Experimental Ecosystem Accounts for the Central Highlands of Victoria

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Cover image by David Blair

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1. Introduction

This report presents the Experimental Ecosystem Accounts for the Central Highlands of Victoria. The primary aim of the report is to determine the extent to which the concepts and accounting structures of the System of Environmental-Economic Accounting (SEEA) (UN 2014a, UN 2014b) can be populated with existing data to aid decision-making at a regional level.

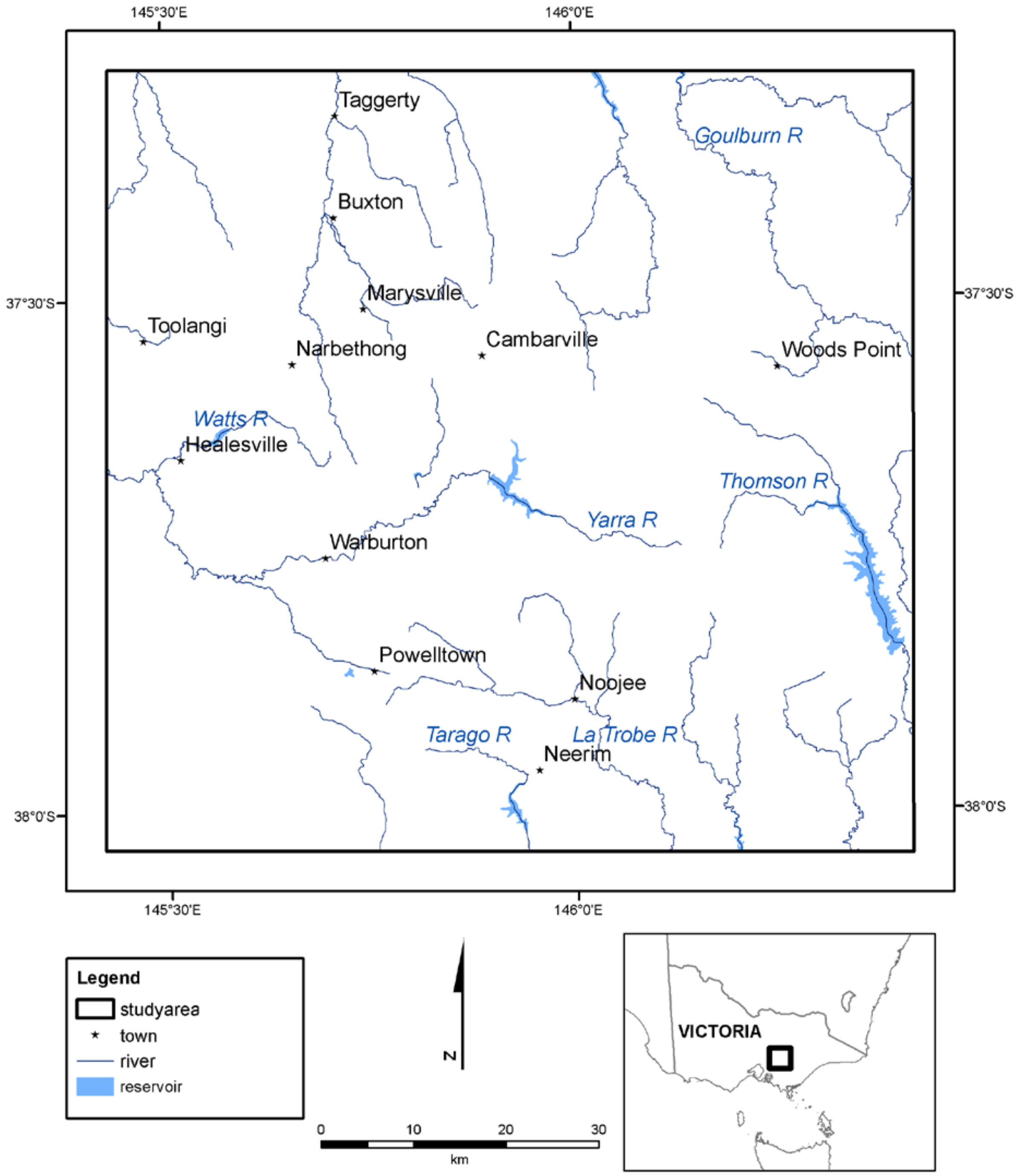
A study area in the Central Highlands region of Victoria (Figure 1.1) was chosen where current land management decisions are contending with controversial land use activities. This area forms part of the Central Highlands Regional Forest Agreement that is due for re-negotiation within 2 years, and areas proposed for addition to the national park network as the Great Forest Reserve System (GFNP 2016). The 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. These activities and their use of ecosystems assets can be either complementary or conflicting. Managing the various activities within the region is therefore complex and requires evaluation of the trade-offs between different land uses.

To assist with the on-going management of the Central Highlands and to test the ability of ecosystem accounting to inform decision-making, information for the region has been transformed into a suite of accounts. The accounts are an integrated presentation of the environmental and economic characteristics of the region, showing both environmental assets (that is, the state of environment) along with the flows or uses of these assets by people (that is, ecosystem services and the products to which they contribute). Specifically, 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.

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 (discussed later). The objective is to provide evidence for decision-making about land management and to provide an accounting platform that 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, filling data gaps, and increased use of remote sensing and information technology.

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: (1) identifying ways to improve their quality; (2) how they may be used by governments and others in natural resource management and; (3) how the experience of producing the accounts can contribute to the on-going development of the SEEA Experimental Ecosystem Accounting (UN 2014b).

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



1.1 System of Environmental-Economic Accounting (SEEA)

The key concepts, terms, units, classifications and accounting principles used in this report are based on the SEEA Central Framework (UN 2014a) and SEEA Experimental Ecosystem Accounting (UN 2014b). The main concepts of environmental and ecosystem accounting are outlined in the respective documents of the international community (UN 2014a, 2014b). These documents describe an integrated accounting structure covering component accounts (land, water, carbon and biodiversity), as well as integrated ecosystem condition and ecosystem services in both physical and monetary terms.

The System of Environmental-Economic Accounting (SEEA) (UNSD 2014a, 2014b) has been developed by the international community to complement the more traditional accounting of the System of National Accounts (SNA) (UNSD 2009) by adding environmental information. The SNA describes the economic state of a nation in terms of monetary transactions between parties in the economy, and is perhaps best known as the framework that gives rise to the aggregate of Gross Domestic Product. Environmental and ecosystem accounts extend this system to incorporate physical transactions, including ecosystems services that support human well-being, as well as transactions between the environment and the economy, like extraction of natural resources and pollution. Ecosystem accounting provides a tool for integrating complex biophysical data, tracking changes in the condition and extent of ecosystems, and linking these changes to economic and other human activity. Such environmental – economic accounts are required to provide information to contribute to government policy and management under the internationally adopted Sustainable Development Goals (UNDP 2015).

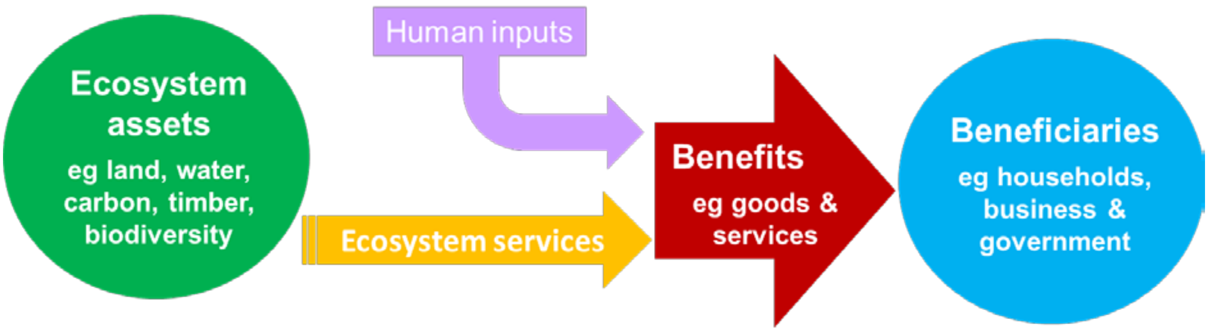
Environmental accounting is focused on particular resources (for example, land, water, timber, energy and minerals), types of pollution (for example, solid waste, effluent, water and air emissions), and transactions related to environmental protection (UN 2014a). Ecosystem accounting is focused on particular geographical areas and the interactions of living organisms and components of the environment (UN 2014b) Ecosystem accounting is based on a model of stocks and flows (Figure 1.2). In this model, ecosystem assets (which are spatially defined areas) provide a flow of services which in combination with human inputs (labour, capital, etc.), produce benefits which can be thought of as goods and services used in the economy, which are then used by a range of beneficiaries (people, business or government).

Stocks or assets are amounts at a particular point in time. Flows are additions or subtractions to stocks over a period of time, and can also be in the form of income and expenditure. Environmental stocks and flows are measured in both physical terms (for example, litres, hectares, parts per million) and monetary terms (for example, dollars). Stocks are defined by their quantity and condition. Environmental flows are defined as natural inputs (water, timber, minerals) and residuals (such as pollution or waste). Ecosystem flows, known as ecosystem services, are classified as provisioning, regulating or cultural services. The products, or goods and services traded within the economy are also recorded. Accounting records the exchanges of stocks and flows between different agents (people, businesses and government) within the economy as well as between the economy

and the environment (or ecosystem). The accounts report the exchanges between agents as well as changes in quantity and condition of stocks and flows over time in response to human activities, disturbance events and other temporal effects.

In ecosystem accounting, all areas are included as ecosystems, regardless of the level of human modification. For example, crops, pastures and built-up areas are included as ecosystems in the accounts. The starting point for ecosystem accounts is usually land cover (such as forest, woodland, grassland) as a proxy for ecosystem extent. From these areas, a range of ecosystem services may be produced and used by people.

Figure 1.2. Model for ecosystem accounting



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

The SEEA has several parts and is supported by a range of additional guidance. The SEEA Central Framework (UN 2014a) is an international statistical standard and covers natural resources (land, water, timber, fish, energy, minerals) and pollution accounts (air emissions). The SEEA Experimental Ecosystem Accounting (UN 2014b) is not yet an international standard but has been developed via United Nations processes, and countries are encouraged to use it in order to "*further develop and enhance this framework*" (p. iv). A range of other documents is available to assist with SEEA implementation. These include providing more detail on specific types of accounts or general compilation guidance, for example:

- General guidance – SEEA Implementation Guide (UNSD 2014c)
- Water – SEEA Water (UNSD 2012a) and International Recommendations for Water Statistics (UNSD 2012b), Guidelines for the Compilation of Water Accounts and Statistics (UNSD 2014d)
- Forests (Castaneda 2016)
- SEEA-Agriculture, Forestry and Fisheries (FAO 2015)
- Ecosystem accounting (World Bank 2014)

The SEEA has been recommended for use by the Australian Government (BoM 2013a), and has been used by a variety of agencies including the Australian Bureau of Statistics (ABS) (ABS 2015a), and the Government of Victoria (Eigenraam *et al.* 2013; Varcoe *et al.* 2015). The Bureau of Meteorology (BoM) uses a system of water accounting (BoM 2014) that can

be related to SEEA (Vardon *et al.* 2012), while the Wentworth Group of Concerned Scientists has also developed a process and metrics for producing accounts (Sbrocchi 2015). There is also a growing Australian literature on ecosystem services (Crossman *et al.* 2013; Stoeckl *et al.* 2011; Tovey 2008; Straton and Zander 2009).

1.2 Outcomes from accounts

The actual and potential outcomes from accounts are covered in the documents of the SEEA Applications and Extensions (EC *et al.* (2014), Smith (2014) and Vardon *et al.* (2012)). Structuring information in the form of accounts identifies interactions between human activities and ecosystem assets, which may be positive or negative. For the Central Highlands, accounts should be able to inform decisions about:

1) Identifying drivers of change, including biodiversity loss, carbon emissions and sinks, water quantity and quality, expansion of built-up land and infrastructure, fragmentation of habitats, and extraction of timber.
2) Tracking progress towards policy targets, such as whether increasing protected areas results in decreasing risks to threatened species and habitats.
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.

It should be noted that the purpose of this report is not to apply the accounts to these issues but to produce information that can inform these issues.

1.3 Terminology, data sources and accounts

The terminology used in association with environmental and ecosystem accounting varies between countries as well as between different levels of government and agencies within Australia. For example, natural capital accounting, natural resource accounting, and environmental accounting are widely used terms. While there may be subtle differences between these terms, the basic underlying concepts are largely the same. In this report, we have endeavoured to use the concepts and terminology of the SEEA (UN 2014a).

For all of the accounts, our 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 concepts and accounting structures, and the study area. In some cases, clarification or additional information was sought from primary data sources (for example, the ABS and DELWP). The particular data sources and methods used for each account are outlined in detail in each section of this report.

A number of accounts for specific assets or services already cover all or part of the Central Highlands region or the economic users of the region. These include:

- Land Accounts Victoria, Experimental Estimates (ABS 2013)
- Water Accounts, Australia (ABS 2015b)
- National Water Account – Melbourne (e.g. BoM 2014)
- State Tourism Satellite Accounts (TRA 2015)
- Value of tourism to Victoria’s regions (Tourism Victoria 2015a)

- Victorian Experimental Ecosystem Accounts (Eigenraam *et al.* 2013)
- Valuing Victoria's Parks (Varcoe *et al.* 2015).
- Melbourne Water Annual Reports (2000-2015)
- VicForests Annual Reports (2005-2015)

The accounts already in existence use a range of different classifications and spatial boundaries, and as such had to be adapted to the study area of the Central Highlands using a range of assumptions and additional data.

Based on an initial assessment of the available data and the potential applications of the accounts, the following accounts were prepared:

- Ecosystem extent (= land cover), condition and land use accounts
- Carbon stocks
- Water asset account and water supply
- Timber asset account and timber supply
- Biodiversity accounts
- Ecosystem services supply and use: provisioning of water, timber and food; carbon sequestration; cultural and recreation services.

The background, data sources and methods for each of these accounts are outlined in separate sections. Details of the methods used to generate the estimates of ecosystem services and condition are found in the resource specific chapters (for example, water provisioning in the Water section). The section on agriculture contains the food provisioning service calculations, while the section on tourism contains the cultural and recreational services. Habitat services are addressed in the biodiversity section.

2. Accounting units, classifications and valuation

2.1 Units

In economics, environmental science and accounting, the objects of measurement, their aggregation and classification are key issues. In national accounting, the objects or units of measurement 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 own or use the activities that they undertake can be spatially located in most cases.

In environmental and ecosystem accounting, the observational units of interest are particular areas and hence are spatial units. The SEEA – Water identifies river basins or water catchments as the preferred areas for accounting but this is not explored in detail. The SEEA Experimental Ecosystem Accounting specifically identify 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 – the spatial boundaries of the areas of land that can be owned is made of polygons.
2) Land cover / ecosystem functional units (LCEU), which are aggregations of BSUs with the same land cover, for example forest type.
3) Ecosystem accounting units (EAU), which 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, only aggregated data (that is, aggregations of BSUs to output areas equivalent to EAUs) were available. 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 LCEU used in this report were based on the classification of vegetation in Victoria (see section 3.2).

2.2 Classifications

A range of additional classifications is required and used in accounting. The sector and industry classifications of the SNA and SEEA have already been mentioned. A range of classifications related to specific resources, for example water, timber and biodiversity is used in each of the sections of this report.

For ecosystem accounting, the Common International Classification of Ecosystem Services (CICES 2016) is recommended as the starting point by the SEEA Experimental Ecosystem Accounting (UN 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.

2.3 Valuation

Monetary valuation of environmental and ecosystem stocks and flows is a critical issue for accounting. Valuation is covered in the SNA, SEEA Central Framework, and SEEA Experimental Ecosystem Accounting. The accounts for the Central Highlands span environmental and ecosystem accounting, and clearly distinguishing what is being valued is important. In particular, it is essential to identify the value of the benefit, which may be equated with the supply of goods and services within the economy (for example, water and timber), and distinguish this from the contributions of ecosystems services to those benefits (Figure 1.2).

Valuation is specifically addressed in the SNA in paragraphs 3.118 to 3.158, the SEEA Central framework in Section 2.7.3 and the SEEA Experimental Ecosystem accounting in Chapter 5. In these documents, the key principle of valuation is the exchange value. Additional information is found in Atkinson and Obst (2016). An exchange value 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 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. 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, service or asset 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, and exchange values do not include this.

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 from within the study area. In the case of VicForests, the information covers all operations in Victoria, not just the study area.

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 in the SNA) could be used to generate such values. For example, by using the net present value method. 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).

The contributions of ecosystem services to the goods and services (or benefits) supplied within the economy needs to be calculated. A range of valuation approaches is identified for ecosystem accounting in the SEEA Experimental Ecosystem accounting (UN 2014b, Section 5.5.2). A selection of these approaches was used to value the different ecosystem services in this report and are summarised in Table 2.1. Details can be found in the relevant sections later in this report.

The selection of an approach for a given ecosystem service depended primarily on the data available. The unit resource method was used for food 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 for food provisioning, cultural and recreational services have been successfully produced by the ABS in the production of Experimental Ecosystem Accounts for the Great Barrier Reef (ABS 2015a). For timber, information on stumpage was included in the Annual Reports of Vic Forests and with additional data on harvest areas and timber volumes that could be modelled for the study area.

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	Food provisioning* Cultural and recreational services ("tourism")
Stumpage	The value of timber sold, less harvesting and haulage costs	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 provisioning services for crops and fodder for livestock production (see UN 2014b, pp. 62-63)

The unit resource rent approach could not be used for water provisioning, as similar data were not available. Information about the costs of water supply is not separated from the costs of sewerage, in data from both the national level data from the ABS and the regional level 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. Past work in the area by Comisari *et al.* (2011) calculated negative rents. However, information on the replacement cost of water was available for desalination, use of recycled water, and the cost of water purchase from other areas. Information on the replacement value of water filtration was available from other areas and these could be applied using a benefit transfer. This replacement cost method for water was used in the Netherlands (Edens and Graveland 2014). The replacement cost method assumes that (1) if the service was lost it would be replaced by users, and (2) that 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 in November 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.

Values for biodiversity were 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. 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.

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 record this in ecosystem accounting is not yet clear in the SEEA.

3. Land

3.1 Introduction

The primary land account was based on land cover, with additional information added 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.

The land cover ecosystem functional units (LCEU) were built from land cover data that was mostly in 250m grids (the basic statistical unit). The land cover classes provided the structure for the accounting, showing the extent of ecosystem types, and the changing areas and uses of different land covers over time.

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.

Native vegetation was classified according to Ecological Vegetation Classes (EVC) (DELWP 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, 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 and Alpine Ash, and were more accurate for calculating the boundaries of ash-type forests and determining forest age. Our EVC groups were reconciled with the SFRI classification of dominant species.

Information on non-native vegetation was derived from the VLUIS (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 or 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.

The matrix of land cover by land use is shown in Table 3.1. Native forests were the dominant land cover with mountain and alpine ash, open and wet mixed forest and rainforest together accounting for 575,737 ha or 78% of the total area. Native timber production was the largest land use with 324,380 ha or 44% of total land use, followed by conservation with 239,019 ha or 32%. 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 area of total agricultural land use is 96,041 ha, but only 58,213 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, National Parks, private land, and water catchment. The classification is from the 2014 Land Use Tenure attribute data (Victorian Government 2015a) (Figure 3.3). The State Forests, administered by the Department of Environment, Lands, Water and Planning (DELWP) are classified by Forest Management Zones. The area of native forest timber production includes the Forest Management Zones of General Management Zone and Special Management Zone where management is for timber production, but recognising that harvesting is not permitted in all areas under the Code of Forest Practices (see Appendix A3.1).

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

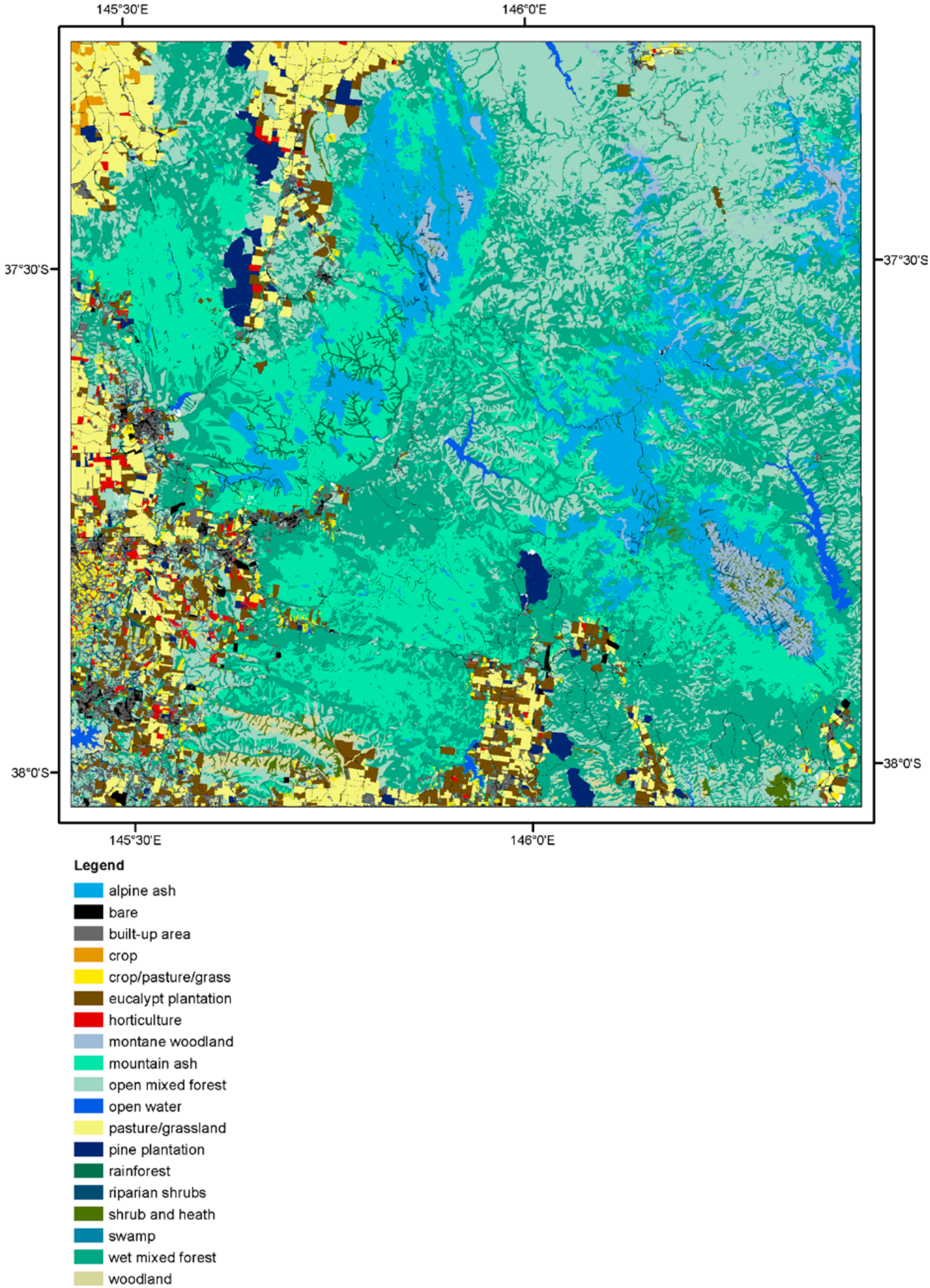


Figure 3.2. Map of land use classes across the Central Highlands region in 2015

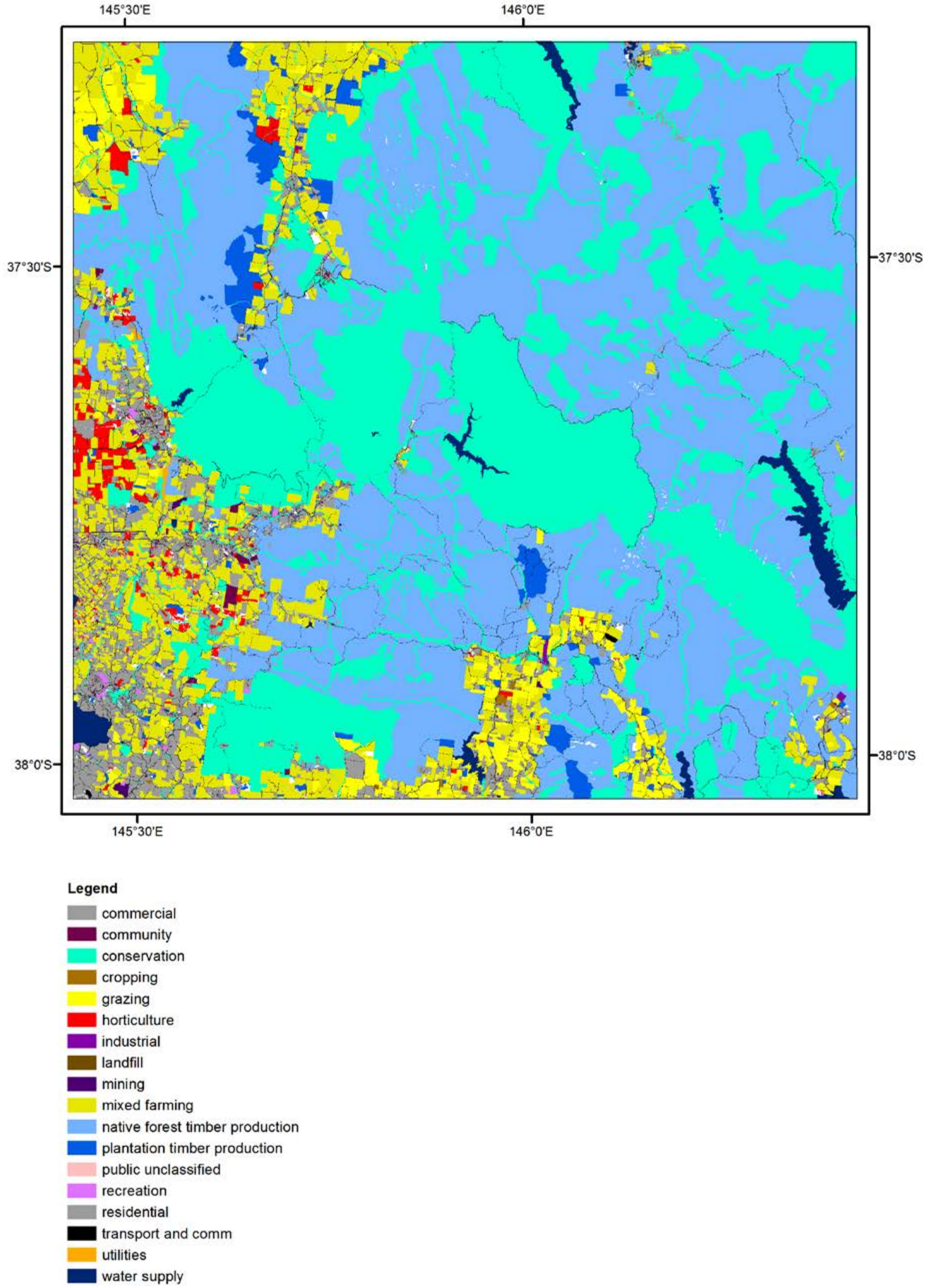


Figure 3.3. Map of land management classes across the Central Highlands region in 2015

