to the economy, for example IVA (Figure 10.7). The relative values can be quantified at each of the points where trade-offs between conflicting land uses occur.

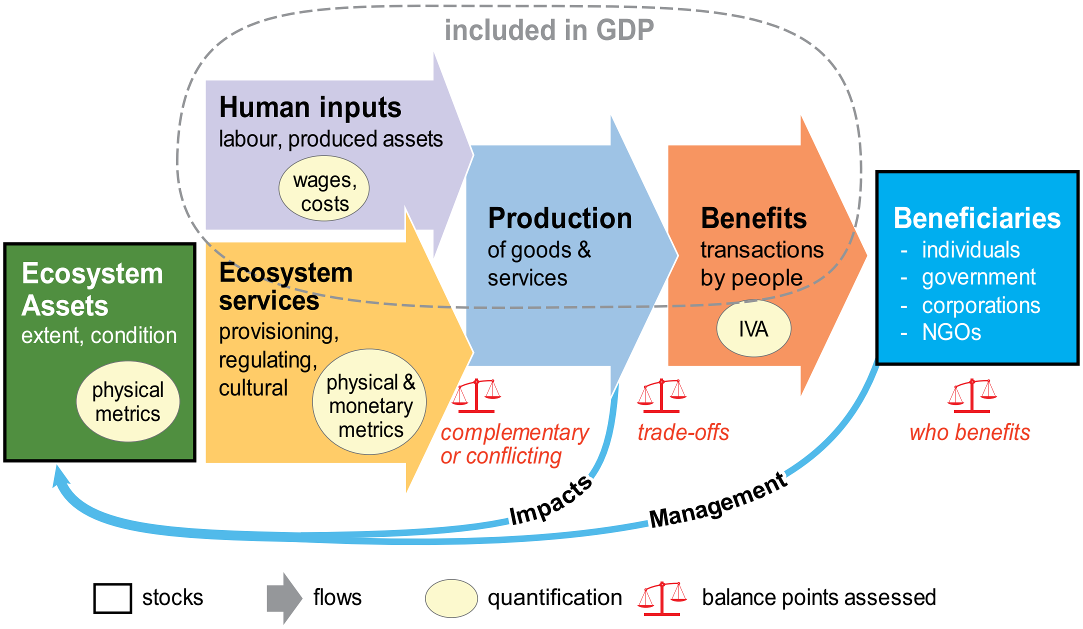


Figure 10.7 Model of the ecosystem accounting system with an example of valuation for each of the components in 2013-14.

Industry	Ecosystem services	Human inputs			Production	Benefits
	($m)	Intermediate consumption ($m)	Fixed capital consumption ($m)	Wages ($m)	Revenue ($m)	IVA ($m)
Agriculture	121	347	94	49	659	312
Water supply	101	601	187	54	911	310
Tourism	49				485	260
Carbon sequestration	63	14	2	15	63	49
Plantation timber	9	34	8	10	64	30
Native timber	19	50	3	8	62	12

10.3.4 Trade-offs between the use of ecosystem services

Trade-offs are required when the same area of land produces more than one ecosystem service or economic good or service, and their uses are incompatible. In addition, the use of one asset may affect the condition of other assets, or the same type of asset in different areas. Examples in the Central Highlands relate to impacts of native forest harvesting on the condition of the ecosystem asset by reducing forest age.

Land use activities of agriculture and settlements have caused major changes in ecosystem extent and condition in the past, which is seen by the comparison of land cover from pre-European settlement to present, with extensive clearing of open mixed forest and riparian shrubs. However, there have not been major changes in the extent of these activities in recent decades, although settlements have been increasing. Within the study area currently, these activities are not considered as conflicting with other ecosystem services.

Trade-offs in values of ecosystem services were derived from analyses of the counterfactual case: the difference in values of services if harvesting had not occurred. The area that has been harvested within the Central Highlands study area is 115,421 ha. Ceasing native forest harvesting would result in losses of timber production. Continued forest growth within this area would result in gains in carbon sequestration and water yield. Accounting for the difference in ecosystem services of carbon sequestration and water yield alone, therefore shows a small net loss (- \$0.7 million yr^{-1}) if harvesting had not occurred (Table 10.8, Figure 10.8). However, ecosystem services for culture and recreation, agricultural and plantation timber production, which currently account for about half the total value of ecosystem services, would also very likely increase and more than account for this difference.