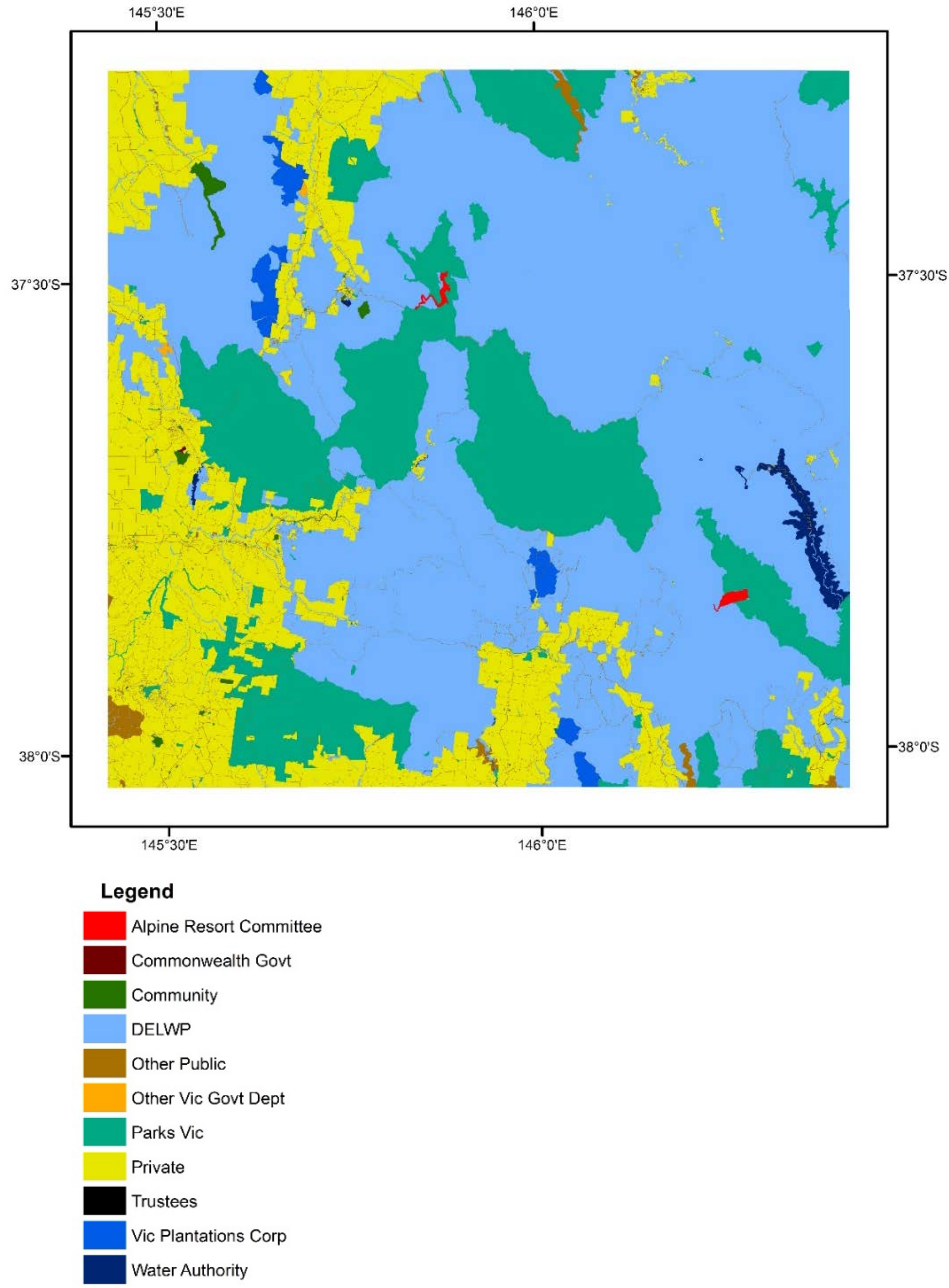


Table 3.1. Area of land (ha) in each land cover by land use class within the study area in 2015

Area (ha)	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	0		65	298	15	1,187
Conservation	28,238	390	1					10,252	53,984	63,440		38		5,523	1,966	3,959	4	1,299	65,610	4,315	239,019
Cropping				42		147	15		2			47	51		0				1		305
Grazing	0			607		4,549			377	485		11,427	1,128		23	17		0	1,214	12	19,840
Horticulture		5				968	2,180		62			3,299	297		61	3		0			6,876
Industrial		358																			358
Landfill															17			7	1		26
Mining		302																			302
Mixed farming	124	31		494	8,421	12,866	1,554		3,161	7,453		25,832	652	33	902	80		0	6,997	420	69,020
Native timber production	36,109	5	1					3,579	82,240	68,540				86				951	132,182	687	324,380
Plantation production						3,376							8,586								11,962
Recreation	0	53	48			193		3	53	94		93	50		37	5		35	87	12	764
Residential	3	544	16,724			3,212	318	0	419	8,058		3,821	259	0	1,466	152		0	4,012	620	39,608
Transport & communication		9,250																			9,250
Unclassified	0	158	0						86	1,404				4	257	179		1,319	813	100	4,320
Utilities		17							24	114					15	0		118	228	9	524
Water storage		63	0		0	0			59	2,178	4,361	0	0		35			244	1,639	381	8,961
Total	**64,476**	**11,832**	**16,907**	**1,143**	**8,421**	**25,310**	**4,067**	**13,835**	**140,583**	**151,951**	**4,361**	**44,582**	**11,025**	**5,646**	**4,812**	**4,397**	**4**	**4,064**	**213,081**	**6,577**	**737,072**

3.5 Anomalies in land classification

When the land cover and land use data are overlaid, anomalies occur because the two spatial datasets are derived from different data sources and at different scales. Land cover data is 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 is 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 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) some differences occur because apparently different land covers and land uses can co-occur. For example, grazing in native forest or plantations, 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.

Some anomalies identify interesting information about the intersection of land cover and land use. For example, native forest on private land could attract similar conservation management as the same vegetation types on public land.

Examples of anomalies in land classification are given in Appendix 3.5. The detection and correction of anomalies meant that the resultant data on land cover and land use could be used with confidence. This work can be fed back to primary data sources to help improve its quality.

3.6 Forest age

Forest age was considered important because it relates to quantities of assets such as water, carbon, timber, tourism and biodiversity, and is needed to calculate various estimates contained in these component accounts. In addition, forest age can be used as a measure of ecosystem condition (see 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.

Fires before 2009 were mapped as a fire boundary, and the impact on all ash forest within this boundary was assumed to be stand replacement. 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 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. 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.

Age Class

0
1
2
3
4
5

(a) **(b)**

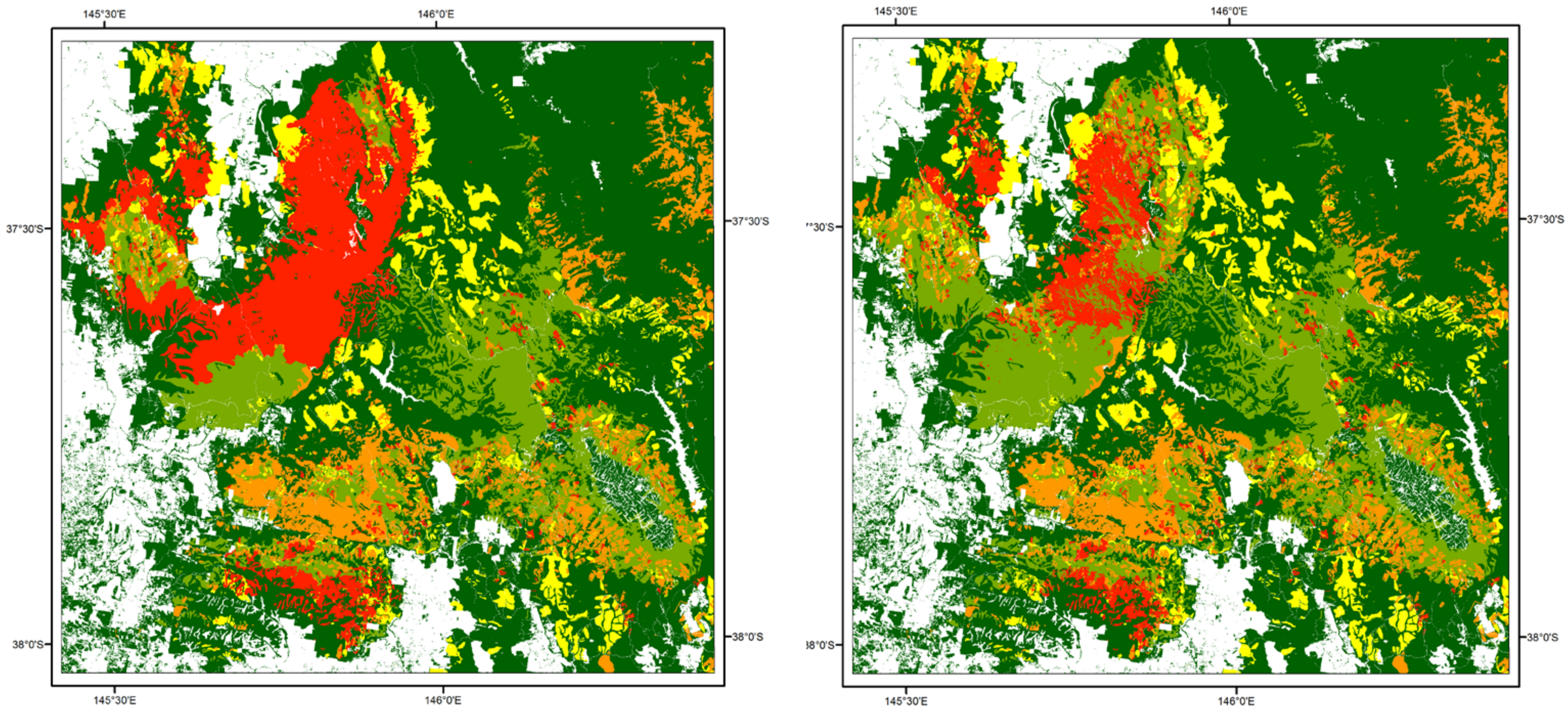
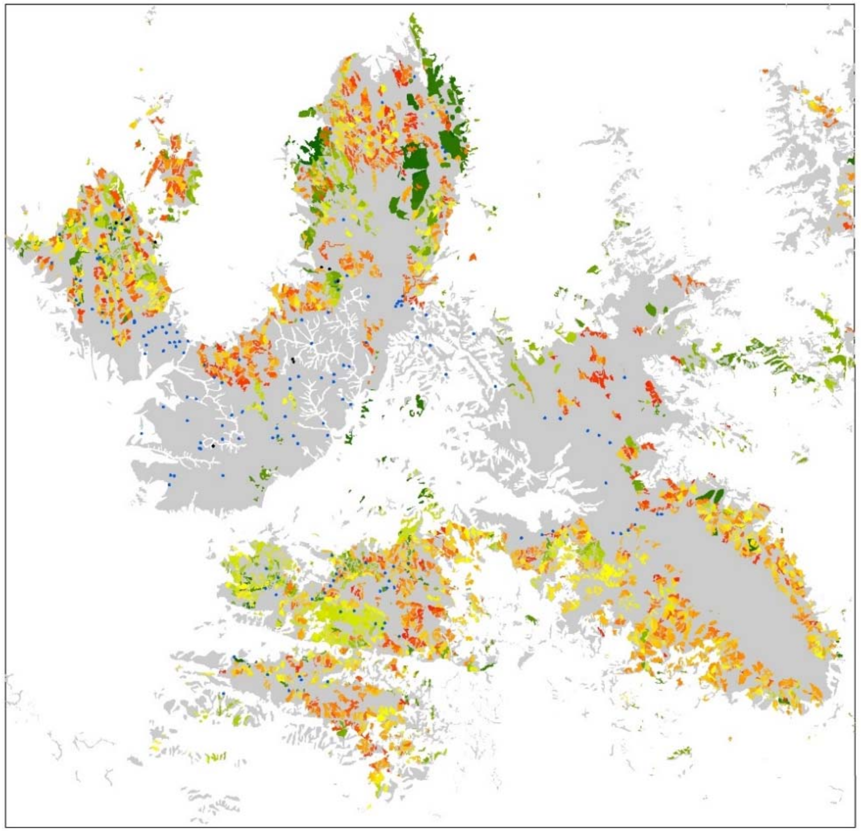


Figure 3.5. Spatial distribution of (a) the history of logging and subsequent regrowth of forests, compared with (b) forest age pre-2009 fire

(a) History of logging in montane ash

● Monitoring sites   Montane ash forest area

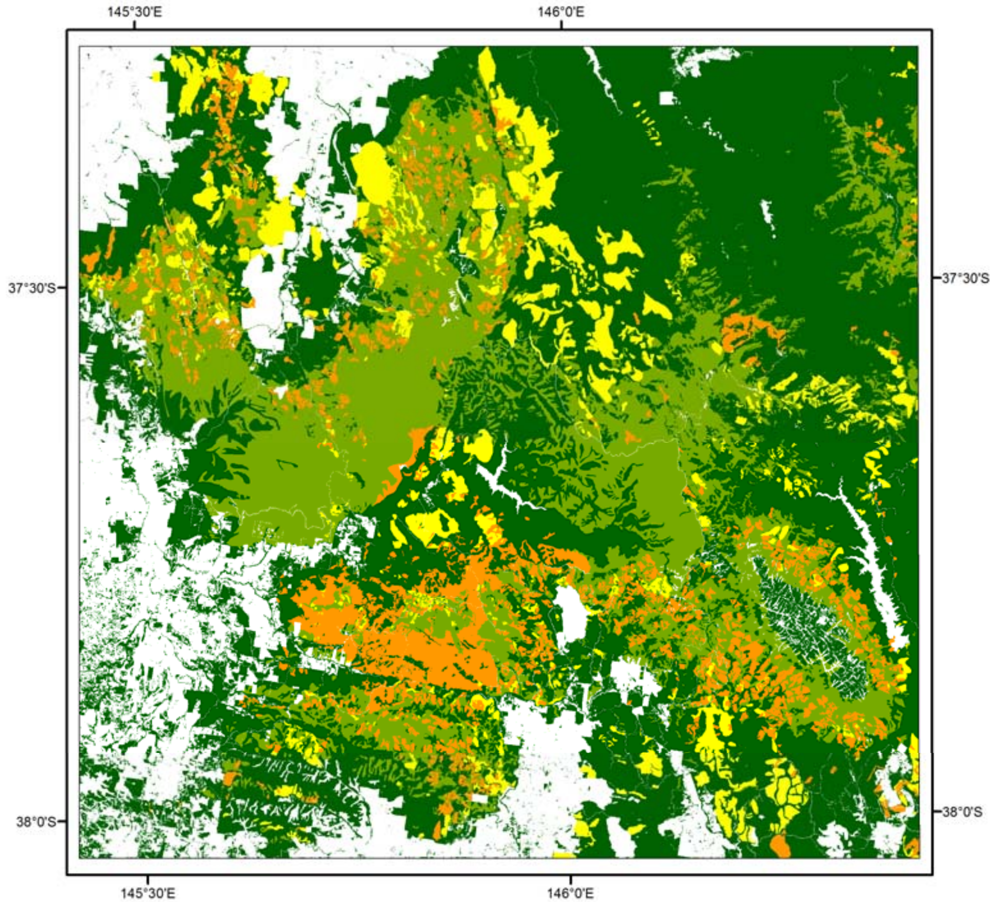
Harvesting by decade: 1960s, 1970s, 1980s, 1990s, 2000s



(b) Forest age classes in all forest land

Age classes: 0: non-forest, 1: before 1939, 2: 1939 - 1959, 3: 1960 - 1982, 4: 1983 - 2008.

Age Class
0
1
2
3
4



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. 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.

The water supply catchments cover an area of 157,000 ha in the Yarra Ranges, with 115,149 ha within the study area. Only some of this area is protected and 8,961 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.

Two accounts were prepared: a water asset account and an ecosystem service account for water provisioning. In the Central Highland, the ecosystem service of water provisioning that is used in water supply, 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.

The water accounts were derived from two main sources of data: (1) Central Highlands study area biophysical data, and (2) Melbourne Water Corporation storage and supply data, and financial statements (Melbourne Water 2016).

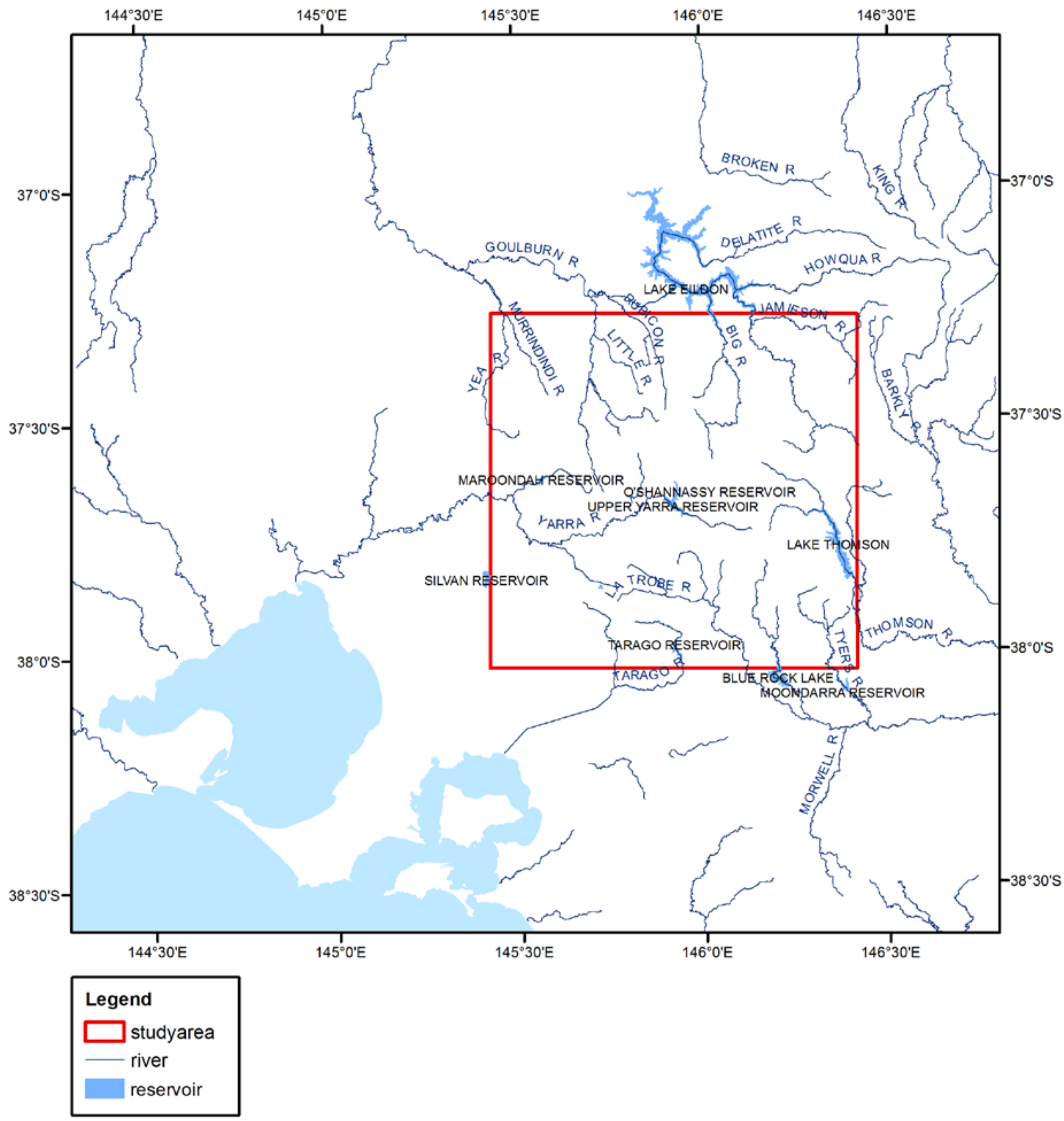
4.2 Water assets

A water asset account was prepared for the water stored in reservoirs within the study area, as well as the runoff within the study area that supplied the reservoirs. The scope of the account does not include the water in rivers, farm dams and groundwater. In addition to water additions and reductions recorded in the water asset account for reservoirs, there are other actual or potential inflows to the reservoirs from other sources, including the desalination plant at Wonthaggi and water transfers from Lake Eildon.

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, as there was no easy way of adjusting for the difference in geographic scope.

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



4.2.1 Data sources and methods

Data describing the characteristics of the ten reservoirs were obtained from the Melbourne Water website. 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 region

Reservoir	Capacity (GL)	Catchment area (ha)	River supply
Thomson	1068	48,700	Thomson River
Upper Yarra	200	33,670	Upper Yarra River
Tarago	37	11,400	Tarago River
Maroondah	22	10,400	Watts River
O'Shannassy	3	11,900	O'Shannassy River

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.

Change in the water stored in reservoirs represents the balance between inflows and outflows, including supply to users. Inflows of water from the catchment area are determined by rainfall, soil water storage capacity, vegetation cover, and evapotranspiration. Outflows of water include evaporation from reservoirs, supply of water from reservoirs to consumers in Melbourne, releases of water for environmental flows and irrigation, and a small amount for hydroelectricity generation.

Rainfall and pan evaporation data were derived from the eMast database (eMast 2016). The data represent the average across the landscape of the study area derived as the average of the eMast 0.01 degree raster cell values resampled to 0.0001 degree to align with the study area.

Water abstraction includes consumption by households and businesses, government and non-governments organisations. This includes water used by schools, universities, hospitals, parks, sportsgrounds, and other institutions. Non-revenue water abstraction includes that used for firefighting and leakage from pipes. Water releases include for environmental releases, refreshening flows and extra allocations.

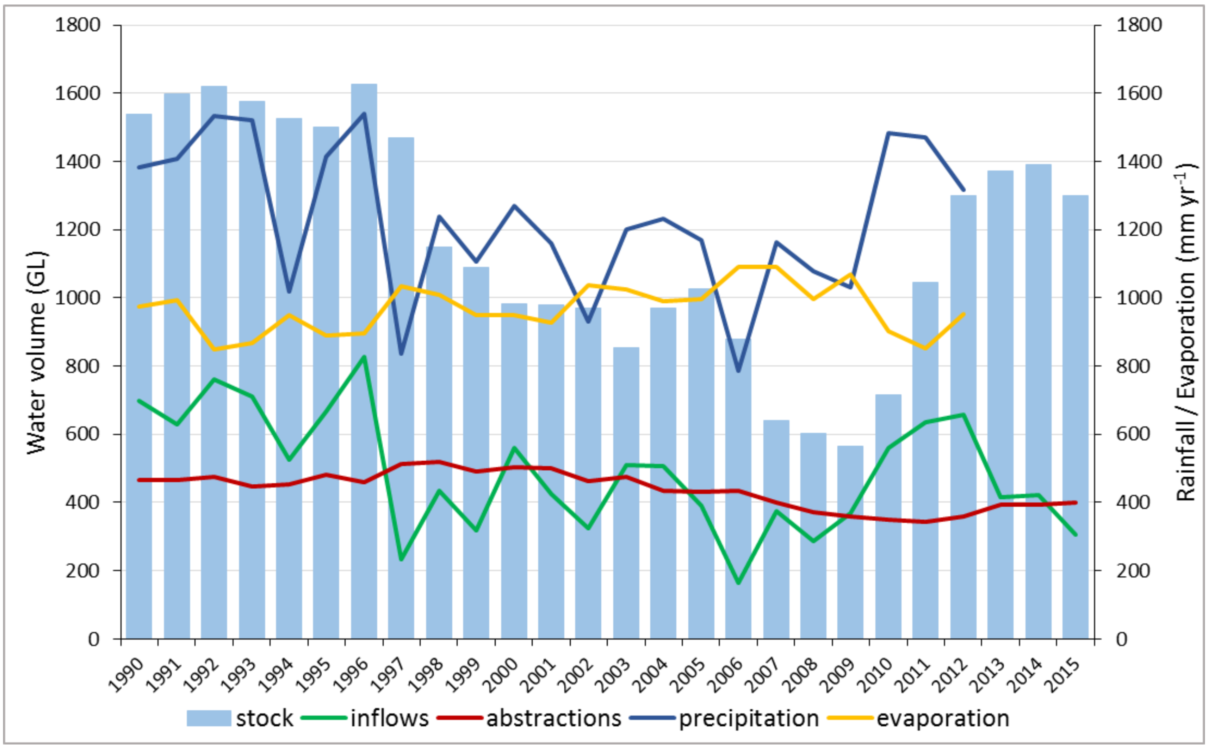
4.2.2 Results

Water asset accounts were prepared for the calendar years 1990 to 2015, in the form of a table (Appendix 4. Water) and summarized in Figure 4.2. The figure shows the time series of water stocks, inflows from precipitation and runoff, and reductions due to abstraction and evaporation. Large variations in stocks, additions and abstractions of water occur annually and as trends during the 25-year period (Figure 4.2).

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. Inflow represents the annual inflow (GL yr^{-1}) to the reservoirs, mainly as runoff of surface water from the forested catchments. The pattern of inflow closely follows the pattern of rainfall. However, runoff is also influenced by season of rainfall and antecedent soil water content. Mean annual river flow for the Yarra River is 429 GL yr^{-1} and the Tarago/Bunyip River is 114 GL yr^{-1}.

The water abstracted in Figure 4.2 is the supply of water by Melbourne Water to its customers. 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. Overall, there is a trend of decreasing water consumption, which is seen in state estimates by the ABS (ABS 2015b). The decrease during, and since, the millennium drought is due to 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 4.2. Time series of precipitation, water storage (stock), inflow (runoff), evaporation and supply (abstraction) for the Melbourne Water reservoirs and catchments within the study area



4.3 Water provisioning service and water supply

4.3.1 Data sources and methods

The physical estimate of the water provisioning service is the runoff or water yield from the study area, which provides inflows to the reservoirs operated by Melbourne Water. 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 each year was estimated using a spatially explicit continental water balance model calculated monthly across our study area (Guo *et al.* 2002, eMAST 2016). 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).

The pattern of 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 fire or clearfell logging for montane ash forest and rainforest, and clearfell logging for mixed species forest. Reduction in water yield is shown as a proportion of the pre-disturbance amount, with an increase for the first 1 to 3 years, then a decrease with the greatest reduction occurring between ages of 13 – 49 years and peaking at 25 years (Figure 4.3). 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 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 the Appendix (Section A4.3).

Melbourne Water uses water provisioning services to supply the city of Melbourne and nearby areas. The water supplied by Melbourne Water is given in their annual reports, 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), DELWP 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.

Figure 4.3. Reduction in water yield in ash forest estimated as a proportion of the pre-disturbance amount in regrowth and old growth forest

Source: Kuczera (1987) for old growth model

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

Reservoir	Water supply (GL)	Source of Entitlement
Thomson	639 (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 water provisioning service based on calculated runoff (water yield) from the catchments within the study area is summarised in Figure 4.4, and 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 as this 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.

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 4.5a and 4.5b 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 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 4.5b, which indicate areas of forest that have been clearfelled and are now regrowth, and the subsequent reduction in runoff.

Figure 4.4. Annual water yield from the catchments within the study area, which provide inflow to the reservoirs

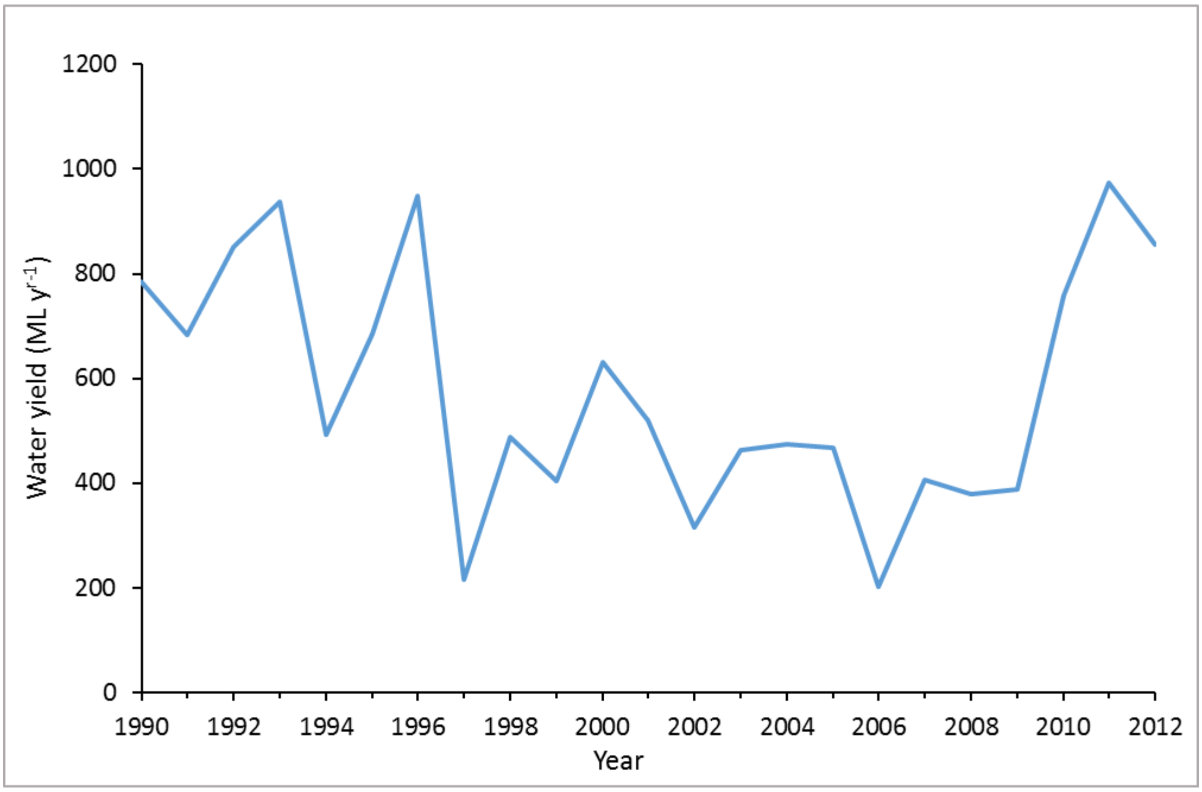


Table 4.3. Water provisioning service of water yield (ML yr^{-1}) for the whole study area classified by land cover, using an average annual total for each 5-year period

Land cover	1990	1995	2000	2005	2010	2015
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 and forest age-class, using an average annual total for each 5-year period

Land cover	Age (yrs)	1990	1995	2000	2005	2010	2015
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

Figure 4.5a. Spatial distribution of runoff in 2012 calculated assuming a constant age of the forest

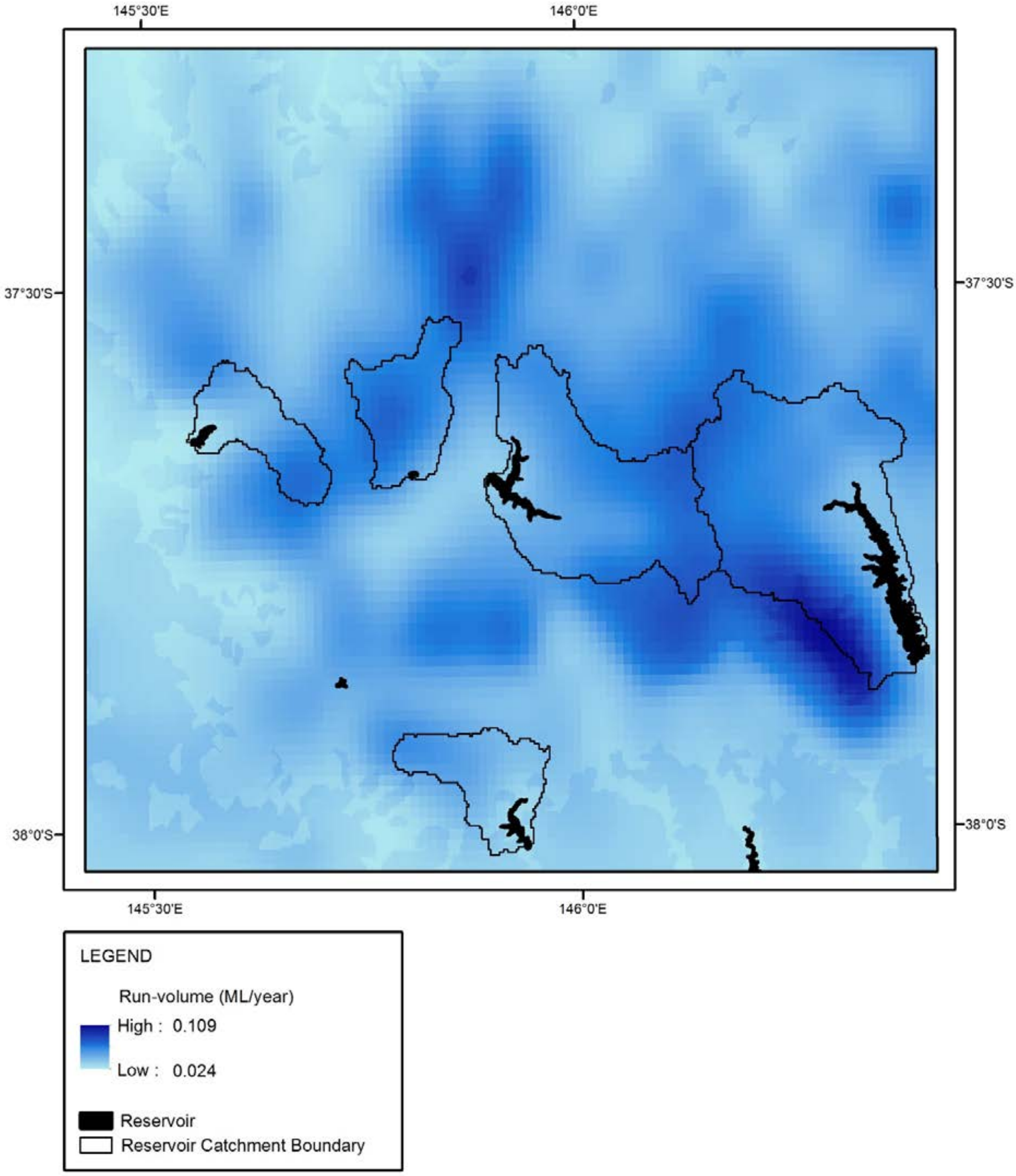
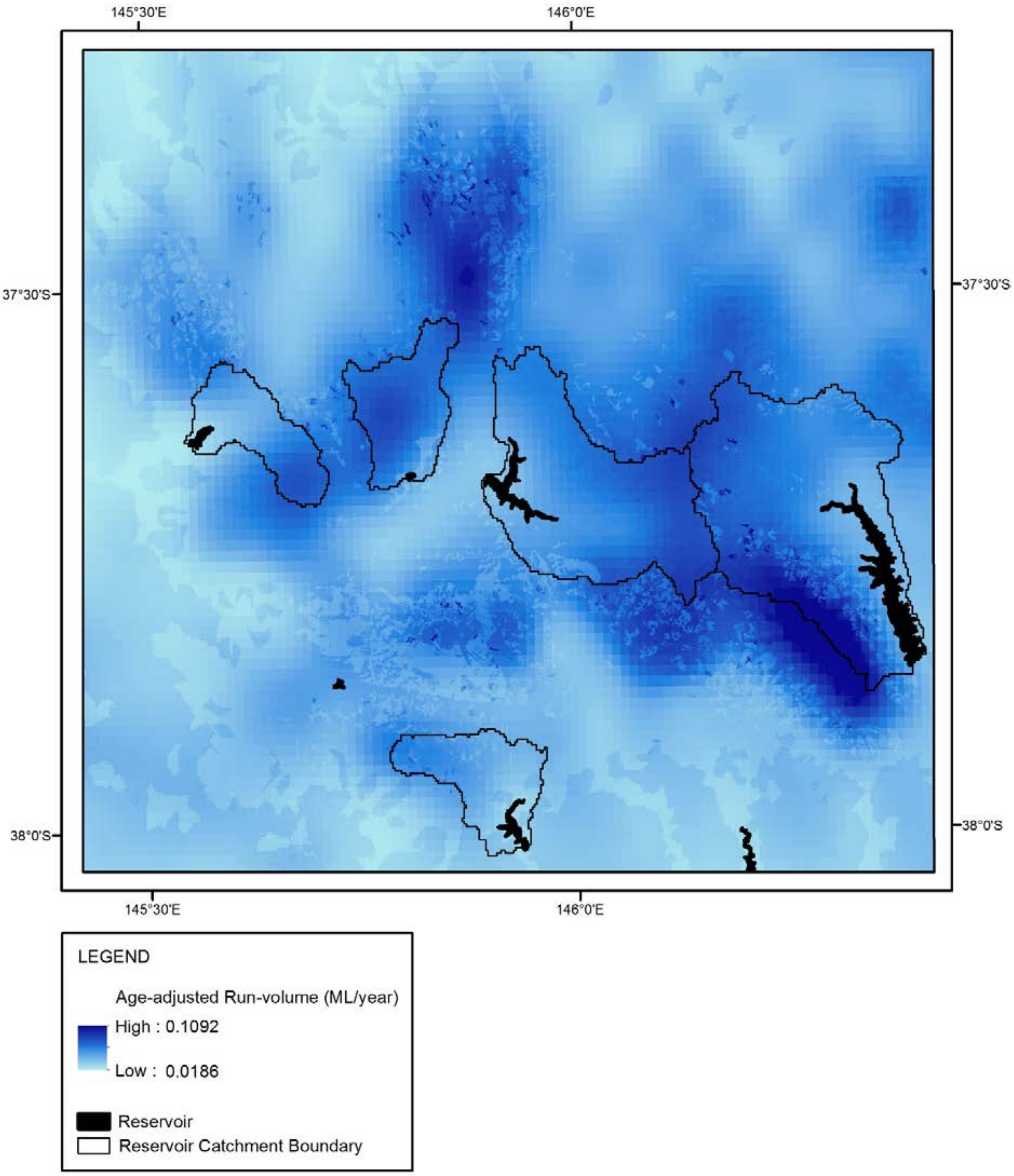


Figure 4.5b. Spatial distribution of runoff in 2012 calculated with changing forest age due to regeneration from wildfire and logging



4.4 Valuation of the water provisioning service and water supply

The water supplied into the economy is the end result of a combination of fixed capital (reservoirs, water mains, pumps, etc.), labour and other inputs, as well as ecosystem services. The volume of water supplied and the revenue received from this supply is known from the annual reports of Melbourne Water, which is owned by the Victorian Government (Melbourne Water 2015). In this account, the runoff is taken to be equal to the volume of the water provisioning service, but the value of the water supplied is not equal to the value of the water provisioning service. This is because the values of the fixed capital, labour and other inputs need to be deducted. In addition, the price of water in Victoria is regulated (see Melbourne Water 2008), which presents another complication that is discussed later. In addition, the water supplied to the economy uses the additional ecosystem service of water filtration, but separate estimates of this have not been made.

4.4.1 Data sources and methods

Melbourne Water financial accounts taken from their Annual Reports were the starting point for providing information on the revenue from water supply as well as production costs and other information. These data were used to generate an estimate of the value added by the company, aligned with the concepts of Industry Gross Value Added in national accounting.

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

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, which would likely lead to the calculation of negative resource rent. These issues have been noted previously in Australia by Comisari *et al.* (2011) and in the Netherlands by Eden and Graveland (2014). 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.

Lack of data also was the reason for rejecting the production function approach. 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. As such, the production function approach would require detailed information on all of the water consumers in Melbourne and, in particular, the value of the water and all other inputs to the productive activities of the business.

Therefore, the replacement cost method was used to value the water provisioning services, broadly following the method of 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.

The physical volume of the water provisioning service was taken to be the runoff calculated as part of the production of the asset account (Appendix 4. Water). 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 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 $1.37 per kilolitre ($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 has not produced any water since it was opened in December 2012. It is unclear if this cost 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. It 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, and it is not known if the water can be transported via the existing water supply network. The price for recycled water charged by Melbourne Water provides a guide: in 2006-07 revenue from recycled water was $2.0 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.

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.

Water filtration services are also an input to production of water by Melbourne Water. However, these services were not estimated separately owing to lack of data for the region. 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).

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 in Table 4.5. The revenue, costs, profit (loss) and industry value added calculations 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 steeply since 2008, with revenue increasing by 500% since 2007-08 (Figure 4.6).

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 $267 million in 2014-15, or $2319 ha^{-1}** (based on the catchment area within the study area of 115,149 ha).

The physical volume and value of ecosystem services used by Melbourne Water are shown in Table 4.6. 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 4.5. It is not known if the amount of water could be supplied by transfer from other regions (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 higher than the value of water revenue until 2009 (Figure 4.7), when revenue began to increase sharply and the Wonthaggi Desalination Plant was commenced.

Figure 4.8 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). When water is in short supply, such as during drought, a key response is to impose water restrictions (such as, no watering of gardens).

Figure 4.6. Volume and value of water supplied to Melbourne Water

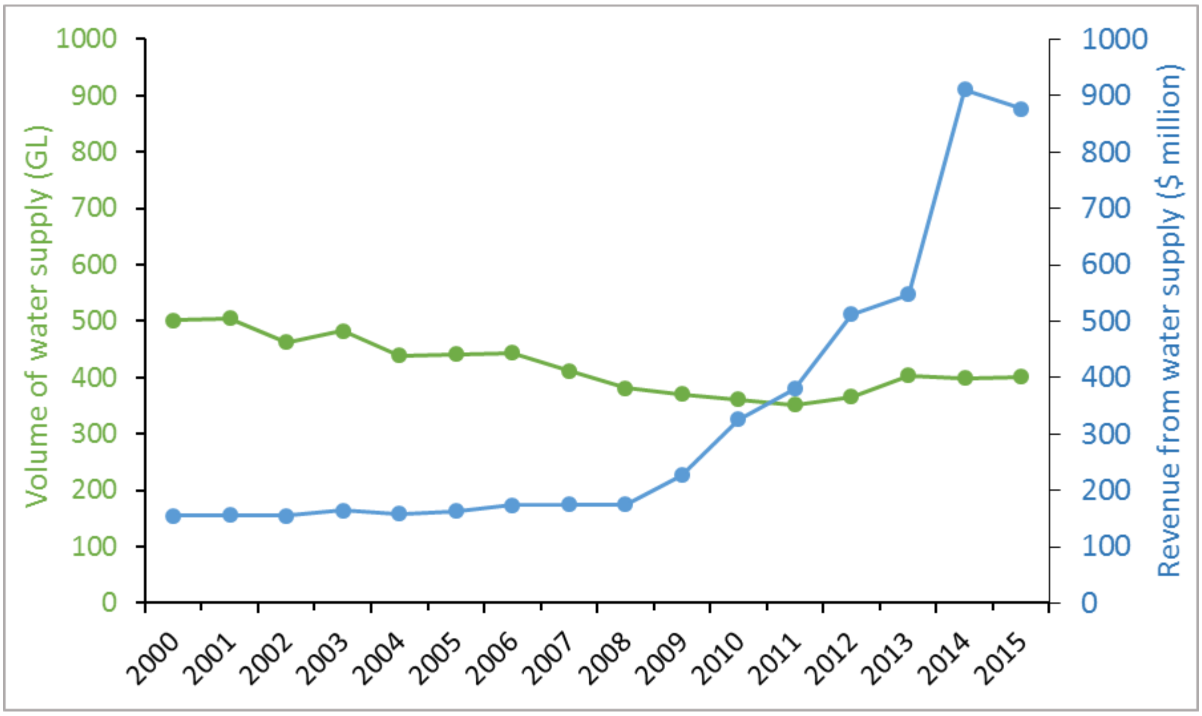


Figure 4.7. Value of water provisioning service used and revenue from water supply

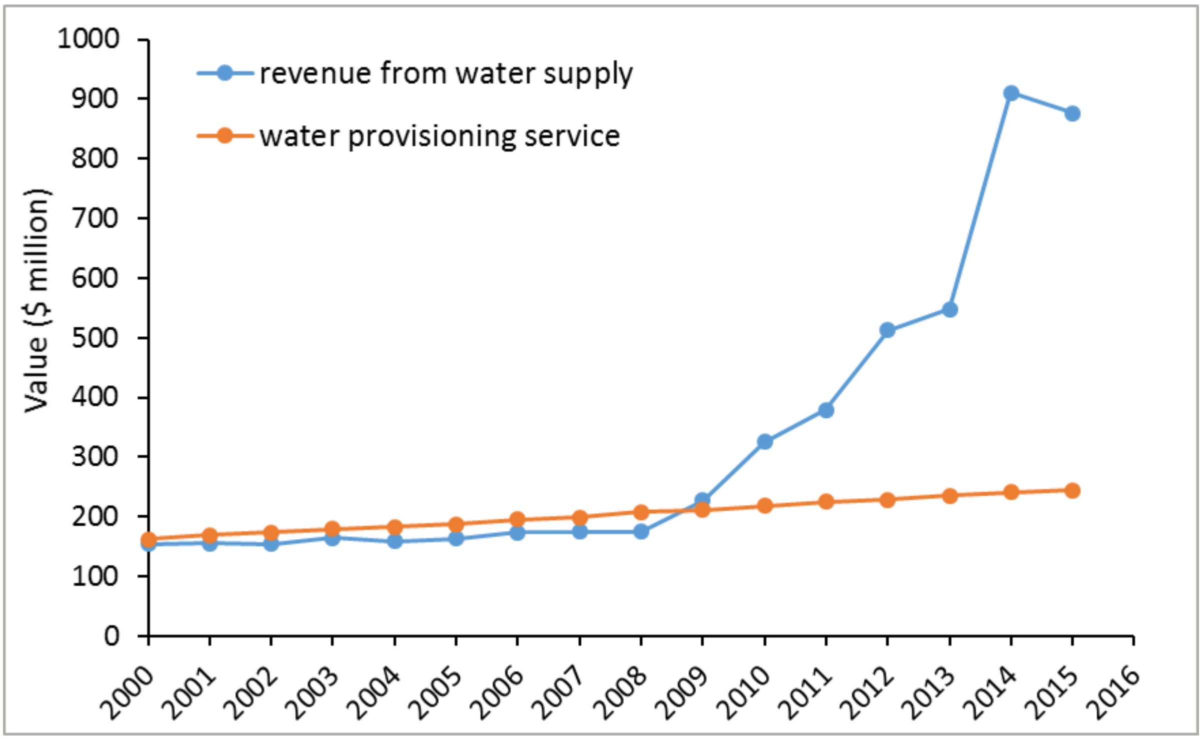


Figure 4.8. Volume of the water provisioning service and the water supplied

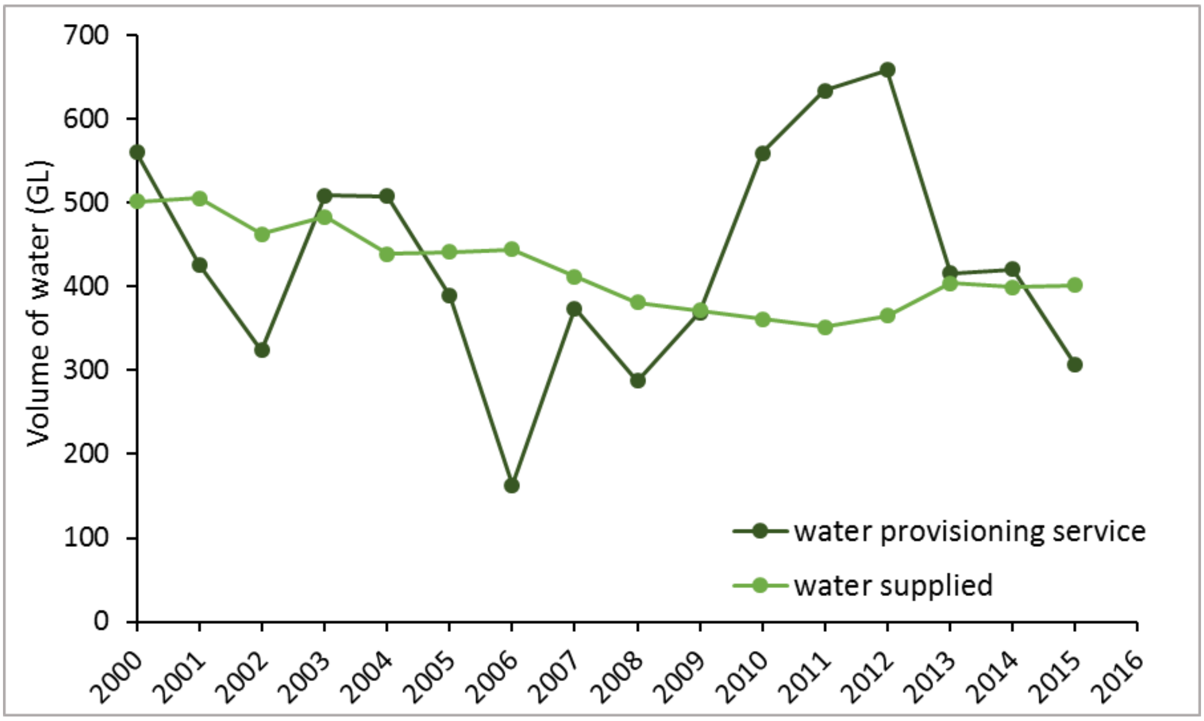


Table 4.5 Accounts for the volume and value of water supply and water provisioning service by Melbourne Water, and the financial accounts that include all Melbourne Water activities