Estimates of the effects of increasing protected areas within the Central Highlands suggest increases in revenue of \$37.3 million as direct gross value added and \$71.1 million as direct and indirect gross value added, with corresponding increases in employment of 470 direct jobs plus 280 indirect jobs after 10 years with public and private investment in the tourism industry (Nous Group 2017). This direct plus indirect value added was used in estimates of potential gains for the tourism industry, with a low range from scenario 1 based on protection of forests (\$7.5 million), to a high range from scenario 3 based on public and private investment in protected forests (\$71.1 million) (Nous Group 2017) (Figure 10.9).

Plantation timber production may increase if it was the main industry to meet the demand for wood products. This could be through more intensive management or an expansion of area, for example onto agricultural land. The potential gains were estimated as half (low range) or all (high range) of the current wood production from native forests.

Additionally, substantial gains would occur for habitat provisioning services for biodiversity through improved ecosystem condition of older forests, although economic valuation is difficult. Older forests reduce the risk of high severity wildfire (Taylor et al. 2014), which enhances ecosystem condition for many services.

Accounting for the difference in IVA, the increase in economic activity from water yield and carbon sequestration (under a potential market) surpass (+ \$8.5 million yr^{-1}) the loss from native forest timber production (Figure 10.9).

Table 10 8. Comparison of the current value of native timber production with the gain in value of carbon sequestration and water yield if harvesting had not occurred and the forest had continued growing. Analysis of the counterfactual case shows the loss from native timber production compared with the gain from carbon sequestration and water yield. Analysis of the physical metrics, ecosystem services and Industry Value Added are based on the area that has been harvested, with values in 2013-14.

	Physical metric	Ecosystem service (\$m yr^{-1})	Industry Value Added (\$m yr^{-1})
Native timber production	0.724 Mm^3 yr^{-1}	18.7	12.2
Carbon sequestration	0.344 Mt C yr^{-1}	15.5	12.6
Water yield	10.5 GL yr^{-1}	2.5	8.1

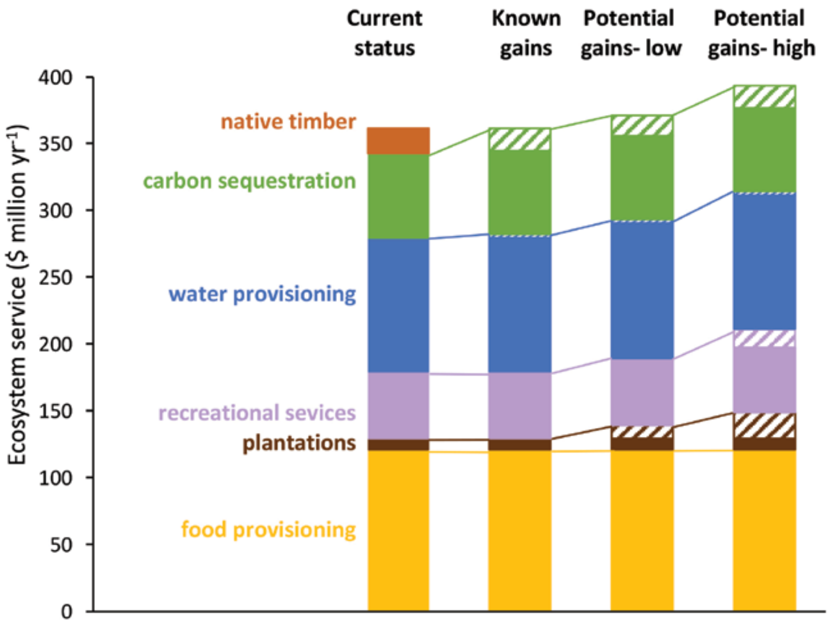


Figure 10.8. Value of ecosystem services (2013-14), and the potential changes if native forest harvesting ceased

Known gains in water yield and carbon sequestration. Potential gains in culture and recreational services, and plantation timber production at an estimated low and high range.