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Revenue and other income	478	461	480	511	504	528	593	588	600	732	858	997	1240	1,258	1,717	1,750
Expenses	281	332	350	361	380	402	424	455	533	604	672	839	970	1,298	1,627	1,634
Profit/(loss) ($m)	204	176	186	218	179	189	228	177	93	174	238	214	373	(62)	132	160
Wages, employee benefits ($m)	34	34	34	37	40	42	47	51	61	65	73	75	104	87	101	106
Estimated IVA ($m)*	239	210	220	256	219	230	274	228	154	239	311	289	476	25	233	267
Total assets ($m)	2,852	2,954	2,995	3,051	3,132	3,263	3,769	3,969	4,436	5,421	8,948	9,755	10,034	14,498	14,339	14,440
Total liabilities ($m)	1,685	1,657	1,667	1,670	1,723	1,770	1,929	2,083	2,449	3,419	4,930	5,380	5,495	10,117	9,856	9,715
Net assets ($m)	1,167	1,297	1,328	1,381	1,409	1,494	1,804	1,886	1,987	2,002	4,018	4,375	4,539	4,381	4,483	4,725
Number of employees (FTE)	481	488	498	512	501	537	614	645	729	807	828	841	**834	832	812	899
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
Revenue from supply ($m)	155	156	154	165	159	164	174	175	176	227	326	380	512	548	911	876
Water provision services																
Volume used (ML)	560,063	426,363	324,202	508,840	507,961	389,269	163,240	374,236	287,465	368,941	559,363	633,776	658,286	415,665	420,935	306,258
Value used ($m)	91	72	56	91	93	73	32	74	60	78	122	143	151	98	101	75
Water in storage																
Volume (ML)	980,775	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

*Depreciation and amortisation are added to profit (loss) before tax and wages and employee benefits. Assumes no taxes or subsidies on products. Assumes no taxes or subsides on products.

**Annual Report unclear whether FTE or total number

Table 4.6 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

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 Highland 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 values 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 A4.1), 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 value 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 clearfell logging and slash burning were based on the results in Keith *et al.* (2015). Areas logged by clearfelling for all forest types were identified from the spatial data of logging history. 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).

After logging, carbon stocks consisted of dead biomass from the remaining slash that decomposed over time, and living biomass in the regenerating forest where carbon accumulation followed the growth curve for the forest type (Appendix A5.2.1.2).

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 approximately 1.6 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.

5.3 Ecosystem services from carbon sequestration

5.3.1 Results

5.3.1.1 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 region. The physical volume of this service is shown in Table 5.2a. An additional estimated 0.05 MtC yr^{-1} could be added to the eucalypt plantation category in 2010-15 to account for the increase in plantation area over that time. 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.

Figure 5.1 Spatial distribution of carbon stock density in the Central Highlands study area in 2015

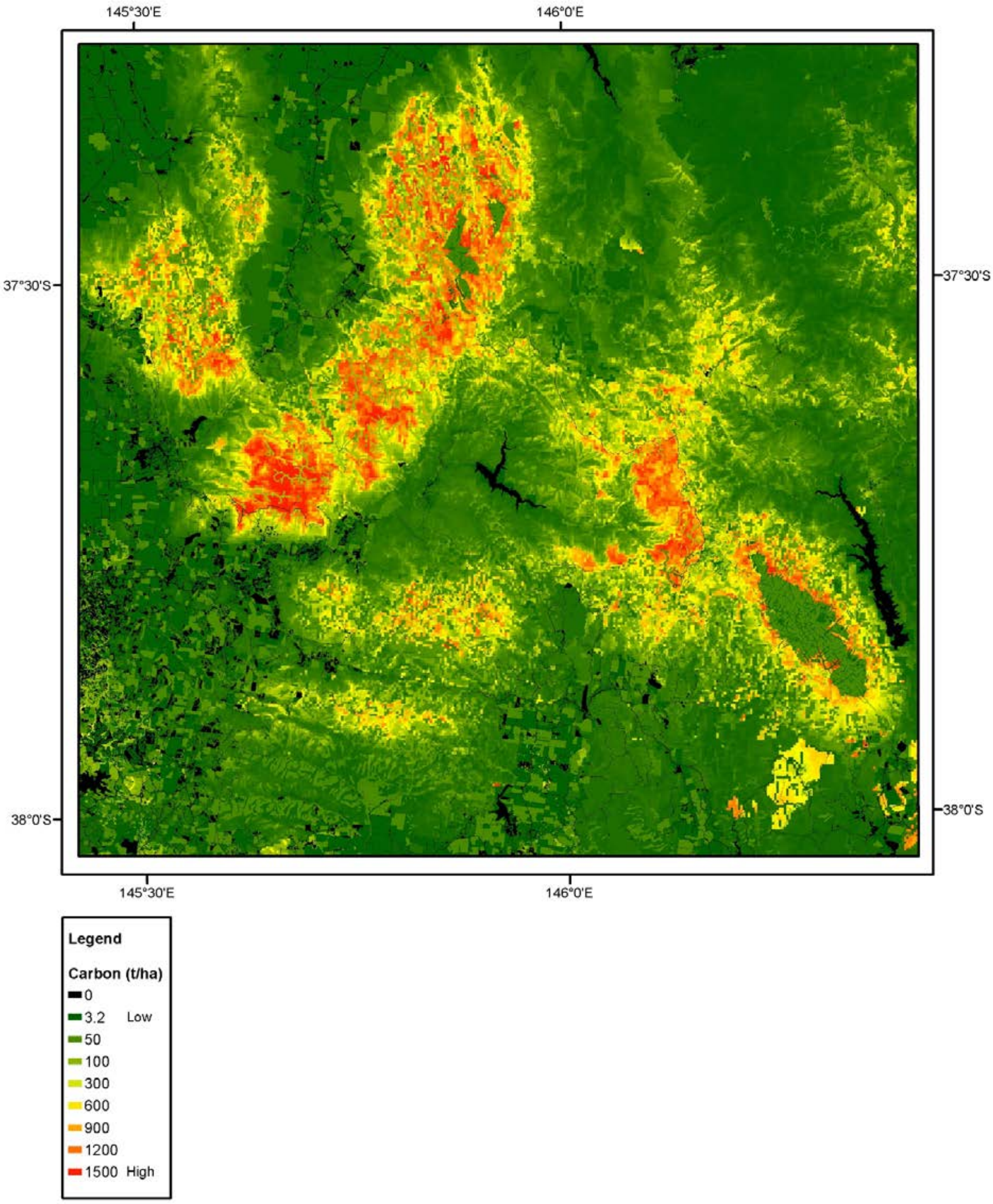


Table 5.1. Total carbon stock in each land cover class within the study area

Land cover	Total carbon stock (MtC)					
	1990	**1995**	**2000**	**2005**	**2010**	**2015**
Montane woodland	2.1	2.1	2.1	2.2	2.1	2.1
Swamp	0.0	0.0	0.0	0.0	0.0	0.0
Shrub/heath	0.1	0.1	0.1	0.1	0.1	0.1
Woodland	1.0	1.0	1.0	1.0	1.0	1.0
Open mixed forest	6.6	7.4	8.2	9.1	9.7	10.7
Mountain ash	47.5	49.2	50.8	52.1	53.1	56.6
Wet mixed forest	18.8	20.7	22.9	25.2	26.9	29.2
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
Bare	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
Horticulture	0.0	0.0	0.0	0.0	0.0	0.0
Eucalypt plantation	3.9	3.9	3.9	3.9	3.8	3.9
Pine plantation	0.6	0.6	0.6	0.6	0.5	0.6
Crop	0.0	0.0	0.0	0.0	0.0	0.0
Built-up area	0.3	0.3	0.3	0.3	0.3	0.3
Open water	0.0	0.0	0.0	0.0	0.0	0.0
Alpine ash	35.6	36.6	37.4	38.3	38.4	39.5
Total	**118.6**	**124.1**	**129.6**	**135.1**	**138.0**	**146.2**

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)				
	1990-95	**1995-00**	**2000-05**	**2005-10**	**2010-15**
Montane woodland	0.002	0.003	0.003	-0.019	0.003
Swamp	0.000	0.000	0.000	0.000	0.000
Shrub/heath	0.000	0.000	0.000	-0.002	0.002
Woodland	0.001	0.001	-0.001	-0.002	0.001
Open mixed forest	0.155	0.164	0.182	0.121	0.183
Mountain ash	0.339	0.310	0.268	0.200	0.704
Wet mixed forest	0.393	0.439	0.458	0.331	0.457
Rainforest	0.006	0.006	0.006	-0.001	0.003
Riparian shrubs	0.000	0.000	0.000	-0.001	0.001
Bare	0.000	0.000	0.000	0.000	0.000
Pasture/grassland	0.000	0.000	0.000	0.000	0.000
Horticulture	0.000	0.000	0.000	0.000	0.000
Eucalypt plantation	0.000	0.000	0.000	-0.033	0.033
Pine plantation	0.000	0.000	0.000	-0.018	0.018
Crop	0.000	0.000	0.000	0.000	0.000
Built-up area	0.000	0.000	0.000	-0.001	0.001
Open water	0.000	0.000	0.000	0.000	0.000
Alpine ash	0.202	0.172	0.182	0.006	0.227
Total	**1.099**	**1.096**	**1.099**	**0.580**	**1.635**

Table 5.2b. Physical volume of gross annual additions to carbon stocks from growth in the Central Highlands

Land cover	Annual additions to carbon stocks (MtC yr-1)				
	1990-95	**1995-00**	**2000-05**	**2005-10**	**2010-15**
Montane woodland	0.003	0.003	0.003	0.003	0.003
Swamp	0.000	0.000	0.000	0.000	0.000
Shrub/heath	0.000	0.000	0.000	0.000	0.002
Woodland	0.001	0.001	0.001	0.001	0.001
Open mixed forest	0.167	0.194	0.212	0.192	0.190
Mountain ash	0.665	0.704	0.751	0.761	0.875
Wet mixed forest	0.426	0.488	0.519	0.488	0.484
Rainforest	0.006	0.006	0.006	0.006	0.003
Riparian shrubs	0.000	0.000	0.000	0.000	0.001
Bare	0.000	0.000	0.000	0.000	0.000
Pasture/grassland	0.000	0.000	0.000	0.000	0.000
Horticulture	0.000	0.000	0.000	0.000	0.000
Eucalypt plantation	0.000	0.000	0.000	0.000	0.033
Pine plantation	0.000	0.000	0.000	0.000	0.018
Crop	0.000	0.000	0.000	0.000	0.000
Built-up area	0.000	0.000	0.000	0.000	0.001
Open water	0.000	0.000	0.000	0.000	0.000
Alpine ash	0.330	0.326	0.324	0.372	0.427
Total	**1.599**	**1.724**	**1.818**	**1.822**	**2.042**

5.3.1.2 Effects of land use

The effect of land use was considered as two components: (1) carbon sequestration as a net change in carbon stock per year, and (2) the change in carbon stock density and total carbon stocks in an area. 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.

All forest areas sequestered carbon in each time period, except the area that has been logged, and the area that was burnt in 2009. The area that has been logged consisted of all recorded cutover areas in the spatial data, which began in 1962. **Gross reduction in carbon stock from the area logged was -14 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 -1.0 MtC, or an average rate of -0.04 MtC yr^{-1}.**

The area available for logging had net sequestration of 14.5 MtC over the 25 years, with an average rate of 0.58 MtC yr^{-1}. This is public land zoned to permit timber production; it is not reserved, and has not been harvested since 1962 (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 1962) was 29.3 MtC over 25 years.

Carbon stock loss from all fires within the study area over the 25 years was -3.5 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.

The change in carbon stock density (tC ha^{-1}) due to the effect of land use type was assessed by comparing stocks in the same forest type but under different land use activities. The area analysed was restricted to the montane ash forest (Mountain Ash and Alpine Ash). The area logged represented logged since 1962. The area unlogged included areas logged before 1962, areas burnt and regenerated, and areas both available and unavailable for logging. **Logged areas had an average of 143 tC ha^{-1} lower carbon stock density than unlogged areas. This represented the carbon stock loss due to logging. Alternatively, this difference represented the carbon sequestration potential if logged forests were allowed to continue regrowing without repeated logging.**

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).

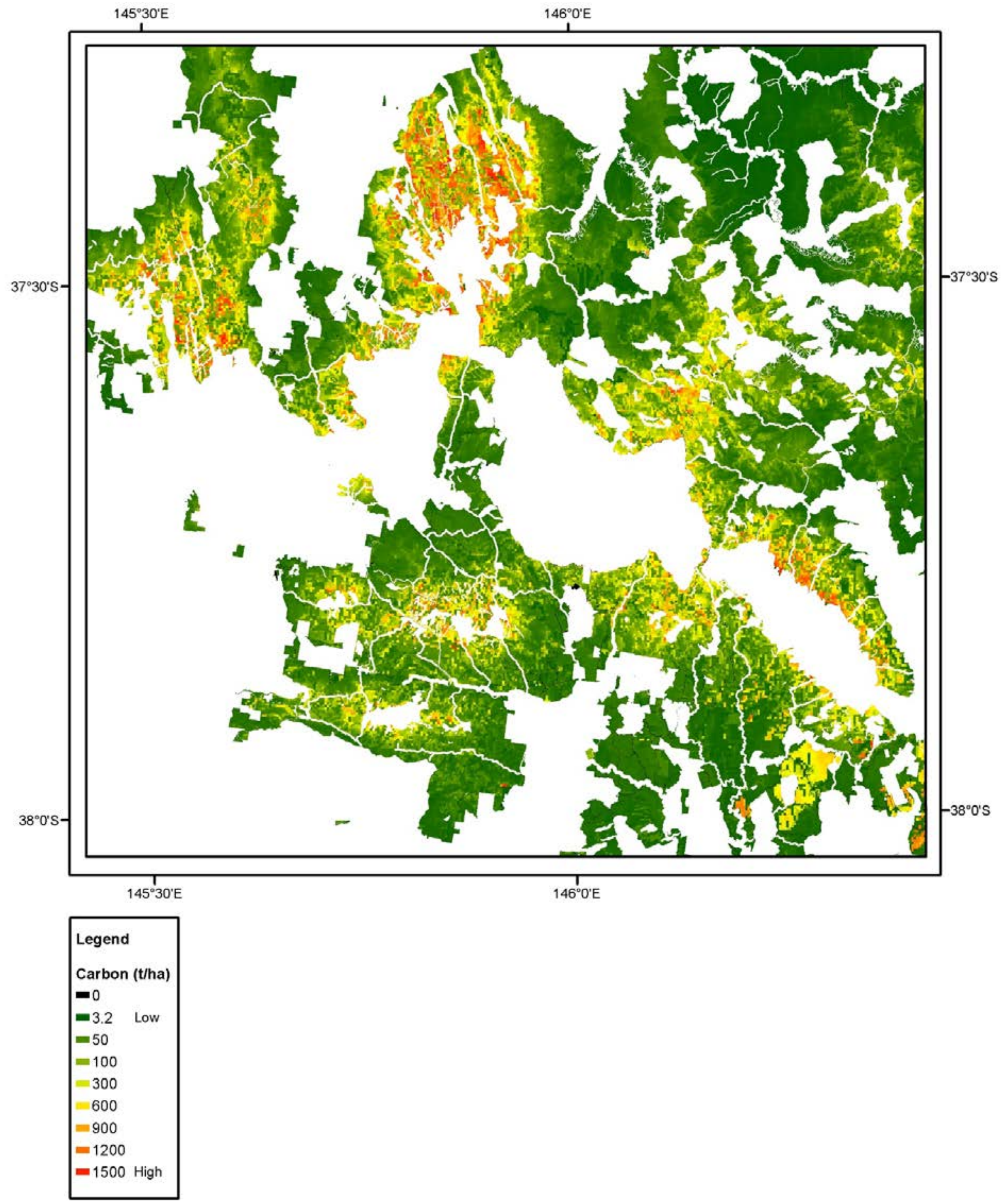
The spatial distribution of carbon stocks across the study region (Figure 5.1) is shown for specific land use areas to differentiate the areas that have been logged, the areas that are available for logging, and specifically, the montane ash forest type that generally has high carbon stocks (Figure 5.2). The effect of logging on changing the carbon stock is illustrated in Figure 5.3, 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.

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 logging area, and (3) total area disaggregated by burnt areas

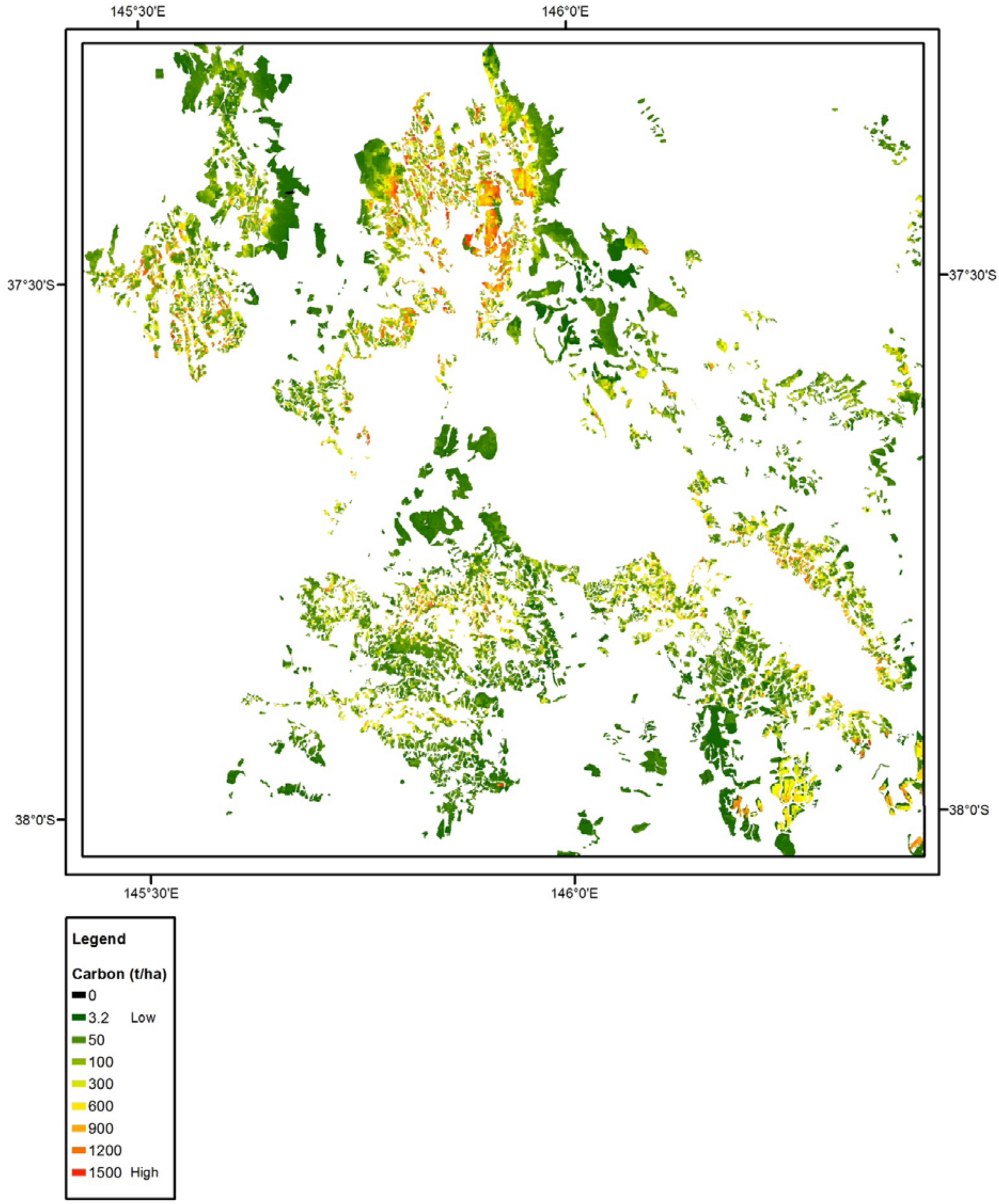
	1991-95	1996-2000	2001-05	2006-10	2011-15
1. Total study area					
Opening stock (MtC)	118.62	124.11	129.59	135.09	137.99
Additions due to growth (MtC 5yrs^{-1})	7.99	8.62	9.09	9.11	10.21
Reductions due to fire (MtC 5yrs^{-1})	-0.07	-0.03	-0.06	-3.24	-0.06
Reductions due to harvesting (MtC 5yrs^{-1})	-2.4	-3.1	-3.5	-3.0	-2.0
Closing stock (MtC)	124.11	129.59	135.09	137.99	146.16
2.a) Area logged					
Opening stock (MtC)	28.50	28.01	27.17	26.34	25.60
Additions due to growth (MtC 5yrs^{-1})	1.94	2.27	2.73	2.94	3.13
Reductions due to fire (MtC 5yrs^{-1})	-0.01	0.00	-0.02	-0.71	-0.01
Reductions due to harvesting (MtC 5yrs^{-1})	-2.42	-3.11	-3.54	-2.97	-1.97
Closing stock (MtC)	28.01	27.17	26.34	25.60	26.74
2.b) Area available for logging					
Opening stock (MtC)	32.97	38.94	35.86	42.04	43.99
Additions due to growth (MtC 5yrs^{-1})	3.09	2.93	3.12	3.11	3.51
Reductions due to fire (MtC 5yrs^{-1})	-0.02	-0.03	-0.02	-1.16	-0.03
Reductions due to harvesting (MtC 5yrs^{-1})	0.00	0.00	0.00	0.00	0.00
Closing stock (MtC)	38.94	35.86	42.04	43.99	47.46
2.c) Area unavailable for logging					
Opening stock (MtC)	57.15	60.24	63.49	66.71	68.40
Additions due to growth (MtC 5yrs^{-1})	3.12	3.25	3.24	3.06	3.57
Reductions due to fire (MtC 5yrs^{-1})	-0.03	-0.01	-0.02	-1.37	-0.01
Reductions due to harvesting (MtC 5yrs^{-1})	0.00	0.00	0.00	0.00	0.00
Closing stock (MtC)	60.24	63.49	66.71	68.40	71.96
3.a) Area burnt 2009 and since					
Opening stock (MtC)	18.01	18.72	19.33	20.16	17.73
Additions due to growth (MtC 5yrs^{-1})	1.07	1.14	1.20	0.97	2.40
Reductions due to fire (MtC 5yrs^{-1})	0.00	0.00	0.00	-2.41	-0.06
Reductions due to harvesting (MtC 5yrs^{-1})	-0.36	-0.54	-0.37	-0.99	-0.36
Closing stock (MtC)	18.72	19.33	20.16	17.73	19.71
3.b) Area burnt 1940 - 2008					
Opening stock (MtC)	11.60	12.81	14.26	15.76	16.85
Additions due to growth (MtC 5yrs^{-1})	1.46	1.72	1.93	2.21	2.27
Reductions due to fire (MtC 5yrs^{-1})	-0.07	-0.03	-0.05	-0.83	0.00
Reductions due to harvesting (MtC 5yrs^{-1})	-0.18	-0.24	-0.38	-0.29	-0.13
Closing stock (MtC)	12.81	14.26	15.76	16.85	18.98
3.c) Area burnt in 1939					
Opening stock (MtC)	86.76	90.28	93.65	96.77	100.96
Additions due to growth (MtC 5yrs^{-1})	5.41	5.70	5.91	5.89	5.50
Reductions due to fire (MtC 5yrs^{-1})	0.00	0.00	0.00	0.00	0.00
Reductions due to harvesting (MtC 5yrs^{-1})	-1.89	-2.33	-2.80	-1.70	-1.48
Closing stock (MtC)	90.28	93.65	96.77	100.96	104.99
3.d) Area unburnt					
Opening stock (MtC)	2.25	2.30	2.36	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	2.36	2.40	2.45	2.49