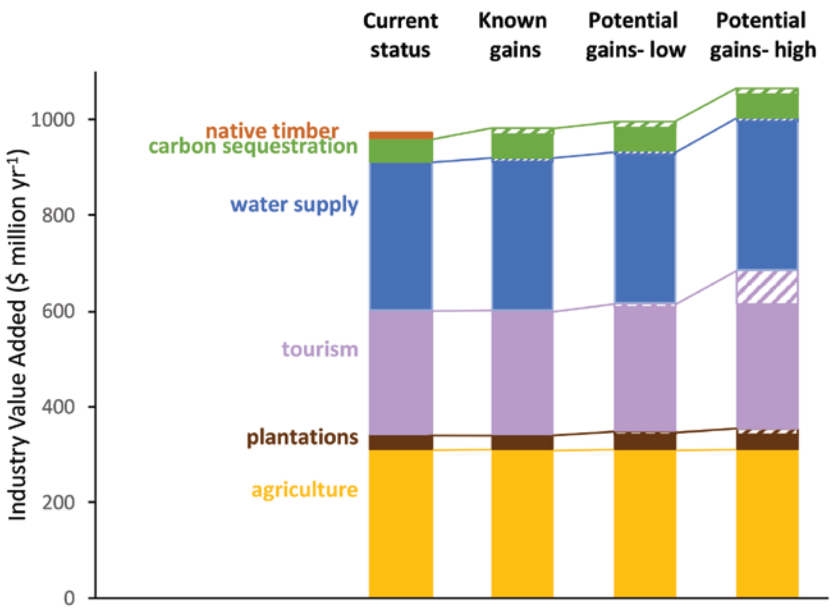


Figure 10.9. Industry Value Added (2013-14), and the potential changes if native forest harvesting ceased
Known gains in water yield and carbon sequestration. Potential gains in tourism, and plantation timber production at an estimated low and high range.

10.3.5 Spatial distribution of ecosystem services

Spatial distributions were calculated for the values of water provisioning services (Figure 10.10), carbon storage (Figure 10.11), native timber provisioning (Figure 10.12), and a combined Interaction Index (Figure 10.13). The interaction of the highest combined values of these services, or 'hotspots', are identified in red. Use of these ecosystem services creates conflict in the forest lands of the study area where harvesting of native timber reduces forest age, which decreases the condition of the forest for water yield and carbon storage. The area of conflict is shown within the current land management tenure where the forest is available for harvesting (Figure 10.14). The 'hotspot' areas of conflict include the higher elevation south-west slopes of the Thompson catchment, and an area in the central north of the study area surrounded by Buxton, Taggerty, Rubicon, Cambarville and Marysville. Mapping of these 'hotspots' identified the locations where trade-offs in the use of ecosystem services are required.

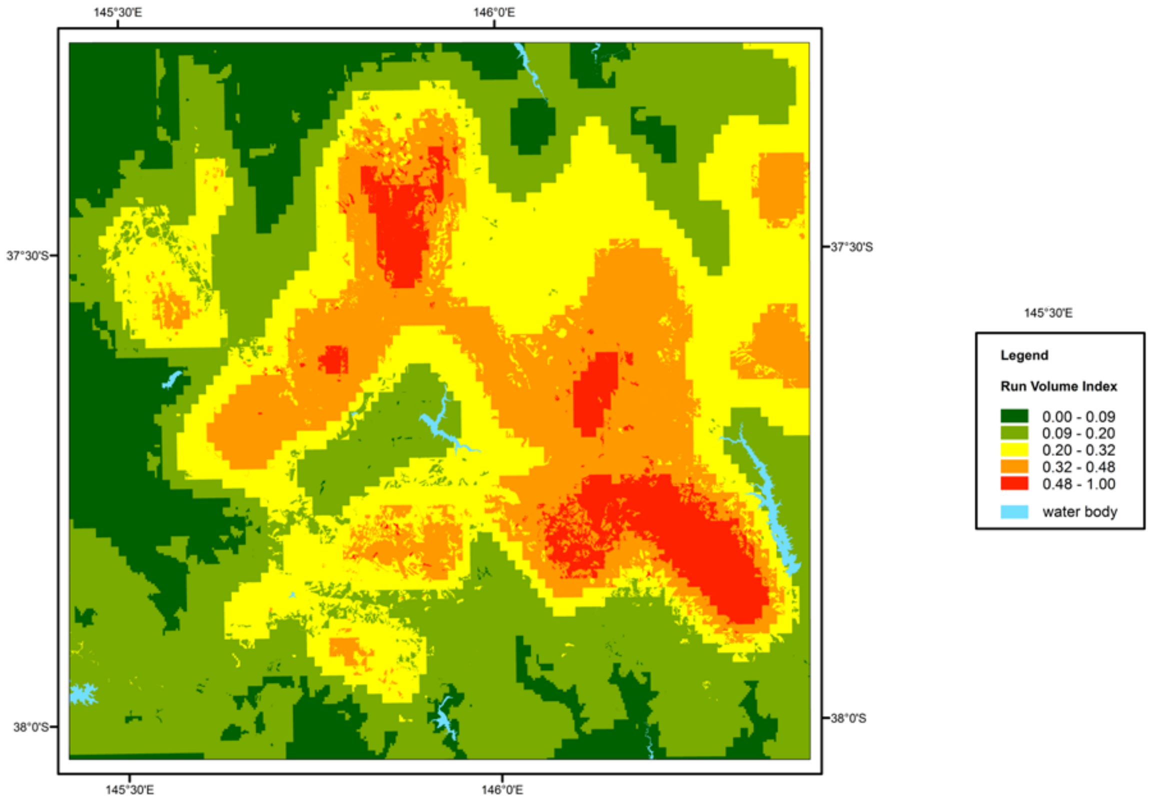


Figure 10.10. Spatial distribution of water yield calculated as a continuous variable (ML yr^{-1}), then range-normalised to an age-adjusted Run Volume Index.