Figure 5.2. Carbon stock (tC ha^{-1}) in 2015 in the areas that are: (a) available for logging, (b) logged previously, and (c) montane ash forest that is available for logging

(a) Areas available for logging



(b) Areas logged previously



(c) Montane ash forest that is available for logging

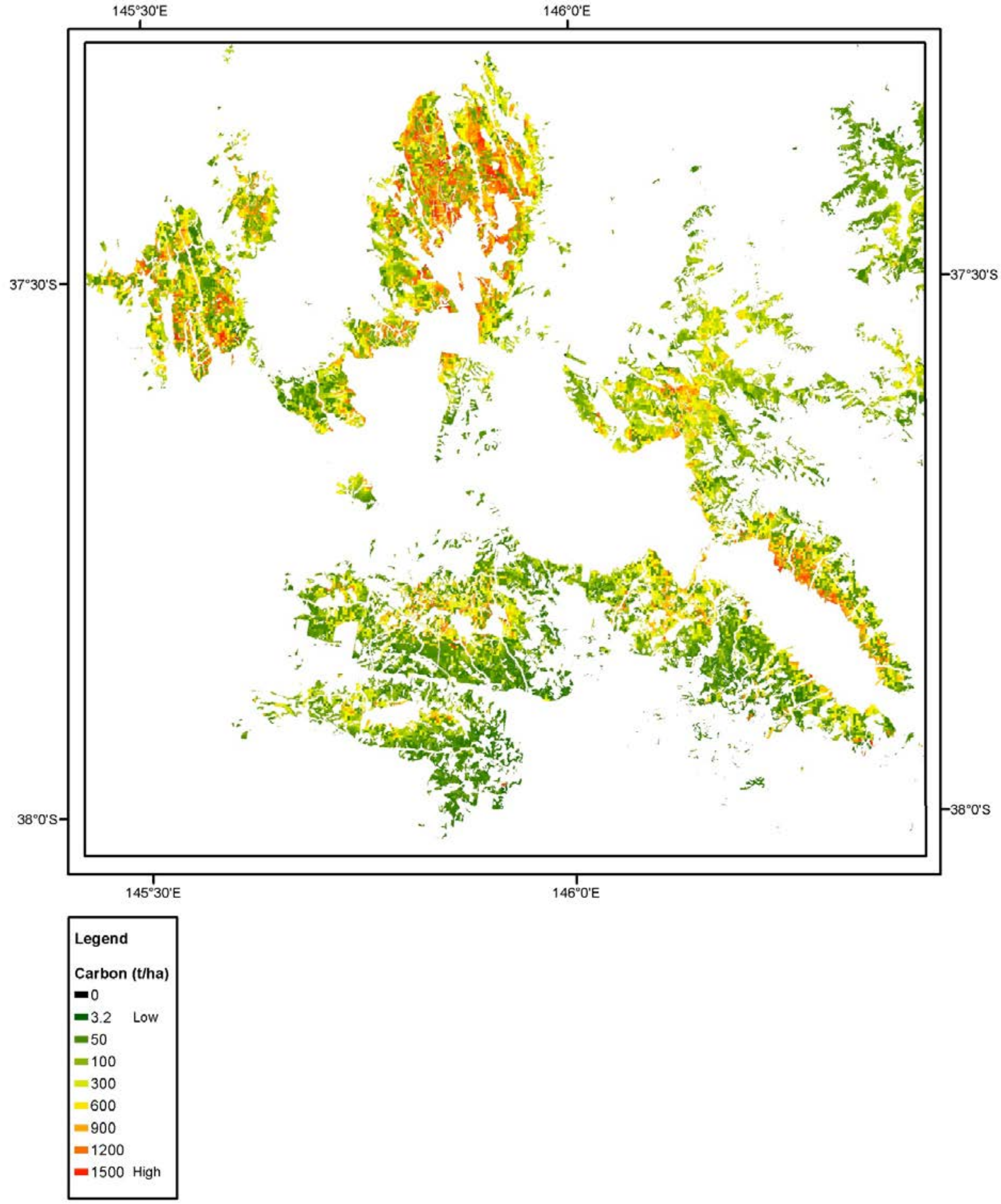
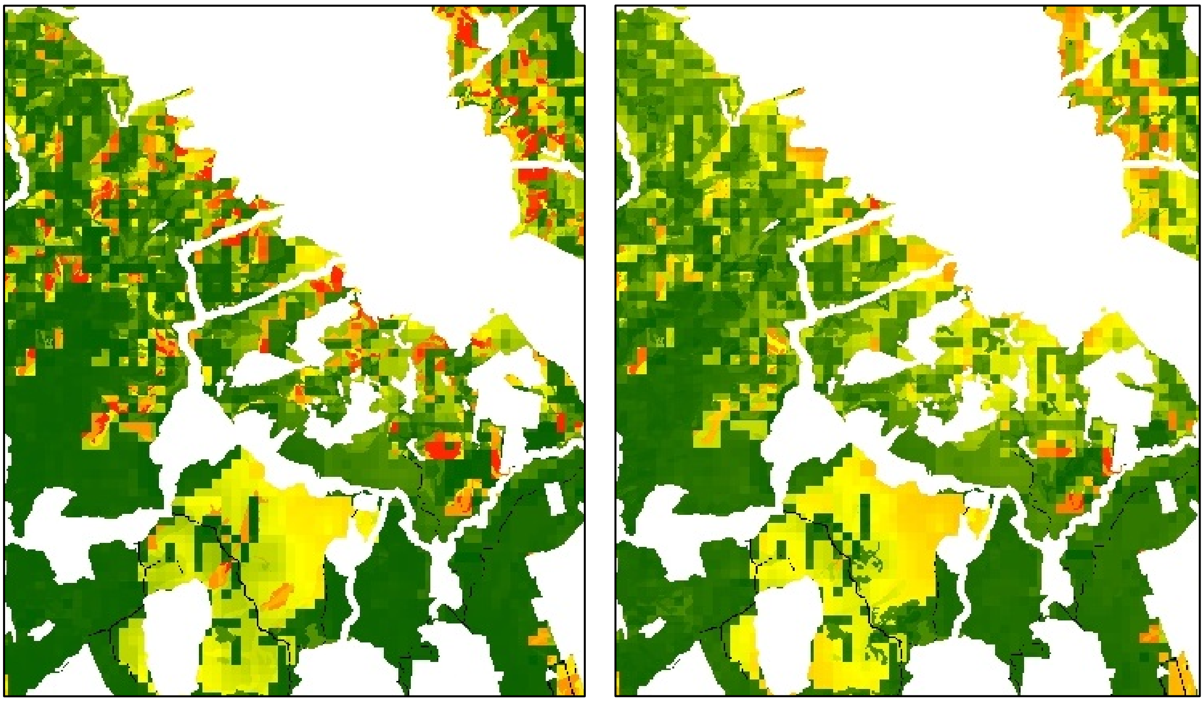


Figure 5.3. Carbon stock (tC ha^{-1}) in the area available for logging in (a) 1990, and (b) 2015, showing a zoomed in section of the study area to the south of the Baw Baw plateau. Legend as in Figure 5.2.

(a) 1990 **(b) 2015**



5.3.1.3 Valuation of carbon sequestration

The ecosystem service of carbon sequestration has a value 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 tC paid by the Australian Government in 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 in 2015 was $20 million (Table 5.2a: 1.635 million tC yr^{-1} x $12.25 tC^{-1}). The previous average carbon price from the first auction in April 2015 of $13.95 would have produced a total value of the service of $22.8 million. The price for the third auction in April 2016 was $10.23 and this value would be applied to the services received in 2016. The price from the second auction in 2015 ($12.25) was applied to other years adjusted for inflation using the ABS Consumer Price Index (Table 5.4). It is acknowledged that the price of carbon was not this for earlier years (e.g. it was $23 per tC under the carbon tax), but this provides an indication of the values.

Table 5.4. Value of carbon sequestration or net annual change in carbon stock in the Central Highlands.

Land cover	Value of carbon sequestration or net annual change in carbon stock ($m yr-1)				
	1990-95	**1995-00**	**2000-05**	**2005-10**	**2010-15**
Montane woodland	0.02	0.02	0.03	-0.20	0.04
Swamp	0.00	0.00	0.00	0.00	0.00
Shrub/heath	0.00	0.00	0.00	0.00	0.00
Woodland	0.01	0.01	-0.01	-0.02	0.02
Open mixed forest	1.14	1.33	1.70	1.32	2.24
Mountain ash	2.49	2.51	2.49	2.18	8.62
Wet mixed forest	2.89	3.55	4.27	3.61	5.60
Rainforest	0.04	0.05	0.06	-0.01	0.04
Riparian shrubs	0.00	0.00	0.00	0.00	0.00
Bare	0.00	0.00	0.00	0.00	0.00
Pasture/grassland	0.00	0.00	0.00	0.00	0.00
Horticulture	0.00	0.00	0.00	0.00	0.00
Eucalypt plantation	0.00	0.00	0.00	-0.36	0.40
Pine plantation	0.00	0.00	0.00	-0.20	0.22
Crop	0.00	0.00	0.00	0.00	0.00
Built-up area	0.00	0.00	0.00	0.00	0.00
Open water	0.00	0.00	0.00	0.00	0.00
Alpine ash	1.49	1.39	1.70	0.07	2.78
Total	**8.08**	**8.86**	**10.23**	**6.38**	**19.97**

Valuation of the ecosystem service of carbon sequestration to determine the effect of land use was based on the same two components: (1) carbon sequestration as a net change in carbon stock per year, and (2) the potential carbon stock density under a change in land use. The difference in carbon sequestration between the area logged and the area unlogged but available for logging, averaged over 1990 – 2015, was 3.13 tC ha^{-1} yr^{-1} (Table 5.5). **At a carbon price of $12.25, the carbon sequestration is equivalent to $38.36 ha^{-1} yr^{-1}.** The area available for logging includes public native forest that is zoned to allow harvesting. This area includes all forest types within the study area.

The potential for increased carbon stock density is 143.3 tC ha^{-1} if logging ceased and montane ash forests were allowed to re-grow, and this is equivalent to $1755 ha^{-1}. Over the area of montane ash forest that has been logged, this potential increase is 7.83 MtC, which is equivalent to $95.89 million.

Table 5.5 Physical carbon sequestration by all forest types averaged over 1990 to 2015, and carbon stock in montane ash forest in 2015.

	Area logged	Area unlogged
(1) Carbon sequestration – all forest types		
Net change in carbon stock (MtC)	-1.76	14.49
Area (ha)	101,639	237,593
Net change in carbon stock density (tC $ha^{-1}yr^{-1}$)	-0.69	2.44
(2) Carbon stock – montane ash forest type		
Carbon stock in 2015 (MtC)	19.87	76.28
Area (ha)	54,629	150,443
Carbon stock density (tC ha^{-1})	363.8	507.1

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 mountain and alpine 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). This report investigated the timber production from native forests only.

Of the total area of native forest harvested in Victoria from 1990 to 2015, an average of 22% of the area was in the Central Highlands study area, with a range from 11% to 49% in different years. There has been a long history of 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 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. Forest that has been thinned have not been included in the logged area because these are relatively small areas, and the volume and products are highly variable.

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 are the **Monitoring Annual Harvesting Performance (MAHP)** in Victoria's State Forests by the Victorian Government Department of Sustainability and Environment (data from 1990-91 to 2008-09). 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. Within the Central Highlands study area, the area logged over the 25 years consists of 88% of the area logged in the Central FMA, 100% of the area logged in the Dandenong FMA, 5% of the area logged in the Benalla-Mansfield FMA, and 33% of the area logged within the Central Gippsland FMA. These percentages were used to calculate the total area and volume harvested each year within the study area. The yield was calculated as a weighted average from the FMA data (49%, 17%, 0.4% and 34% for the four FMAs, respectively). In many of these annual 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 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 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 after wildfire, prior to the logs deteriorating. Yields are lower during drought because of wood splitting. 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 values 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 values presented in graphs of yield as the average for the FMA in the report (Figure 6.1). 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 values 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 values from these two sources is shown in Figure 6.1 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 account tables, the graphs of 10-year time series of sawlog yield data presented in the body of the report have been used, rather than the results from calculating the coupe data.

3) NCAS Technical Report 32

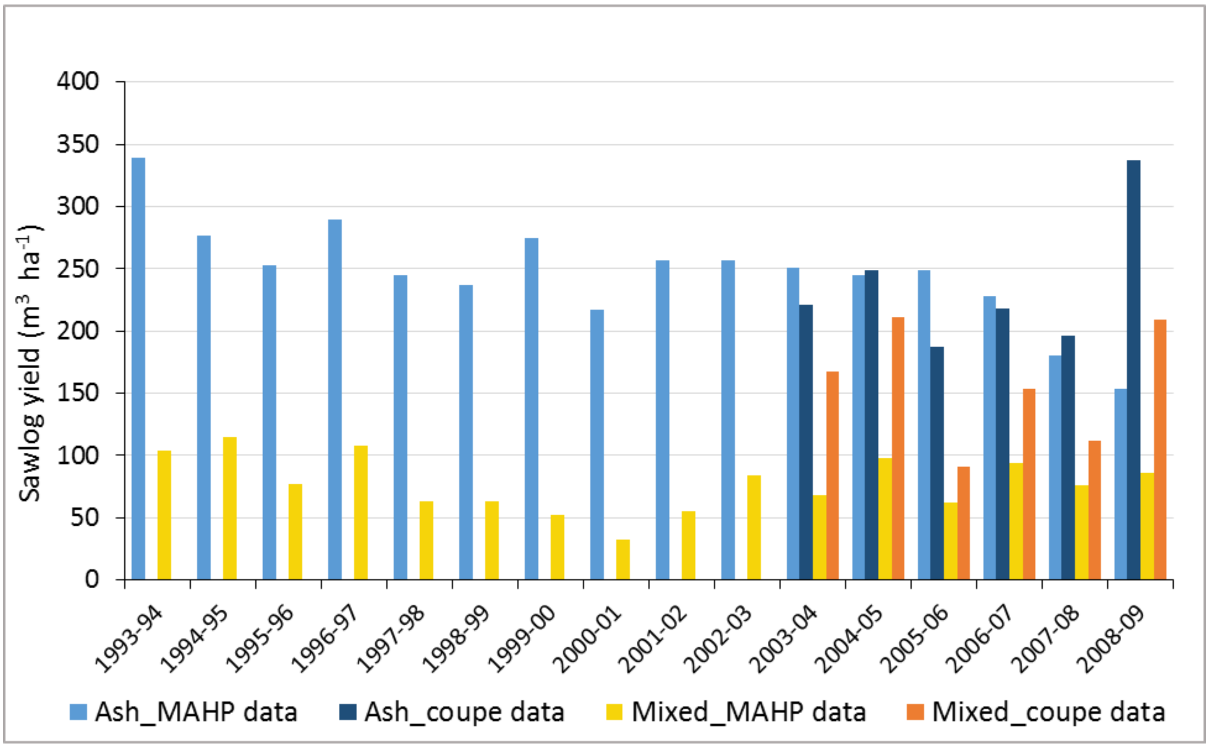
Historical data and expert opinion were used to derive estimates of timber yields in forestry regions of Australia by forest type and silvicultural type over 5-year time periods up to 2000 (Raison and Squire 2007). Sawlog yield was calculated as the volume divided by area of

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 6.1. 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 maps, 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 Figure 6.4, and aggregated for each 5-year period. 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, which has changed over the course of the time series and is currently VicForests. 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 timber product yield were derived from 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 region. Wood product used for pulp and paper were classified as 'residual', and products used for timber were classified as 'sawlogs', even though the latter included products such as fibreboard, packing wood and construction wood. These estimates of plantation timber products are general and used in the results of the ecosystem service physical supply tables (Tables 10.6 and A10.1).

6.2.2 Results

Two sets of results are presented for area harvested, volume and yield, based on the data sources from reports and spatial data. The area harvested assessed from the spatial data is larger than the area from the graphs in the FMA reports, which used the proportion of the area logged in each FMA within the study region. A possible reason for the difference in area estimates is the silvicultural systems that were included. The same systems were extracted for both analyses of area logged, but the records may not be well referenced spatially. The discrepancy is less for the last decade (14 – 17%) and this may reflect improved systems of recording and mapping.

Yield is calculated from specific coupe data within each Forest Management Area by VicForests. However, the estimated yield for the study area could be underestimated because average FMA data were used. The Central and Central Gippsland FMAs produce similar volumes of timber annually, however within the study region, the area logged consists of 88% of the Central FMA but only 33% of the Central Gippsland FMA. The harvested volume and yield in the Central Highlands study area is likely to be higher than the average for the rest of the Central Gippsland FMA, and therefore using an average value for the FMA could produce an underestimate.

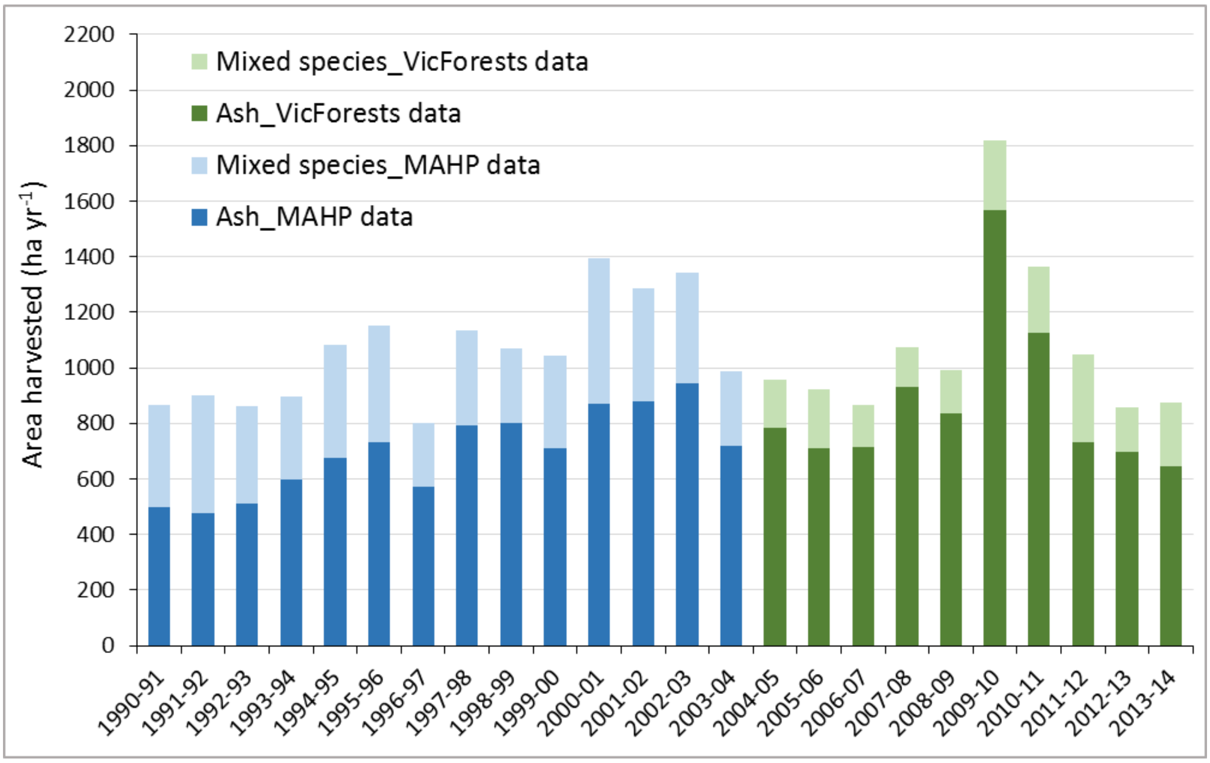
In the accounts that integrated the asset and financial information, the data reported by VicForests for their timber production were used. This appeared to be the conservative estimate of the asset.

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**	**2009-14**	**1990-94**	**1995-99**	**2000-04**	**2005-09**	**2009-14**
1. a) MAHP FMA reports	Ash	240	228	235	196						
	Mixed sp.	68	63	79	88						
	Total						560	503	399	473	
1. b) VicForests FMA reports	Ash				251	269				464	438
	Mixed sp.				85	134				308	334
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		

Figure 6.2. 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)

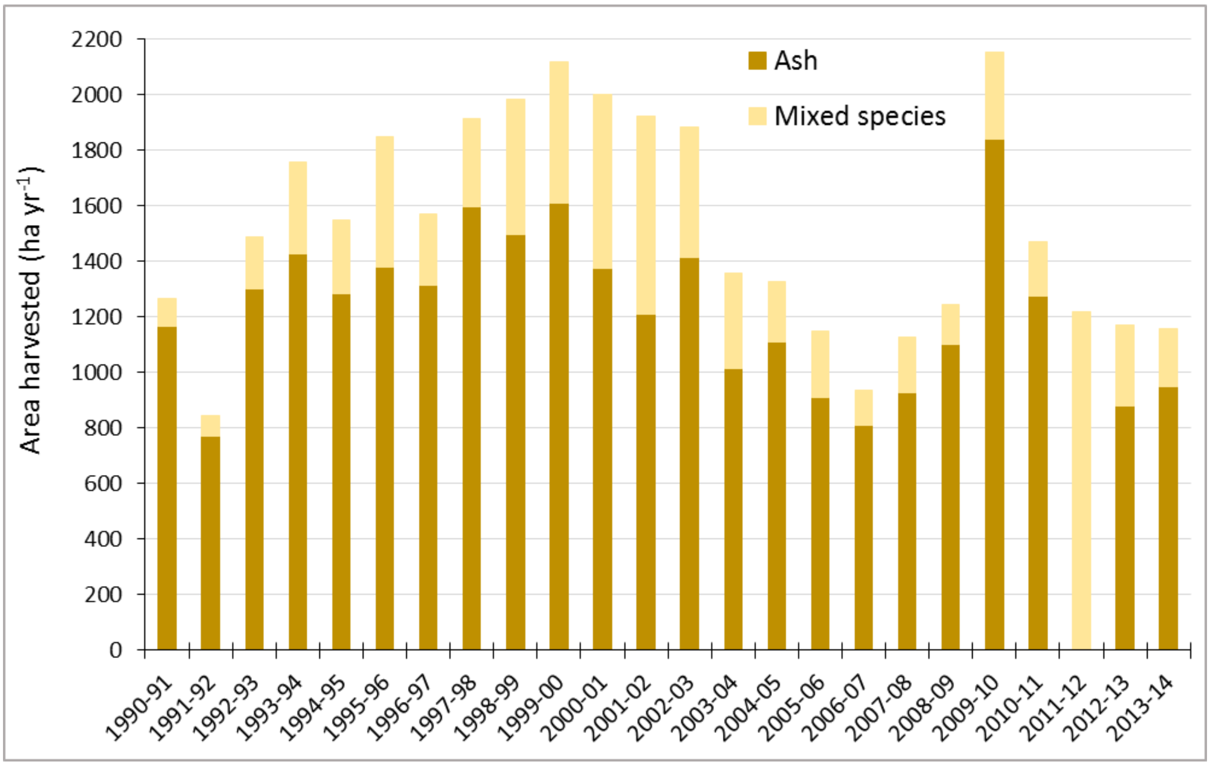
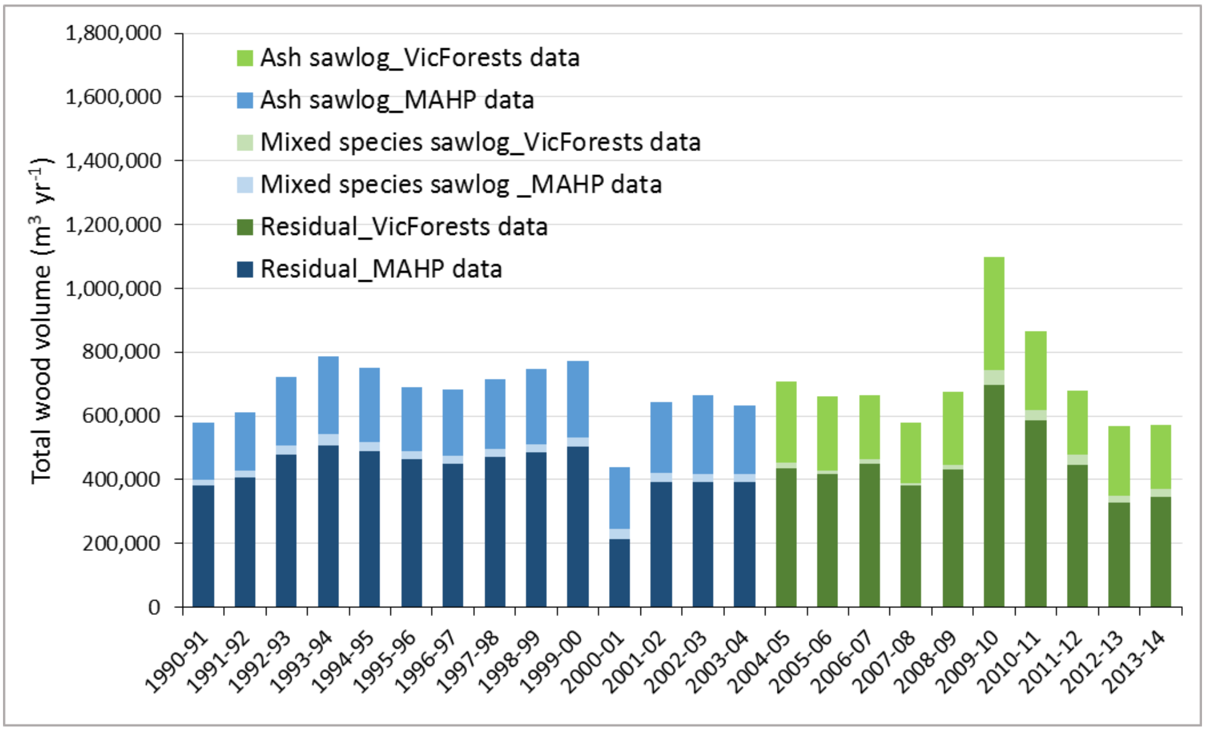


Figure 6.3. Annual volume of sawlog and residual log harvested (m^3 yr^{-1}) from ash and mixed species forest types within the study area. Data from different sources are compared: (a) data from reports from MAHP (1990-91 to 2003-04), and VicForests (2004-05 to 2013-14), and (b) spatial data from VicForests (1990-91 to 2013-14). [residual log volume data not available for 2001-02 to 2003-04 in (a) and estimated.]