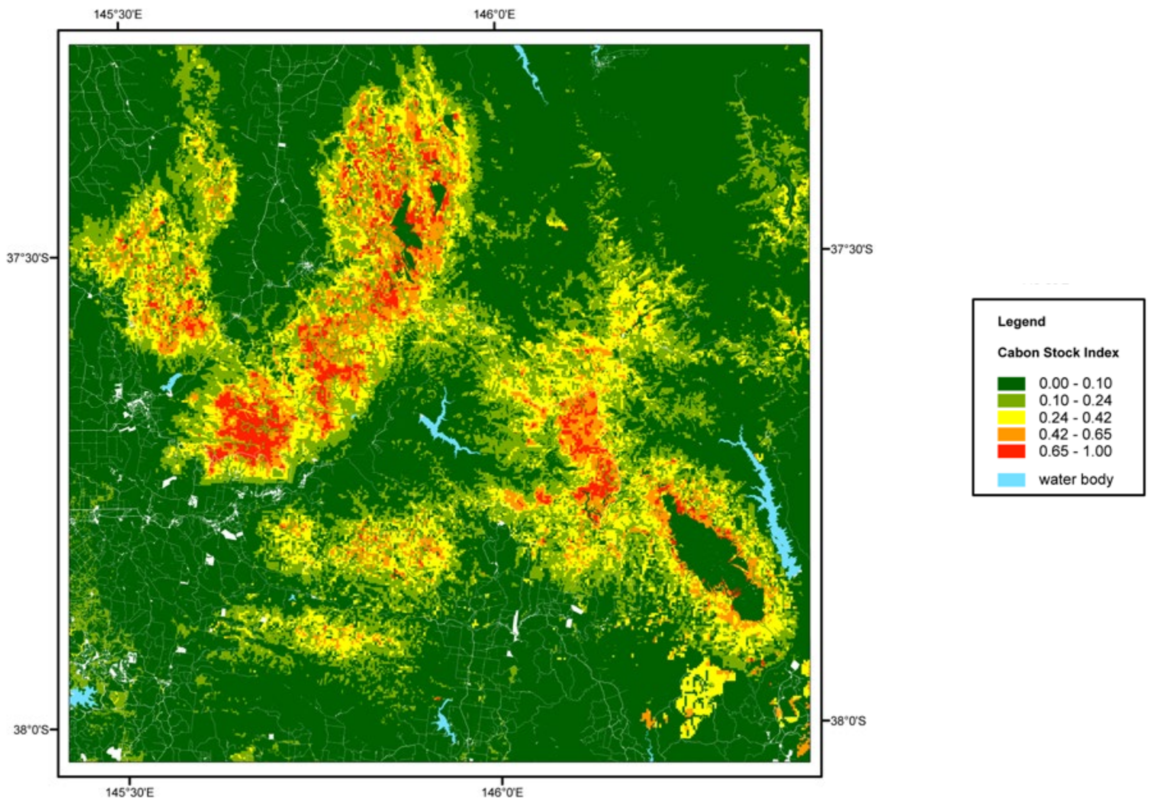


Figure 10.11. Spatial distribution of carbon stock density calculated as a continuous variable (tC ha^{-1}), then range-normalised to a Carbon Stock Index

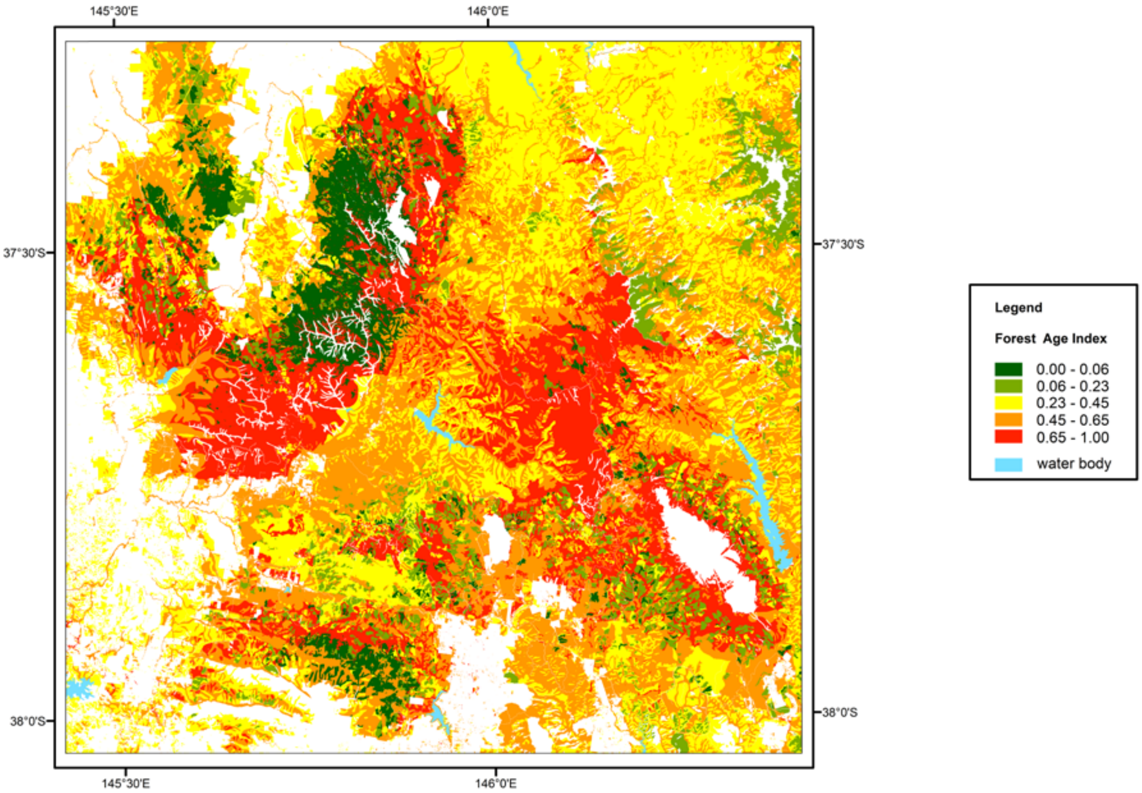


Figure 10.12. Spatial distribution of the native timber asset calculated from forest age weighted by forest type, then range normalised to a Forest Age Index

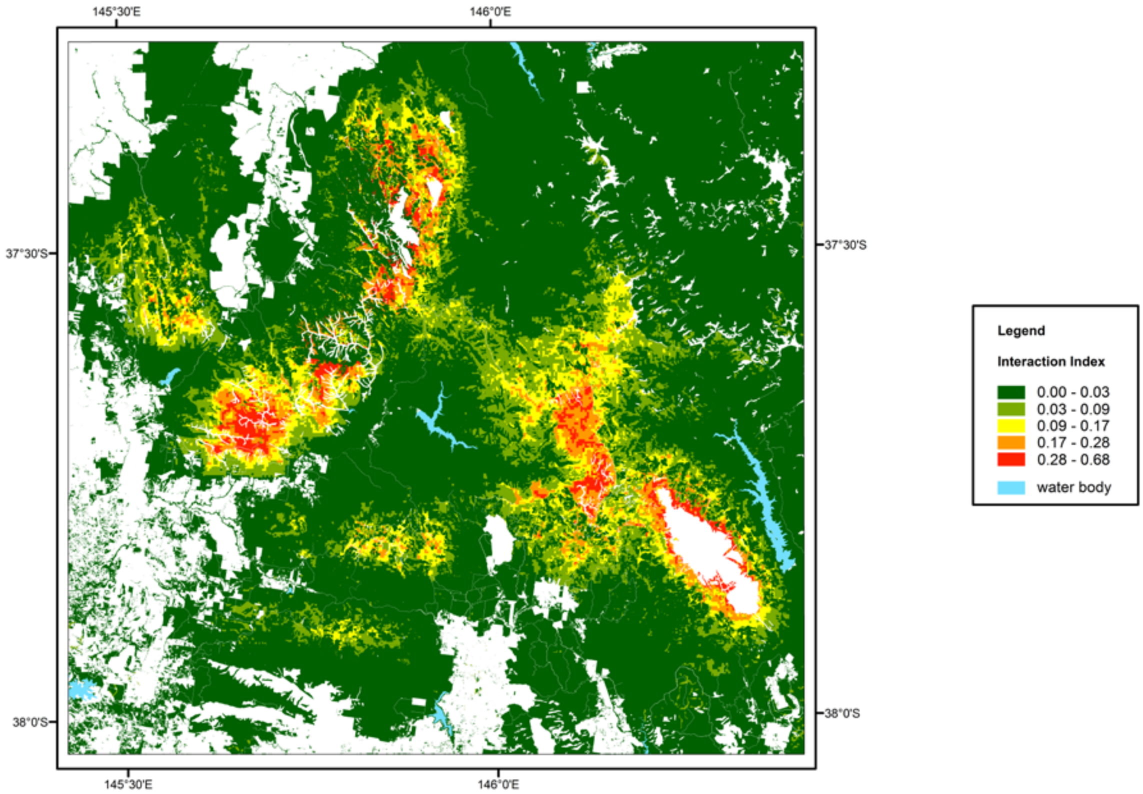


Figure 10.13. Spatial distribution of the interaction of values of water provisioning, native timber provisioning and carbon storage calculated as an Interaction Index which is the product of the three component indices