(a)



(b)

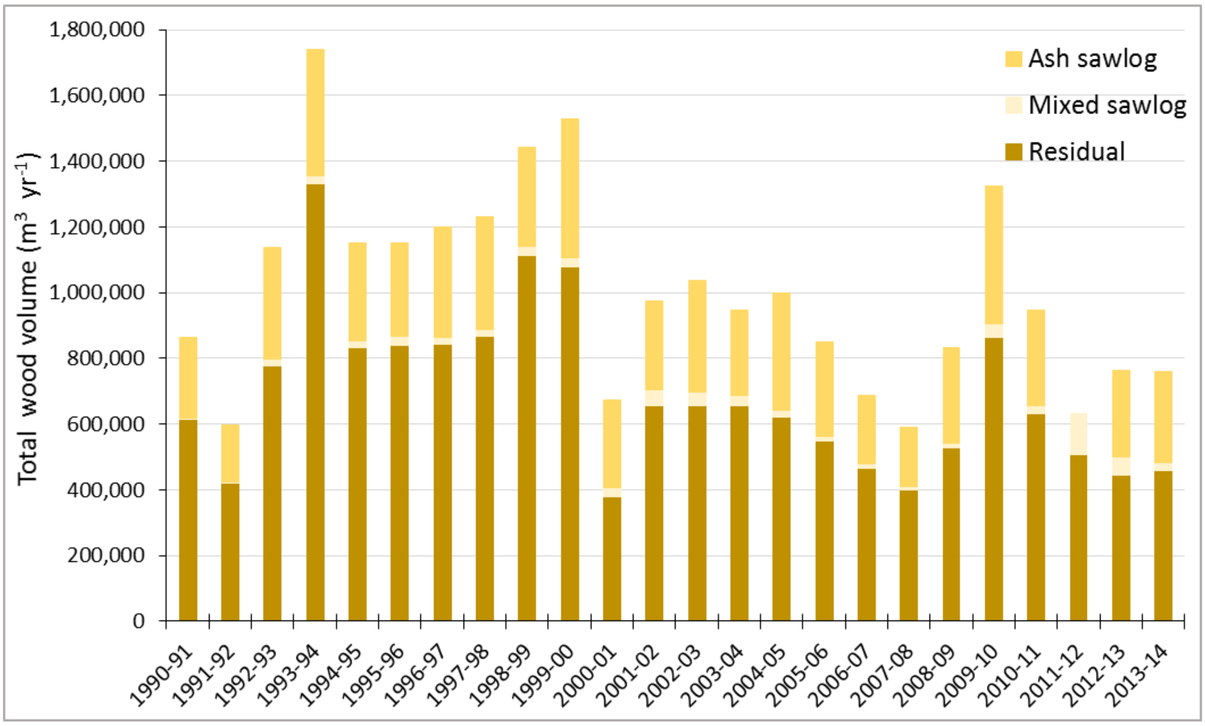


Figure 6.4. Annual yield of sawlog and residual log harvested from ash and mixed species forest types within the study area; data sourced from MAHP (1990-91 – 2003-04) and VicForests (2004-05 – 2013-14) reports. [residual log volume data not available for 2001-02 to 2003-04 and estimated.]

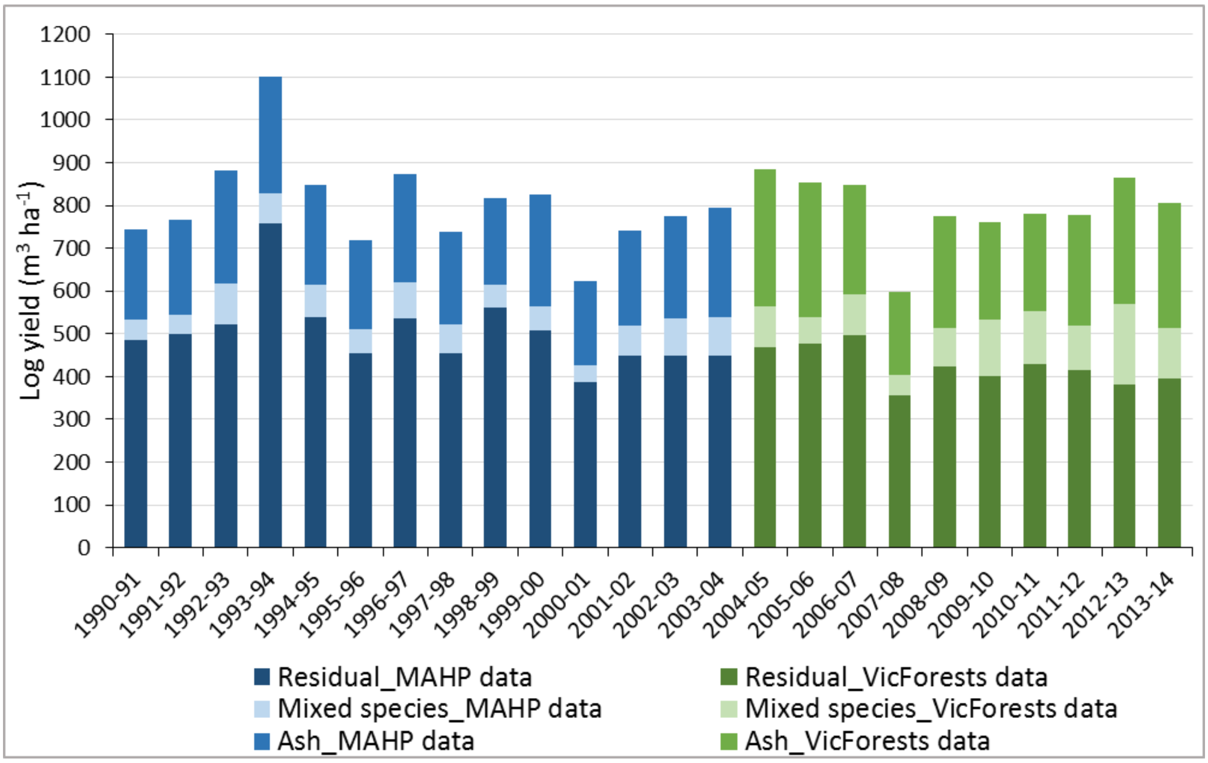


Table 6.2. Total area, yield and volume harvested over 5-year time periods used for accounting

(a) Data sourced from MAHP and VicForests reports.

	1990-94	1995-99	2000-04	2005-09	2010-14
Area (ha $5yr^{-1}$)					
Ash	2,762	3,608	4,146	4,758	4,005
Mixed	1,847	1,592	1,796	914	1,175
Yield (m^3 ha^{-1})					
Ash sawlog	240	228	235	251	269
Mixed sawlog	68	63	79	85	134
Residual	560	503	399	431	405
Volume (m^3 $5yr^{-1}$)					
Ash sawlog	1,051,046	1,099,677	1,119,862	1,206,872	1,084,278
Mixed sawlog	134,076	133,994	137,603	90,791	135,225
Total sawlog	1,185,123	1,233,671	1,257,465	1,297,662	1,219,503
Residual	2,263,580	2,371,761	1,597,760	2,379,636	2,133,671
Total	3,448,702	3,605,432	2,855,225	3,677,298	3,353,174
Volume (m^3 yr^{-1})					
Ash sawlog	210,209	219,935	223,972	241,374	216,856
Mixed sawlog	26,815	26,799	27,521	18,158	27,045
Total sawlog	237,025	246,734	251,493	259,532	243,901
Residual	452,716	474,352	319,552	475,927	426,734
Total	689,740	721,086	571,045	735,460	670,635

(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	240	228	235	251	269
Ash residual	560	503	399	464	438
Mixed sawlog	68	63	79	85	134
Mixed residual	560	503	399	278	334
Volume (m^3 $5yr^{-1}$)					
Ash sawlog	1,444,180	1,688,251	1,492,538	1,383,235	1,037,380
Mixed sawlog	70,135	122,989	167,782	90,483	287,990
Total sawlog	1,514,315	1,811,240	1,660,320	1,473,718	1,325,370
Residual	3,976,254	4,742,471	2,499,865	2,808,507	2,550,474
Total	5,490,570	6,553,711	4,160,186	4,282,225	3,875,844
Volume (m^3 yr^{-1})					
Ash	288,836	337,650	298,508	276,647	207,476
Mixed	14,027	24,598	33,556	18,097	57,598
Total sawlog	302,863	362,248	332,064	294,744	265,074
Residual	795,251	948,494	499,973	561,701	510,095
Total	1,098,114	1,310,742	832,037	856,445	775,169

6.3 Timber provisioning service and timber supply

6.3.1 Data sources and methods

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. A value for the biological assets, which is the value of timber, is also recorded in the balance sheet of the (government owned) company. 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). The information in the Annual Reports and other documents relates to all of the operations of VicForests, which extend beyond the study area.

Data for the area and volume of wood harvested from within the study area were available (Figures 6.2 and 6.3). The information on the area and physical volume of production from the Central Highlands was used to scale the information included in the Annual Reports of VicForests to generate estimates of the value of timber supplied from the study area, based on the stumpage value, as well as a calculation of profit (loss) and industry value added.

The timber provisioning service of ecosystems is used by VicForests in the generation of timber for supply to market. A physical estimate of the timber provisioning service could be the annual growth (or increment) in the amount of wood available for harvest by VicForests. This would be for all areas managed Vic Forests. It excludes the wood growth in national parks and all other land tenure types that are not accessible to VicForests.

The physical ecosystem service was taken to be the physical 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. The value of the timber provisioning service was taken to be the stumpage value, scaled to the Central Highlands study area as per the physical measure of this service.

6.3.2 Results

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 values 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 figure represents the annual contribution**

of the industry to GDP. For the timber industry, the contribution was $9.4 million in 2014-15, or $29 ha^{-1}. The value of ecosystem services in the study area used by VicForests was $14.8 million in 2014-15 or $46 ha^{-1}.

Table 6.3. Summary data, VicForests, all Victorian operations and for Central Highlands, 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
All revenue and other income	39	103.4	132.8	130.3	144.8	139.3	119.4	106.3	105.8	111.5
Revenue from forest products	*37.2*	*99.1*	*125.8*	*125.3*	*131.6*	*131.4*	*116.7*	*104.5*	*104.3*	*107.7*
Stumpage	*35.5*	*28.4*	*28.5*	*29.5*	*24.5*	*31.8*	*29*	*30.8*	*31.4*	*34.8*
Total expenses	36	103.4	132	136.1	143.1	137.2	118.9	105.3	103.6	107.2
Profit/(loss) before tax ($m)	3.0		0.8	(5.8)	1.7	2.1	0.5	1.0	2.2	4.3
Profit/(loss)after tax ($m)	2.1	(0.2)	0.5	(5.0)	3.6	2.3	-0.1	0.8	3.4	4.7
Wages, employee benefits ($m)	*13.3*	*14.4*	*13.7*	*13.7*	*13.3*	*14.1*	*13.7*	*13.9*	*13.7*	*12.8*
Estimated IVA ($m)*	21.5	19.1	15.3	12.5	19.9	20.6	15.2	15.9	20	21.5
Total assets	35	38	55.4	54.2	73.7	88.7	93.9	80	94.7	94.7
Of which timber assets			7.1	10.9	10.9	16.2	30	29.5	48.6	48.7
Total liabilities	11.8	16.9	26.6	23.4	36.8	42.5	48.4	36.1	37.4	32.7
Net assets	23.2	21.1	28.9	30.7	36.9	46.3	45.5	43.9	57.3	61.9
Number of employees (FTE)		140	143			128	115	112	98	107
Number of contractors engaged			500-600				376	413	438	400
Total area harvested (ha)	4900	5628	6427	5579	5047	4979	4296	3327	2972	3017
Central Highlands area harvested (ha)	921	867	1073	991	1820	1363	1048	858	875	
Central Highlands area harvested (% of total Vic)	19%	15%	17%	18%	36%	27%	24%	26%	29%	
Total volume harvested (m^3)	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 sales volume (m^3)	661,295	663,298	577,744	677,047	1,097,914	865,439	678,588	567,792	570,720	
Central Highlands sales volume (% of total)	*36%*	*40%*	*29%*	*40%*	*59%*	*51%*	*48%*	*45%*	*47%*	

*Depreciation and amortisation are added to profit (loss) before tax and wages and employee benefits. Assumes no taxes or subsidies on products.

Table 6.4. VicForests, Central Highland operations, financial estimates, 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 ($m)	0.8	-0.1	0.1	(2.0)	2.1	1.2	0.0	0.4	1.6
Estimated IVA ($m)	7.8	7.6	4.5	5.0	11.8	10.5	7.2	7.2	9.4
Timber supply									
Volume supplied (m^3)	661,295	663,298	577,744	677,047	1,097,914	865,439	678,588	567,792	570,720
Revenue from supply ($m)	13.4	39.3	37.0	50.3	77.8	67.1	55.5	47.1	49.0
Timber provisioning services*									
Volume used (m^3)	661,295	663,298	577,744	677,047	1,097,914	865,439	678,588	567,792	570,720
Value used ($m)	12.8	11.3	8.4	11.8	14.5	16.2	13.8	13.9	14.8

*This is stumpage value for the Central Highlands

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, plus a range of other inputs, such as energy and fertilizers. In addition to these factors, which are already accounted for in standard economic statistics, agricultural production relies on a range of ecosystem services.

The SEEA Experimental Ecosystem Accounts (UN 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 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).

This study used the resource rent approach to valuing the ecosystem services used in agricultural production. This 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 levels of production and costs of production. Information about the physical volume of the production of agricultural production (ABS 2012) is available for ABS statistical areas. These do not match with the study area. However, some assumptions were used to generate estimates of production for the study area. The value of agricultural production is available for Victoria as a whole, and by using the physical data, an estimate for the value can also be made. 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 output, 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

Agriculture production and costs were obtained from the ABS. These sources were:

- 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 boundaries 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 approach (see Section 2.3) was used for calculating the combined value of the ecosystem services of “Provisioning services for crop production” and “Provisioning of fodder for livestock”, which was the method used by the ABS in their estimates for these services in the Great Barrier Reef Region (ABS 2015a). 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 7). 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

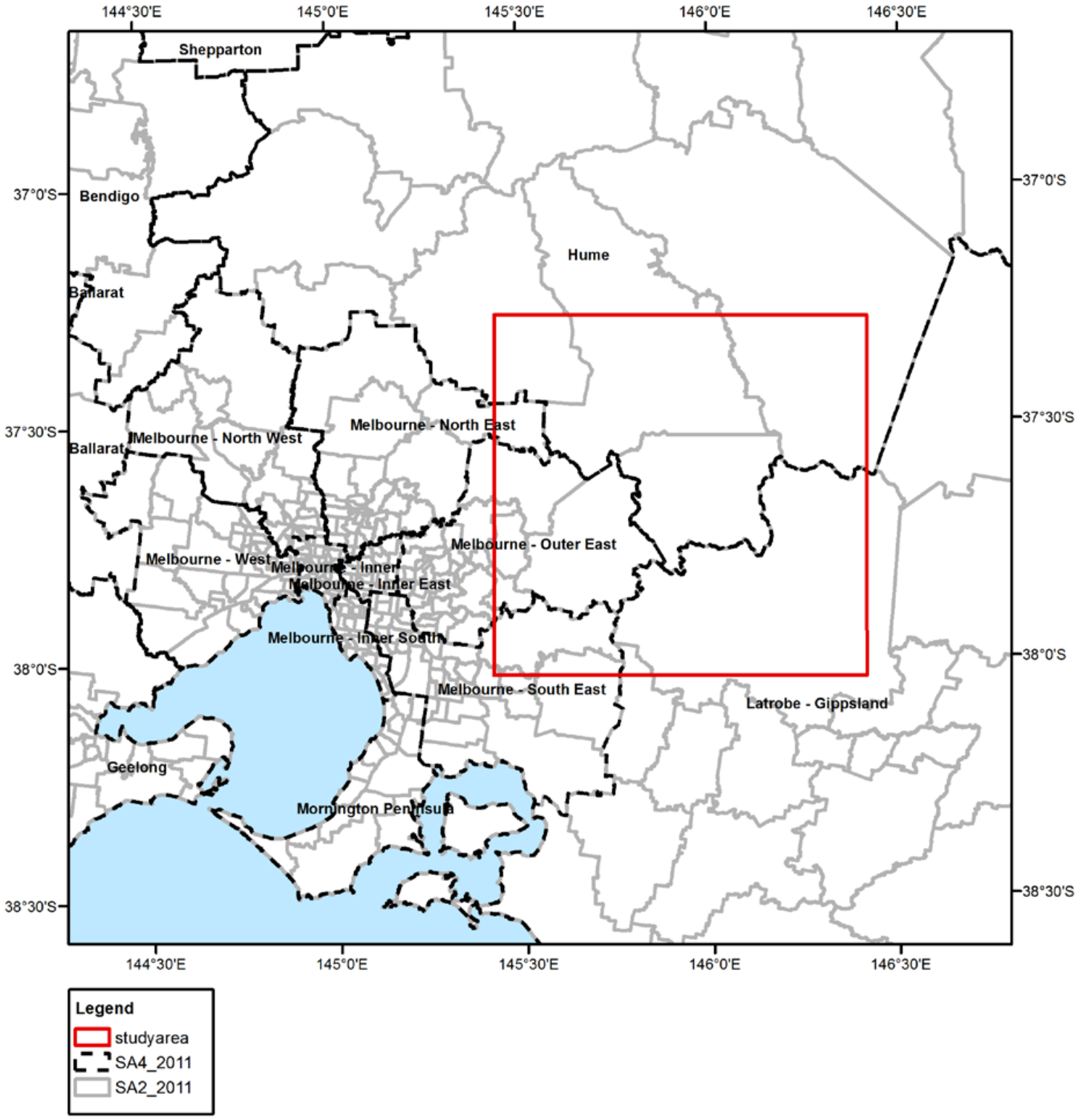


Table 7.1 ABS Statistical Areas: percentage within study area

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). Overall, the value of production has increased from $435.7 million in 2010-11 to $494.6 million in 2014-15, whereas the percentage of overall 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)
Industry value added	194.4	230.6	212.7	256.7	238.7
Gross value of agricultural products supplied	435.7	449.9	410.3	474.1	494.6
Provisioning services for crop and fodder production used by agriculture	58.4	84.9	100.1	120.5	103.5

8. Tourism

8.1 Introduction

The Central Highlands are used various recreational purposes. The region includes national parks and other reserves, as well as wineries and other tourist attractions. 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 valued 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). 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. In this report, we used a top-down approach, as the lower level data were not available for this report. In this report, the 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 (Table 8.1). The value of the cultural and recreational ecosystem service in the same year was $42 million. **The value of tourism per hectare, based on the total area of the study region (Table 3.1), was $353 ha^{-1}**.

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	42

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). The aim of this target is to place biodiversity into mainstream decision-making frameworks of policy-makers (Rode *et al.* 2012). The target states that biodiversity values should be included as part of national accounting or the System of National Accounts, which produces the indicator of Gross Domestic Product. 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 values 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 conceptions (Mace *et al.* 2012). 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 (which are reported earlier). 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. 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 include the number of large trees with hollows for nesting by cavity-dependent species, old trees that have decorticating bark that are habitat for insects and other arthropods, and the 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 the 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 this report, 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 in 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, however, 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 and VicForests Operating Procedures Regulatory Handbook 2014, which cover Victorian land under the jurisdiction of VicForests.
2) Parks Victoria Plan of Management for Yarra Ranges National Park
3) Atlas of Living Australia for the defined area of the study region, with species filtered by threat category.

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 (IUCN 2015).
2) National: Australian Government Environmental Protection and Biodiversity Conservation Act (EPBC Act 1999) lists of Threatened Fauna and Flora (DotE 2016), with the criteria for listing defined in the EPBC Regulations 2000 (DotE 2000).
3) State: Victorian Government Flora and Fauna Guarantee Act (1988), and the Victorian Advisory Lists for Threatened Vertebrate Fauna and Flora (Victorian Government 2015b).

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. (Historical information is not provided for the Victorian Fauna and Flora listings.) From these data, a table of change over time in the threat categories was constructed.

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 9.1. 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.

These differences result in different species being listed in each of the systems. Hence, there are more species in the 'Total' column 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, and thus 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

	IUCN	EPBC	FFG	Total number of species listed*
Mammals	4	6	9	15
Reptiles	1	1	5	5
Amphibians	3	4	6	6
Fish	4	4	6	6
Birds	4	4	28	34
Invertebrates	7	1	26	27
Plants	0	16	84	92

*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. However, the change in category of species 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 for one taxonomic group is possible because there is existing research data from long-term monitoring in the Central Highlands study area. 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. There is also monitoring data 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 in a forest 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. Arboreal marsupial species 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 more general biodiversity.

We analysed the site data of animal occurrence to investigate the abundance of animals and species in relation to forest age class and the change over time in abundance. 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 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 so that there was a 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 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. Whether 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 value 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 of sites 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: an assigned age category with five levels; and 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 period 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 values 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 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 data for 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; $\chi_{prob} < 0.001$; 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 slopes of the curves were not significantly different between the age categories for numbers of animals or species, but the slopes were different for the number of Leadbeater's Possums, with less change over time in Logged and no occurrences in Fire 2009 age categories (Figure 9.1).

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:

LBP – young 2009 regrowth, Alpine Ash old growth forest
FTG – young regrowth from logging or 2009 fire
YBG – young 2009 regrowth, rare in regrowth from logging
RTP – young 2009 regrowth
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 values at P<0.01.