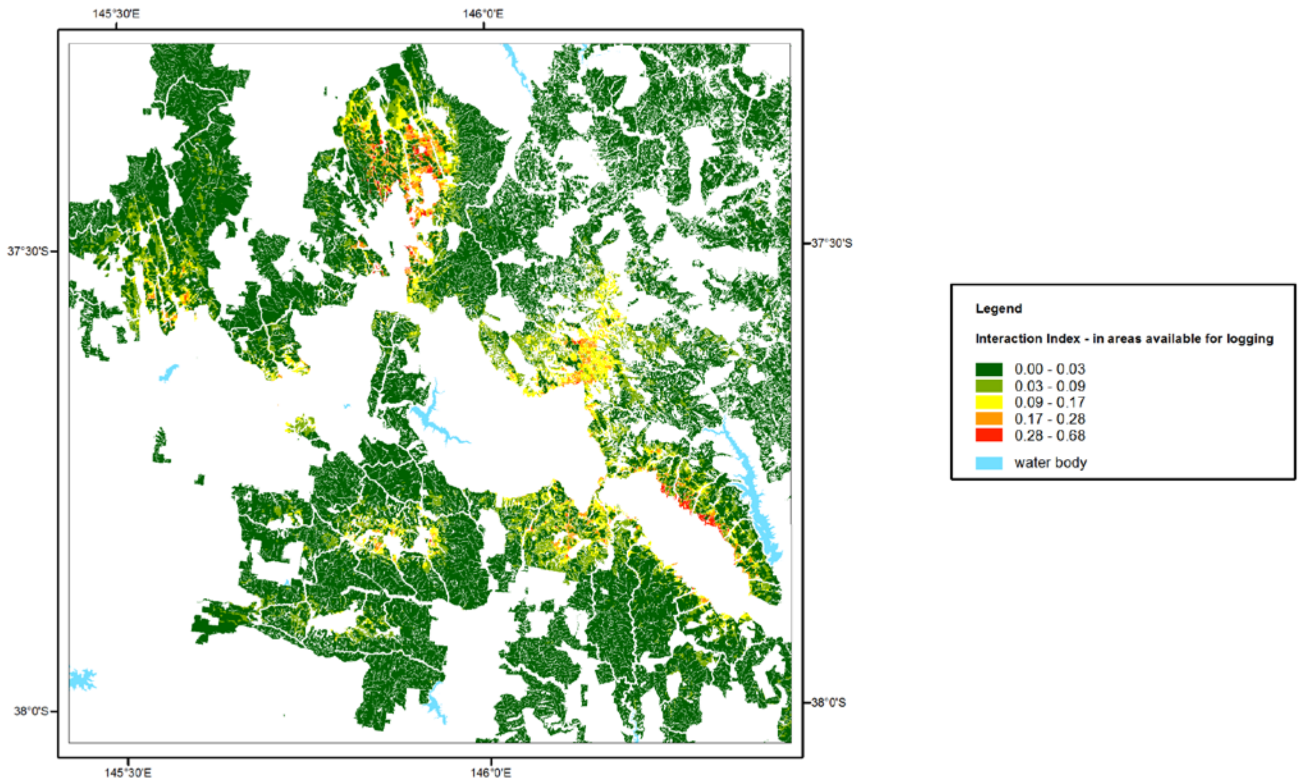


Figure 10.14. Spatial distribution of the Interaction Index of values for water provisioning, native timber provisioning and carbon storage in the area with land management tenure available for logging. Areas of highest values in red identify the 'hotspots', where maximum provisioning for native timber conflicts with maximising services of water provisioning and carbon storage.

11. Conclusions

Application of ecosystem accounts

Ecosystem accounts present a unifying framework for existing diverse data from monitoring environmental and economic activities in a region, and a consistent methodology for evaluating trade-offs between uses of ecosystem assets and their services. The accounts offer a compelling foundation for decision-making about natural resource management by presenting an integrated picture of benefits of ecosystems to society based on metrics that matter to human well-being. Application of ecosystem accounts has implications for better recognising ecosystem services, identifying trade-offs to improve ecosystem condition, and defining solutions to environmental-economic conflicts.

Evaluating ecosystem assets and services for their contribution to human well-being is now considered a critical component for improving how decisions are made about natural resource management at regional, national and international scales. This is evidenced in the internationally agreed Sustainable Development Goals that aim to achieve sustainable development by 2030 (UN 2015). The SEEA provides the international statistical standard framework for measuring the linkages between the environment and the economy, and the contribution of ecosystems to the economy and other human activity. The Central Highlands study has provided an example of implementation of this framework with valuation of ecosystem services and their contribution to the economy, which were compared across natural resource sectors to inform decisions about relative values and trade-offs required in changing management.

New insights into solving land management conflicts

The Central Highlands ecosystem accounts provided new insights and understanding of complex trade-offs between competing land uses, including:

i. Contributions of ecosystem services to industries were quantified in physical and monetary terms so that the services providing the greatest benefits were identified, and included in criteria for management decisions. In the Central Highlands, water provisioning, carbon sequestration, cultural and recreational services, and regulating services for agricultural production should be prioritised, whereas native timber provisioning services had the lowest value. Non-monetary benefits must also be included in the assessment of priorities.

ii. Greater transparency of costs and benefits by explicitly identifying industries that are subsidised. For example, water supply is subsidised through a fixed price and timber production through low returns on investment by government. The benefits of these subsidised activities can be assessed in terms of efficient use of government funds and identification of beneficiaries.

iii. Identification of complementary or conflicting activities. Water supply, carbon sequestration, biodiversity conservation and nature-based tourism are complementary activities (agriculture and plantation forestry are located on different areas of land). Conversely, native forest timber production reduces the value of forest assets for other activities.

iv. Identification of additional policy and market instruments required to improve resource management. For example, carbon sequestration in native forests is an ecosystem service that occurs and benefits the public, but currently has no market because it is not included in Australian government regulations. Applying a market price for carbon identified the potential benefit of native forest protection as a carbon abatement activity.

The accounts for the Central Highlands demonstrated that the values of ecosystem services used in water supply and agricultural production were an order of magnitude higher, and services of carbon sequestration and culture and recreational services were also higher, than the services from native timber provisioning. The trade-offs between native timber harvesting and other ecosystem services are clearer. Gains in value from ceasing harvesting were concluded by Clark (1994), Creedy and Wurzbacher (2001), and Spring *et al.* (2005) in economic analyses of timber, water and carbon resources in ash forests. The value of water quantity and quality and carbon sequestration will increase in the future due to increased demand from a growing population and limited scope for increasing dam capacities, as well as the increasing rate of climate change and need for mitigation.

In such comparisons of industries in terms of value and resource use, it is important to distinguish between industries that are substitutes or complements, related to their place in the supply chain and their requirement for inputs (land, capital and labour). In this context, the main issue for increasing plantation forestry is the potential substitutes for the input of land: whether there are more productive uses for the land.

Lessons learned

Implementing the SEEA ecosystem accounts in the Central Highlands has identified conceptual issues, data gaps and topics that require further consideration, and these include:

i. Biophysical data are collected mostly at the site scale, but this must be scaled up to the landscape scale to be used in accounts. This is one of the most critical processes in implementing ecosystem accounting.

ii. The experimental design for establishing monitoring systems and collecting site data is paramount so that the data can be scaled up successfully.

iii. Site and spatial data need to be linked through relationships derived between site data and ecosystem characteristics that can be presented spatially, from remote sensing, survey, or ground-based classifications. The most relevant ecological processes that determine these relationships for different ecosystems need to be identified.

iv. Ecological processes need to be defined in terms of functions over time, for example carbon accumulation, decomposition, mortality, reproduction, dispersal, and collapse of dead trees. These functions are used in deriving accounts of change over time in ecosystem assets.

v. Drivers of ecological change need to be identified and quantified, such as disturbance events and degradation processes. These drivers are important to understand the reasons for change in the past that are documented in the accounts, and to allow prediction of future changes.

vi. Economic data is generally for large spatial areas not related to biophysical characteristics. Methodological development is needed to improve spatial attribution of economic and social data to match environmental data. More detailed economic data that is region and industry specific would be valuable.

vii. Selecting the boundary for a study area is complex because the many sources of data integrated in the accounts use different boundaries, such as natural resource management area, catchments, local government, statistical areas, ecosystem types and land use regions,. No single boundary will accommodate all the different sources of data. Furthermore, social, geographical and policy considerations all play a role in the selection of appropriate boundaries. Thus, consideration should be given to the appropriate boundaries and how these may impact findings, particularly in terms of how the choice of study area can best address the policy questions that need to be answered.