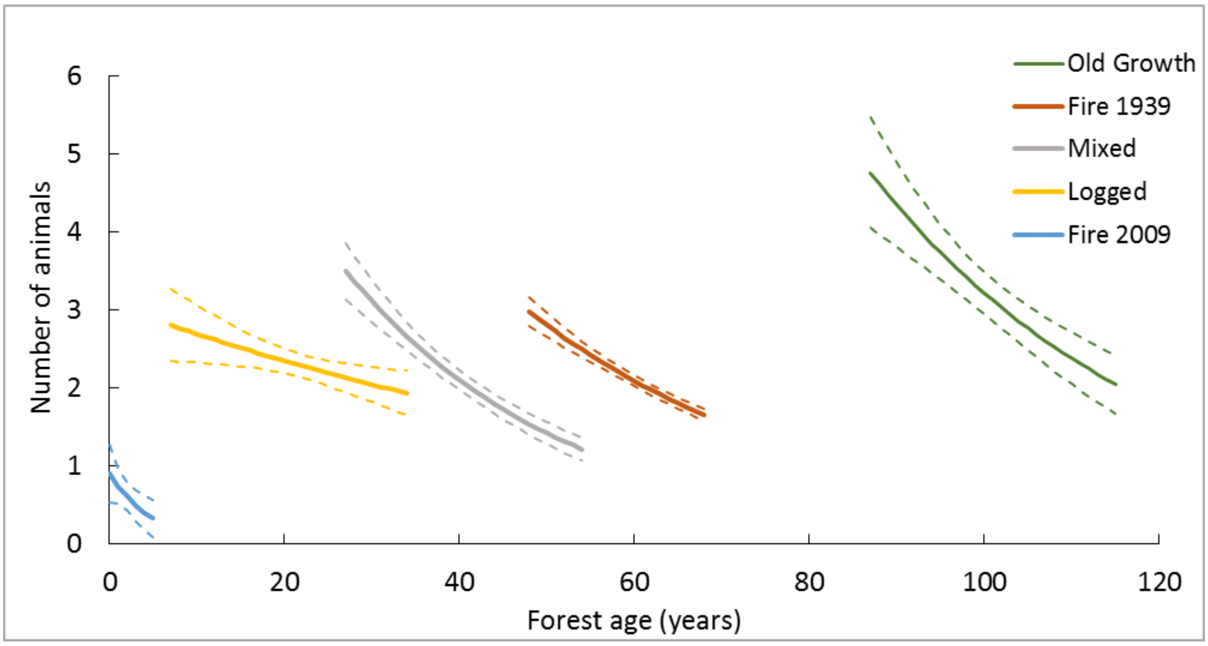
Table 9.5. Numbers of animals significantly decreased over time for all forest age categories

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

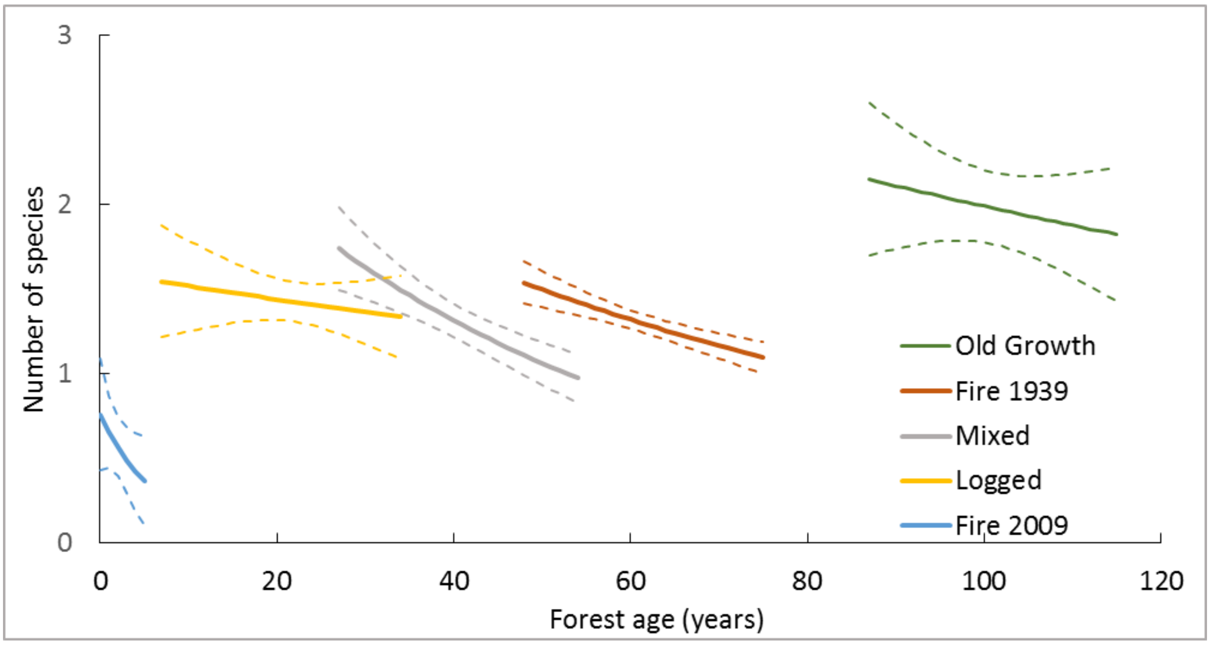
Figure 9.1. Change over time in numbers of animals within each forest age category

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

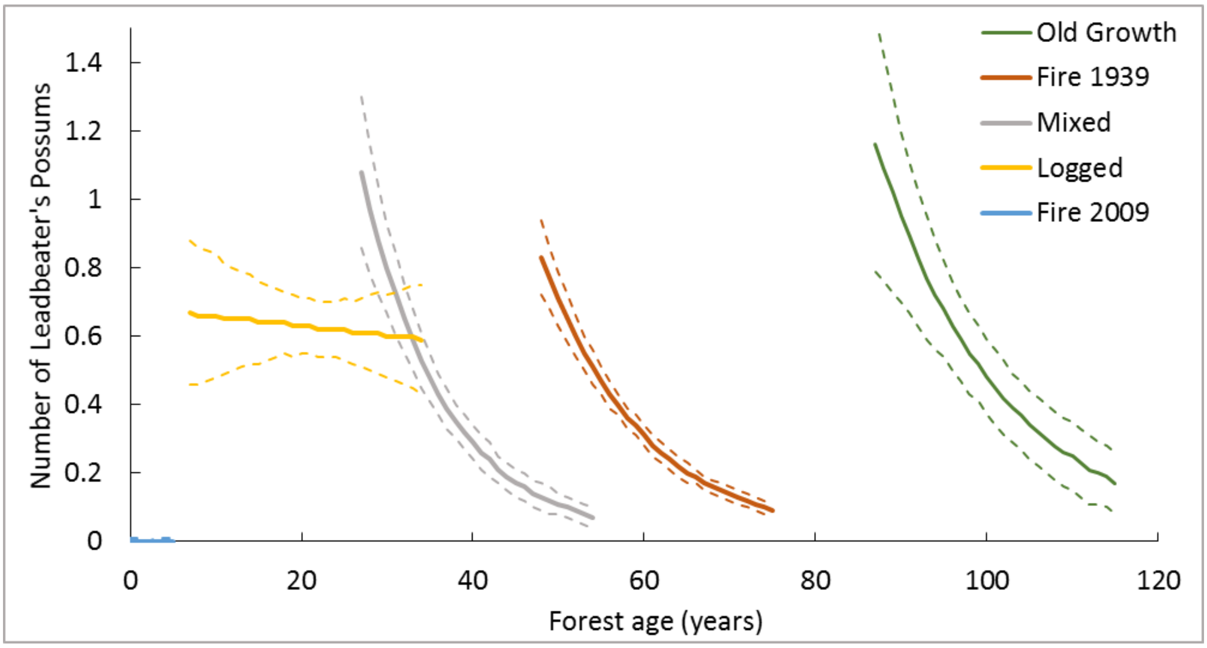
(a) Number of animals



(b) Number of species



(c) Number of Leadbeater's Possums

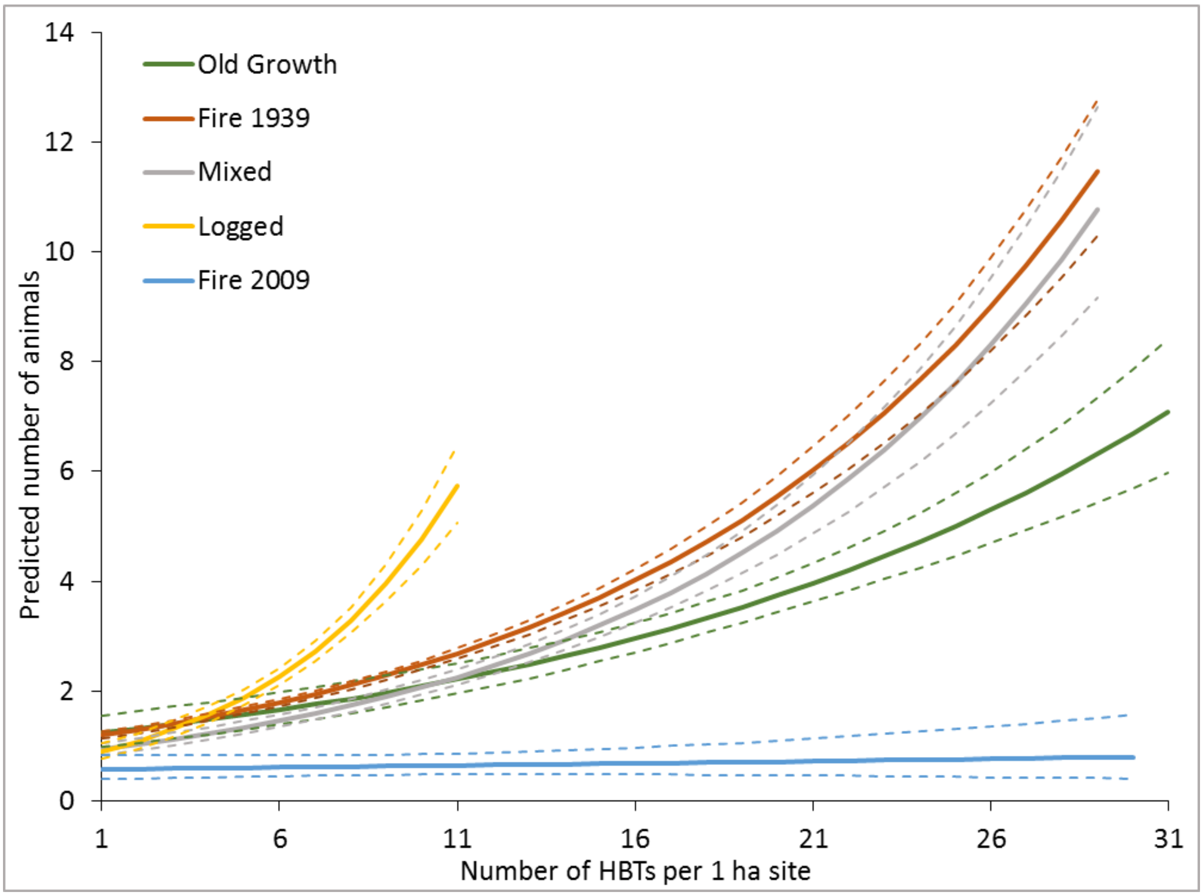


9.4.3.2 Relationship between arboreal marsupials and habitat attributes

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 value 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 9.5). This is consistent with the disturbance history where the 1939 stands regenerated from wildfire, together with 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. 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 9.5). 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. 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 9.5. Number of HBTs per 1 ha site and rate of loss and gain per year in forest age categories over the 28 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 values at P<0.01.

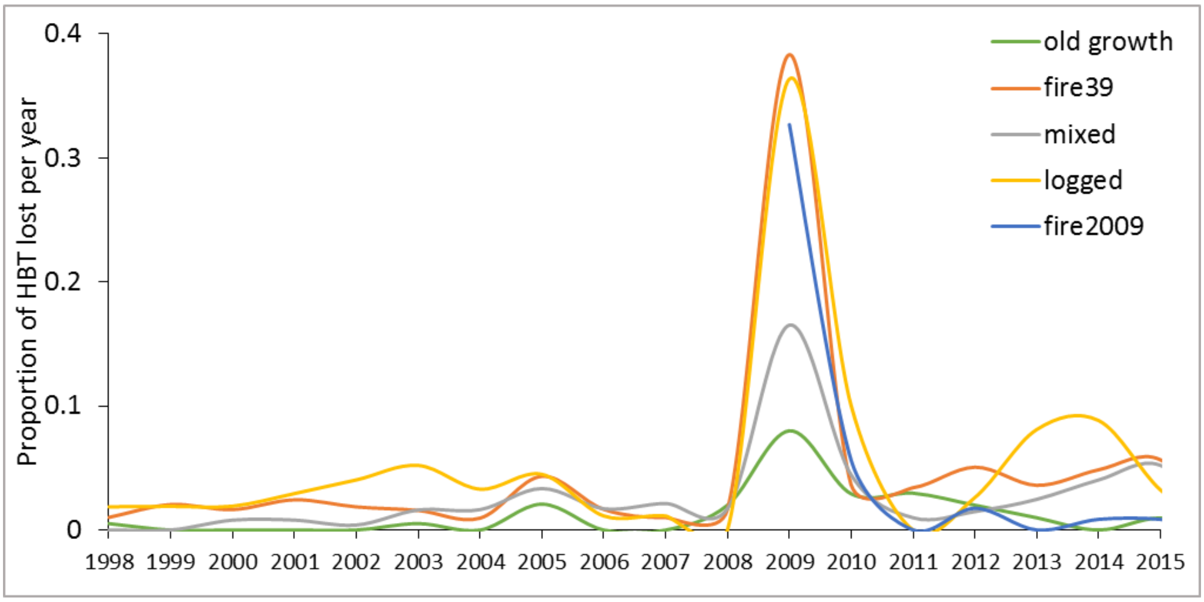
The dynamics of HBTs across all sites is shown in Table 9.6, with the numbers of standing trees, lost and gained over different time periods before and after the 2009 fire. Number of HBTs lost over the whole time period of 1998-2015 was 585 trees, or 47% of the population. During the pre-fire time period 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.

Table 9.6. Dynamics of the population 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 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

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.

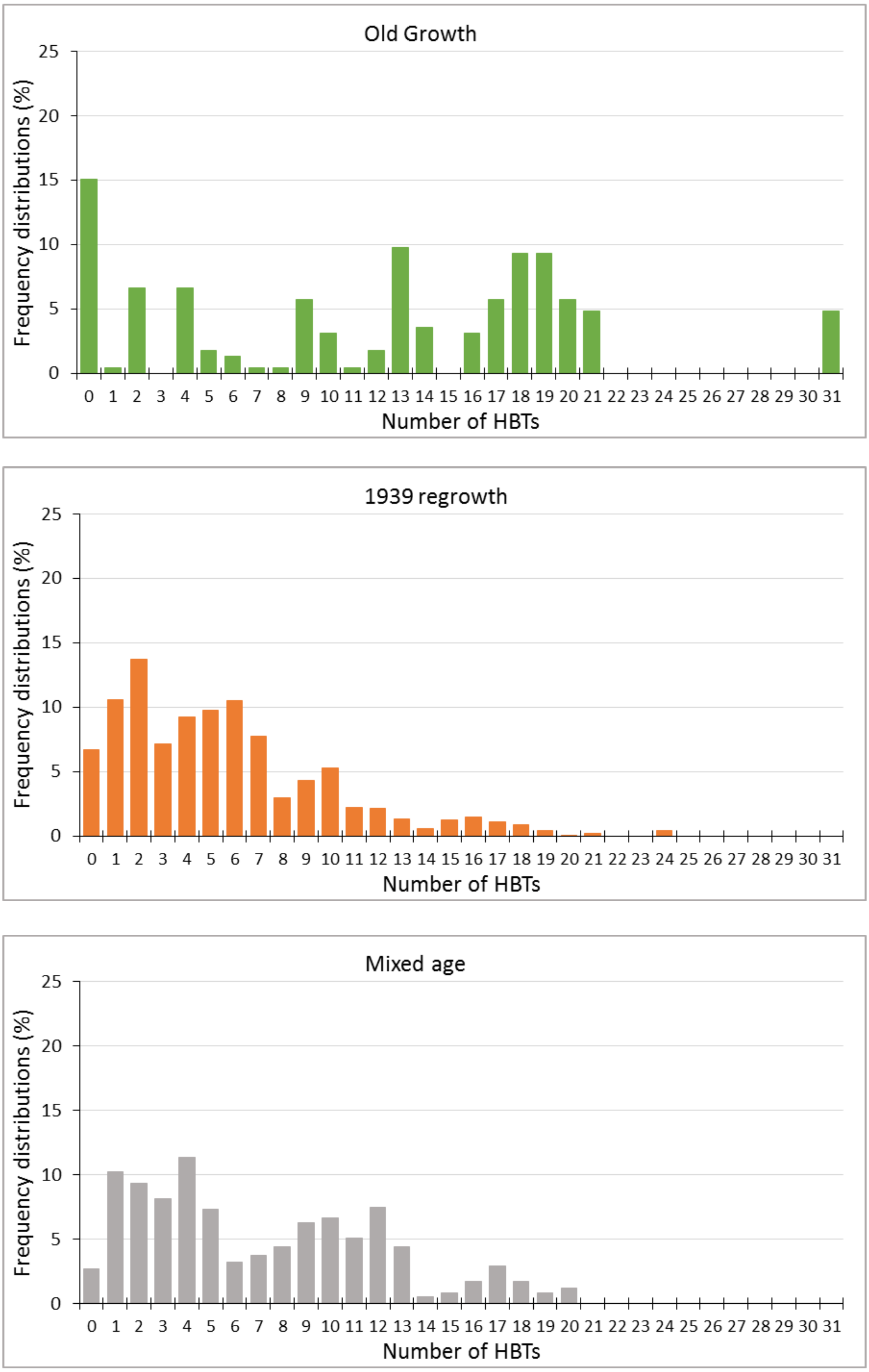
Figure 9.3. The proportion of HBTs lost per year over the sampling period from 1998 to 2015

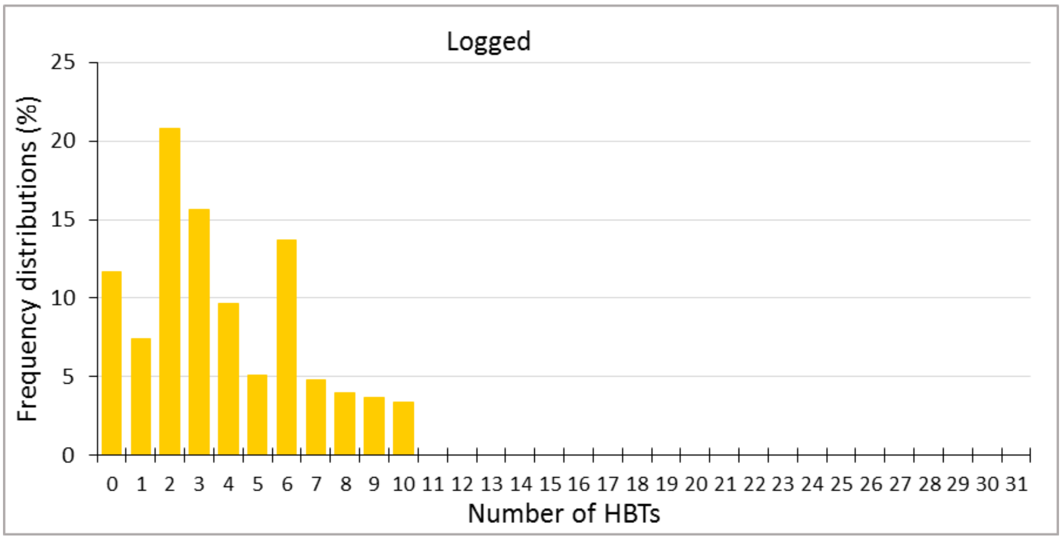


The frequency distribution of HBTs in relation to forest age category shows the pattern of change in this habitat resource as areas of forest were disturbed and regrew (Figure 9.4). Old growth has the greatest mean and maximum numbers of HBTs per site. Fire 2009 has a great range in numbers of HBTs, 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 for the 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





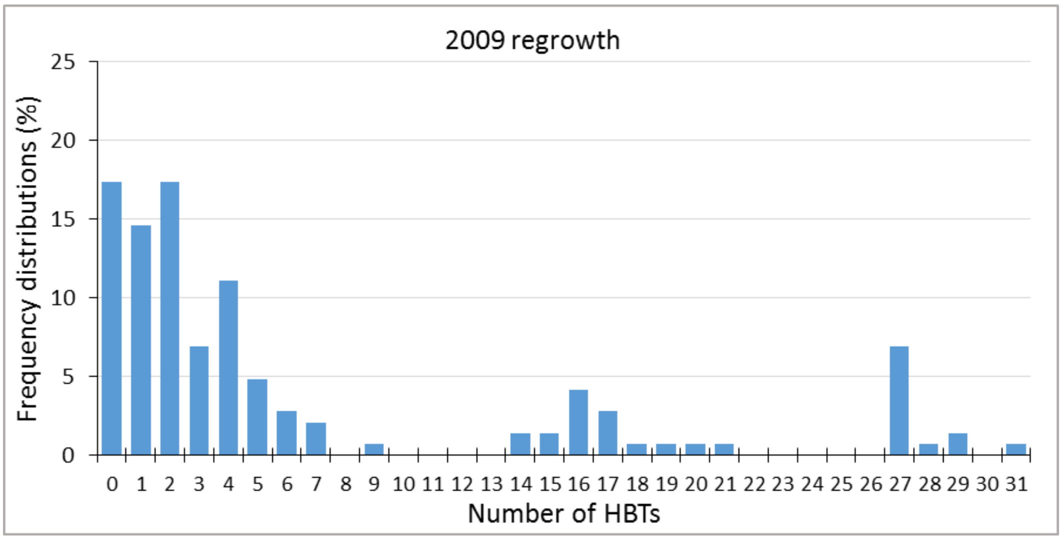
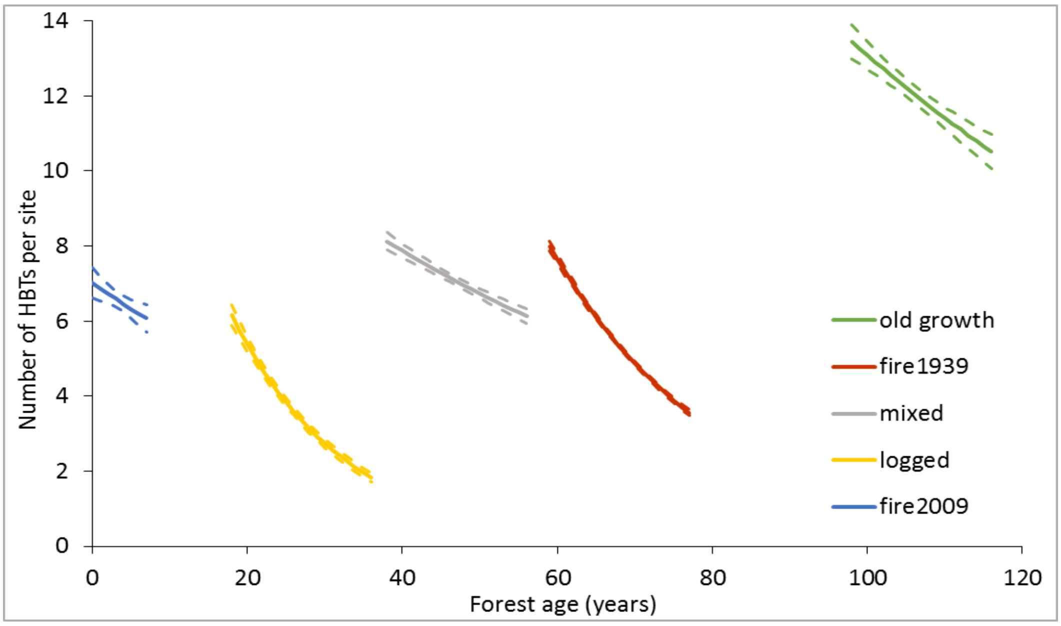


Figure 9.5. Change over time in number of HBTS in each forest age category



Solid lines represent mean values 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 HBT, 65% of sites had ≤ 4 HBT, 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: (1) the relationship between animal occurrence and the habitat attribute of HBTs, and (2) the effect of forest age and disturbance type on the provisioning of HBTs. The general trend has been a decline in the numbers of animals over time, which is related to the reduction in numbers of HBTs. The effect of disturbance by wildfire was demonstrated by the 42% loss of HBTs, and the effect of logging was demonstrated by the 70% loss of HBTs. Numbers of HBTs have declined over the last few decades because these disturbance events have created a greater loss with trees collapsing than gain in trees developing new hollows. 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.

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 HBT.

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 produces HBT 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 so that they no longer provide hollows. Fire in young regrowth stands results in few HBT because dead small trees are

susceptible to rapid collapse and lack the volume to support large cavities (Gibbons and Lindenmayer 2002).

The impact of logging on HBTs is that only a few large, old trees may be retained 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 were 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 this process 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 HBT depend on the combined effects of fire and logging. Abundance of HBT 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.* (2014) 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 the HBT population. It is unlikely that new HBTs will be recruited in the next 40-50 years in the montane ash forest region 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. 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 relationships 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 there are areas of forest that 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 Valuation of the ecosystem service of biodiversity

Biodiversity is more difficult to quantify in absolute terms than other natural assets like water, carbon and timber. Translating the value of biodiversity as a natural asset or determining its contribution to ecosystem services is difficult. Estimating values for biodiversity were 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 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, ABS 2016b). As noted by the

authors, the 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, how to measure and record this in ecosystem accounting is not yet clear in the SEEA.