Glossary

Amortisation: Repayments of principal on a loan. Does not include interest payments.

Cultural services: The intellectual and symbolic benefits that people obtain from ecosystems through recreation, knowledge development, relaxation and spiritual reflection.

Depreciation: Loss in value of an asset due to aging. In the concept used by economists and applied in the SNA, depreciation is calculated as the consumption of fixed capital. In the concept used in business accounts, depreciation is calculated as an allocation of costs of past expenditures on fixed assets over subsequent accounting periods.

Consumption of fixed capital: The decline during the course of the accounting period in the current value of the stock of fixed assets owned and used by a producer as a result of physical deterioration, normal obsolescence or normal accidental damage. Equivalent to depreciation plus amortization.

Ecosystem accounting: Accounts that integrate complex biophysical data about ecosystem assets and the interaction of living and non-living components as natural processes within a spatial area. Data include ecosystem extent and condition, the services they provide, tracking changes in ecosystems over time and linking those changes to economic and other human activity. Accounting is in both physical and monetary terms and spatial areas form the basic focus for measurement.

Ecosystem assets: Spatial areas comprising a combination of biotic and abiotic components and other elements that function together as a specific combination of ecosystem characteristics forming a system.

Ecosystem services: The contribution of ecosystems to benefits used in the economic and other human activity. Distinction is made between (i) the ecosystem services, (ii) the benefits to which they contribute, and (iii) the well-being that is ultimately affected.

Environmental accounts: Accounting for stocks and flows of individual environmental assets, and their relationship to the economy.

Exchange value: The actual outlays and revenue for all quantities of a product that are transacted. It is equal to the market price multiplied by the quantity transacted. It is based on the assumption that all purchases pay (and producers receive) the same price on average, and hence excludes consumer surplus. Exchange values are those that underpin national and business accounting frameworks, as they can be estimated based on observed transactions.

Gross Domestic Product: A monetary measure of the market value of all final goods and services produced in a period. It is an aggregate measure of production equal to the sum of the gross values added of all units engaged in production (plus any taxes, and minus any subsides, on products not included in the value of their outputs).

Gross Operating Surplus: The surplus or deficit accruing from production before taking account of any interest, rent or similar flows payable or receivable and before the deduction of consumption of fixed capital.

Gross Value Added: The value of Output less the value of Intermediate Consumption.

Industry Value Added: A metric used in the System of National Accounts that quantifies economic activity and contribution of the industry to GDP. IVA represents the exchange value and can be calculated in three ways: expenditure, income and production. In the income method, IVA is equal to Gross Operating Surplus plus Mixed Income plus Wages. In the production method, IVA is equal to Revenue from Sales less Intermediate Consumption.

Intermediate Consumption: Consists of the value of the goods and services consumed as inputs by a process of production, excluding fixed assets whose consumption is recorded as consumption of fixed capital.

Mixed Income: The surplus or deficit accruing from production by unincorporated enterprises owned by households; it implicitly contains an element of remuneration for work done by the owner, or other members of the household, that cannot be separately identified from the return to the owner as entrepreneur but it excludes the operating surplus coming from owner-occupied dwellings.

Net present value: The value of an asset determined by estimating the stream of income expected to be earned in the future and then discounting the future income back to the present accounting period.

Output: The goods and services produced by an establishment, excluding the value of any goods and services used in an activity for which the establishment does not assume the risk of using the products in production, and excluding the value of goods and services consumed by the same establishment except for goods and services used for capital formation (fixed capital or changes in inventories) or own final consumption.

Provisioning services: Contributions to the benefits produced by or in the ecosystem, for example an organism with pharmaceutical properties. The associated benefits may be provided in agricultural systems, as well as within semi-natural and natural ecosystems.

Regulating services: Services resulting from the capacity of ecosystems to regulate climate, hydrologic and biogeochemical cycles, Earth surface processes and biological processes.

Resource rent: The economic rent that accrues in relation to environmental assets, including natural resources.

Revenue: The value of output sold, that is the number of units times the price per unit.

Unit resource rent: Resource rent is the economic rent that accrues in relation to environmental assets, including natural resources. Unit resource rent is the resource rent per unit of resource extracted.

Wages: Employees' gross remuneration, that is, the total before any deductions are made by the employer in respect of taxes, contributions of employees to social security and pension schemes, life insurance premiums and other obligations of employees.

Welfare economics: A branch of economics that studies how the distribution of income, resources and goods affects the economic well-being.

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Further information:

http://www.nespthreatenedspecies.edu.au/

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