9.6 Conclusions

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

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, and the numbers of animals has decreased over time in all forest age categories. **Disturbance by wildfire resulted in a 42% loss of HBTs, but logging reduced numbers of HBTs by 70%. 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.**

10. Ecosystem accounts

10.1 Introduction

Ecosystem accounts consist of assets and their ecosystem services. 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 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 so it is recommended in the SEEA-Experimental Ecosystem Accounts (UN 2014b) that the most relevant components of ecosystem assets be identified to provide aggregated information for measuring trends and comparisons. 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

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. Impacts of Aboriginal occupation on ecosystems were recognised, although this was less in the dense, wet montane forests than other vegetation types, but for the analysis, a reference state needed to be set and data were available for this. The Victorian Ecological Vegetation Classes (EVCs) are mapped for an indicative age of 1750 based on an assumed distribution of natural vegetation classes.

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 identified 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 the effects of stand-replacing disturbance events and increments in growth with age.

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 (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. More than half of the area of riparian shrubs has been changed and this would likely have a large impact on water supply.

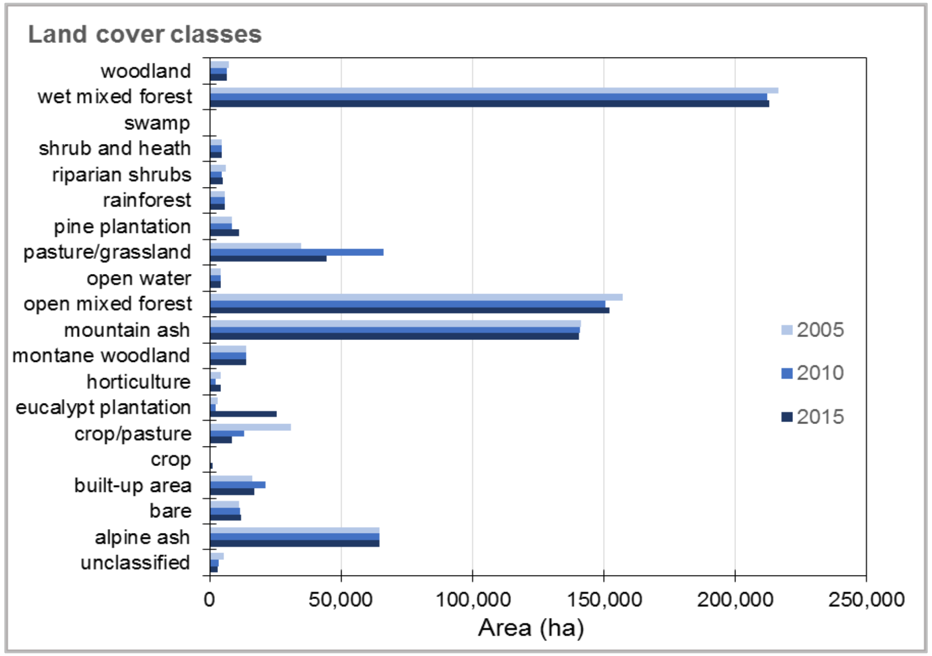
Over the 10-year period from 2005 to 2015, the extent of different ecosystems has been reasonably stable (Figure 10.1 and Table 10.2). The main changes have been due to changes in land use and the consequent vegetation type, mainly non-native vegetation. Wet mixed and open mixed forests have decreased 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 eucalypt but also pine, 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 (Ecological Vegetation Classes) from 1750 to 2005

Area (ha)	**Opening stock (1750)**	**Additions**	**Reductions**	**Closing stock (2005)**
Alpine ash	74,839		-36	74,802
Bare	19	4,361		4,379
Montane woodland	23,722		-7	23,715
Mountain ash	117,895		-2,236	115,659
Open mixed forest	256,837		-47,230	209,607
Rainforest	12,545		-8	12,538
Riparian shrub	21,714		-11,552	10,162
Shrub and Heath	6,227		-1,295	4,932
Swamp	4		0	4
Wet mixed forest	206,047		-23,224	182,822
Woodland	15,804		-7,429	8,375
Total	**735,652**	**4,361**	**-92,981**	**646,995**

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

(a)



(b)

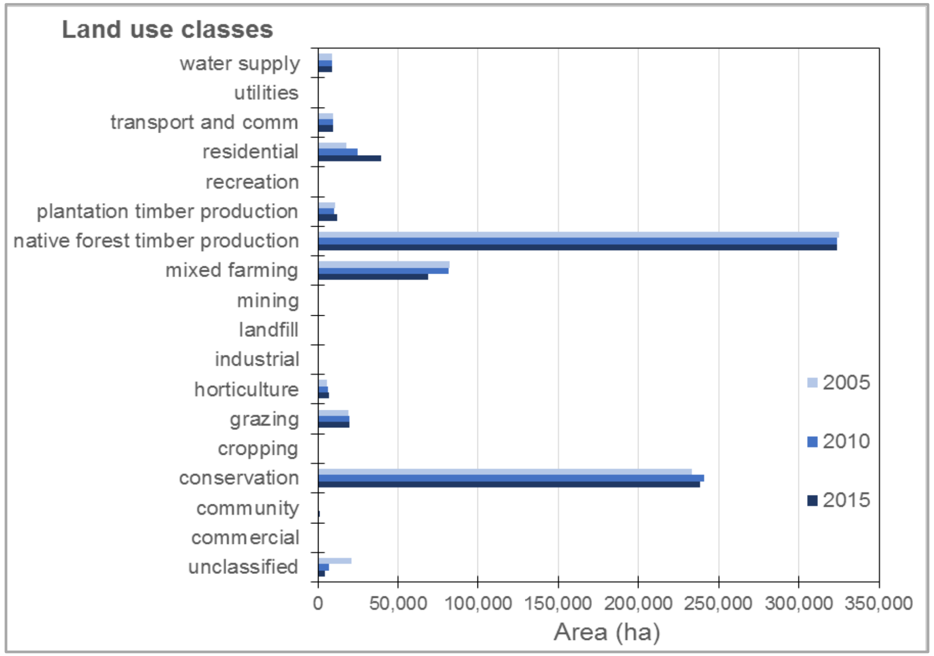


Table 10.2. Change in ecosystem extent (ha): 2005, 2010 and 2015

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

Changes in areas of age class from 1990 to 2015 in each forest type category 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 better 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 aged 56-75 years old decreased from 113,811 ha to 78,289 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 aged 56 – 75 years old decreased by 22,237 ha or 39%, and increased in areas of younger forest in the 7 – 32 years by 13,834 ha due to logging, and the ≤ 6 years class by 10,974 ha due to fire and/or logging.
- Areas of rainforest aged 56 – 75 years old decreased by 984 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 75 years decreased steadily over time, by 2.5% and 1.7% 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 little logging in these forest types.

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 small 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

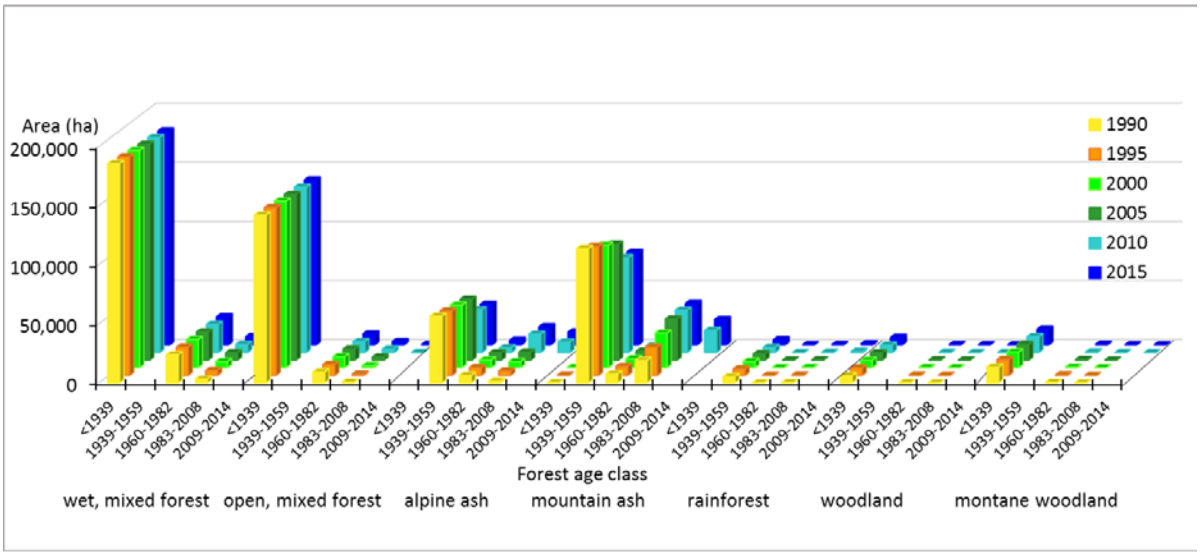


Figure 10.3. Maps of forest age class derived from regeneration time at 5-year time intervals from 1990 to 2015

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

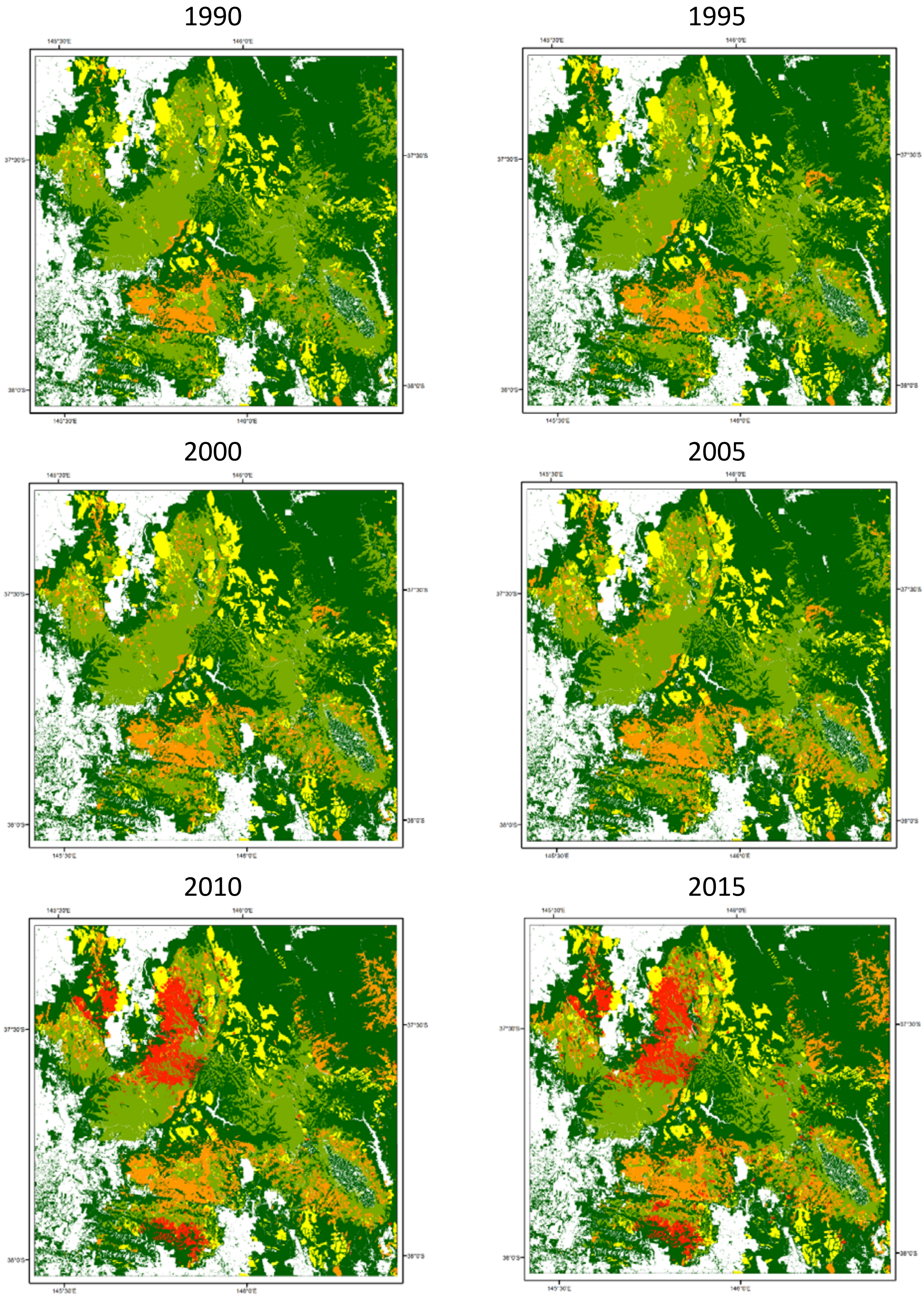


Table 10.3. Account for the change in area for each forest type and age class from 1990 to 2015

Land Cover class	Age	1990	change	1995	change	2000	change	2005	change	2010	change	2015
Wet mixed forest	< 1939	185,588	-768	184,821	-1,169	183,651	-1,137	182,515	-654	181,861	-933	180,928
	1939-59											
	1960-82	23,832	0	23,832	0	23,832	0	23,832	0	23,832	0	23,832
	1983-08	3,304	768	4,072	1,169	5,241	1,137	6,378	533	6,911	0	6,911
	2009-15								120	120	933	1,053
Open mixed forest	< 1939	142,072	-350	141,722	-795	140,926	-705	140,221	-379	139,842	-224	139,618
	1939-59											
	1960-82	9,266	0	9,266	0	9,266	0	9,266	0	9,266	0	9,266
	1983-08	702	350	1,052	795	1,848	705	2,553	304	2,857	0	2,857
	2009-15								76	76	224	299
Alpine ash	< 1939											
	1939-59	56,519	-2,144	54,375	-1,538	52,837	-1,399	51,438	-15,127	36,311	-2,028	34,282
	1960-82	6,482	-26	6,456	-1	6,455	-190	6,264	-2,337	3,928	-17	3,911
	1983-08	1,474	2,171	3,645	1,539	5,184	1,589	6,774	8,667	15,441	-133	15,308
	2009-15								8,796	8,796	2,178	10,974
Mountain ash	< 1939	216	0	216	0	216	0	216	0	216	0	216
	1939-59	113,811	-4,756	109,056	-5,565	103,491	-5,483	98,008	-17,674	80,334	-2,045	78,289
	1960-82	7,595	-17	7,578	0	7,578	-7	7,571	-2,011	5,560	-8	5,552
	1983-08	18,975	4,773	23,747	5,565	29,312	5,490	34,802	920	35,722	-637	35,085
	2009-15								18,765	18,765	2,690	21,455
Rainforest	< 1939								0		0	
	1939-59	5,324	-1	5,323	-1	5,322	0	5,322	-982	4,340	0	4,340
	1960-82	57	0	57	0	57	0	57	-18	40	0	40
	1983-08	265	1	266	1	267	0	267	-1	265	0	265
	2009-15								1,001	1,001	0	1,001
Woodland	< 1939	6,224	0	6,224	0	6,224	0	6,224	-2	6,222	0	6,222
	1939-59											
	1960-82	196	0	196	0	196	0	196	0	196	0	196
	1983-08	23	0	23	0	23	0	23	0	23	0	23
	2009-15								2	2	0	2
Montane woodland	< 1939	13,316	-1	13,315	0	13,315	0	13,315	-1	13,314	0	13,314
	1939-59											
	1960-82	509	0	509	0	509	0	509	0	509	0	509
	1983-08	10	1	11	0	11	0	11	1	12	0	12
	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 (1962 – 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 be suitable and actually 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

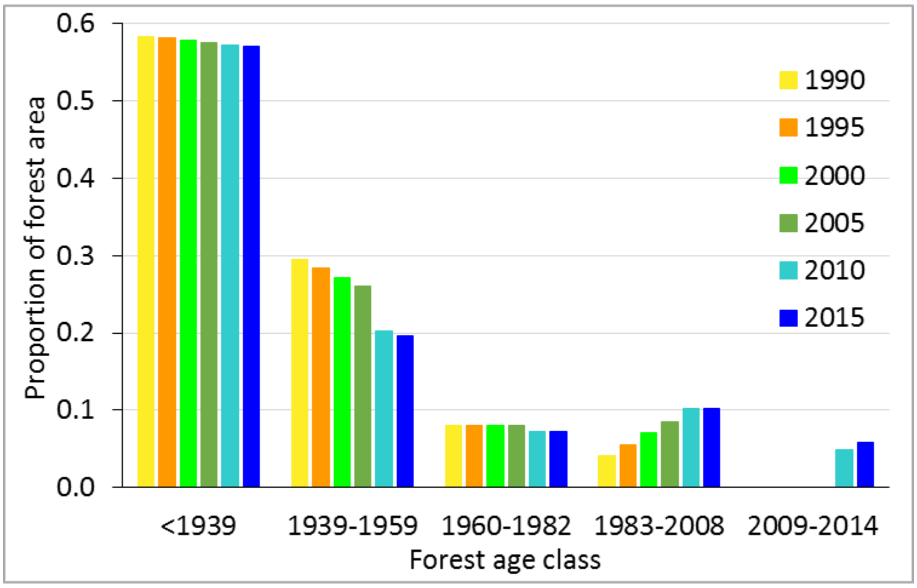
Area (ha)		**Land Cover class**		
Land management	Open mixed forest	Mountain Ash	Wet mixed forest	Alpine Ash
Logged	12,422	39,525	31,796	15,105
Available	58,373	46,080	104,668	23,015
% logged	17.5	46.2	23.3	39.6

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 0.1% 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 state. 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.

Additionally, the Victorian Government has defined modelled old growth boundaries 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, 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 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 A10.). 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 2015, while Figure 10.5 shows the value of ecosystem services over time. For most of the time period, the most valuable ecosystem service was from water provisioning, but in recent years this was overtaken by the provisioning services for crops and fodder production.

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. Little 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). 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

2010-15		Land cover						
Ecosystem service	Units	built[a]/ bare	open water	crops / pasture/ horticulture	plantations	native open vegetation	native forest	total
Area	Ha	32,803	4,361	58,213	36,335	29,624	575,737	737,072
	%	4.5	0.6	7.9	4.9	4.0	78.1	
Provisioning services								
Food [b]	t							
Water	GL yr^{-1}	0.99	0.14	0.14	0.12	0.22	3.39	3.97
Timber - sawlogs	m^3 yr^{-1}				257,793		304,920	
Timber - residual logs	m^3 yr^{-1}				247,294		524,045	
Regulating services								
Carbon sequestion[c]	MtC yr^{-1}	0.00	0.00	0.00	0.10	0.01	1.58	1.69
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 region, 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

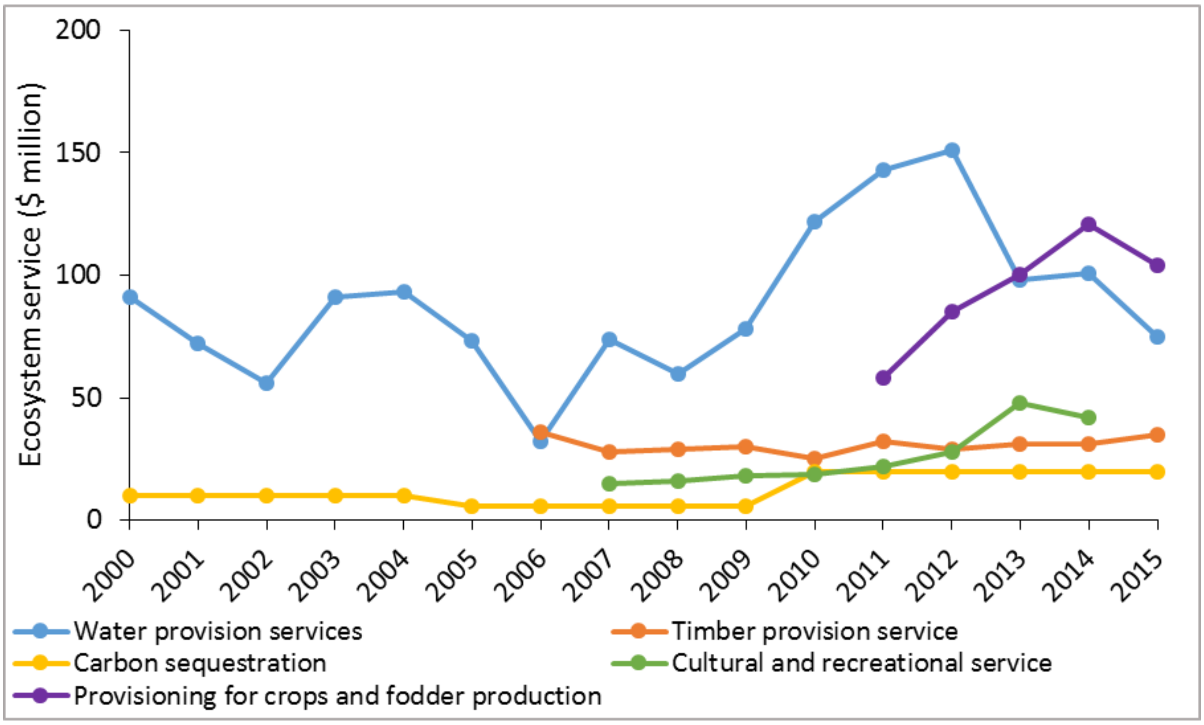
Table 10.6 Use of ecosystem services in the Central Highlands study area by industry and households, 2015

	Industry						Households	Total
Ecosystem service	Agriculture $m	Forestry $m	Water supply $m	Tourism* $m	All other industries $m	*Subtotal industry* $m	$m	$m
Provisioning services								
Food	104					*104*		104
Water			75			*75*		75
Timber		35				*35*		35
Regulating services								
Carbon sequestration							20	20
Cultural and recreational services								
Tourism				**42		***42*		**42
Total	**104**	**35**	**75**	****42**		***256***	**20**	**276**

* Tourism is a collection of activities, not an industry

** Data for 2014

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



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Appendices

Appendices are numbered in alignment with the section numbers of the main report.

A3. Land

A3.1 Spatial data sources

LAND COVER

'Land Cover' classes were initially allocated on uncleared land by grouping the 2005 version of extant Ecological Vegetation Class (EVC) types in 'NV2005_EVCBCS' (https://www.data.vic.gov.au/data/dataset/native-vegetation-modelled-quality-site-condition-and-landscape-context-2005).

These were subsequently modified on public land by the more detailed forest type information in the 2013 version of State-wide Forest Resource Inventory (SFRI) data, 'SFRITrev2013' (http://services.land.vic.gov.au/catalogue/metadata?anzlicId=ANZVI0803002820&publicId=guest&extractionProviderId=1), where available, and by plantation information in the 2015 version of Forest Management Zone (FMZ) data, 'FMZ100' (http://www.giconnections.vic.gov.au/content/vicgdd/record/ANZVI0803002608.htm).

Then, 'Land Cover' classes on private land were adjusted using land cover and land use classes in several versions of the Victorian Land Use Information System
https://www.data.vic.gov.au/data/dataset/victorian-land-use-information-system-2006-2007
https://www.data.vic.gov.au/data/dataset/victorian-land-use-information-system-2010-2011
https://www.data.vic.gov.au/data/dataset/victorian-land-use-information-system-2014-2015

Finally, water, road and structure classes in these data, overwrote any previous allocations on all land.

LAND USE

'Land Use' classes were allocated on public land by grouping classes in the 2015 version of Forest Management Zone (FMZ) data, 'FMZ100'
http://www.giconnections.vic.gov.au/content/vicgdd/record/ANZVI0803002608.htm
Private land was grouped by classes in the 2014/2015 version of Victorian Land Use Information System.
https://www.data.vic.gov.au/data/dataset/victorian-land-use-information-system-2014-2015).

LAND MANAGEMENT

We used the 2015 version of 'PLM25' (https://www.data.vic.gov.au/data/dataset/public-land-management-plm25), which describes public land management, where Public Land is defined as land held by/vested in/or owned by DELWP and other government departments, public authorities, Commonwealth government and municipalities.

FIRE HISTORY

We used the 2015 version of 'FIRE_HISTORY' (https://www.data.vic.gov.au/data/dataset/fire-history-records-of-fires-primarily-on-public-land) which represents the spatial extent of fires recorded since 1903 primarily on public land, and is attributed for wildfire and prescribed burn.

The assumption was made that wildfires result in regeneration of ash forests and rainforest. However, additional fire severity information was available for the 2009 wildfires. https://www.data.vic.gov.au/data/dataset/victorian-bushfires-severity-map-2009-polygons For these fires, regeneration was only assumed for the two most severe classes – Crown Burn and Crown Scorch.

LOGGING HISTORY

We used the 2015 version of 'LASTLOG25' http://services.land.vic.gov.au/catalogue/metadata?anzlicId=ANZVI0803002521&publicId=guest&extractionProviderId=1 A coupe-based logging history overlay of most recent harvesting activities, attributed by time period and silvicultural method. Harvesting, other than 'Thinning from Below' and 'Single Tree Selection' was assumed to result in forest regeneration.

OLD GROWTH FOREST

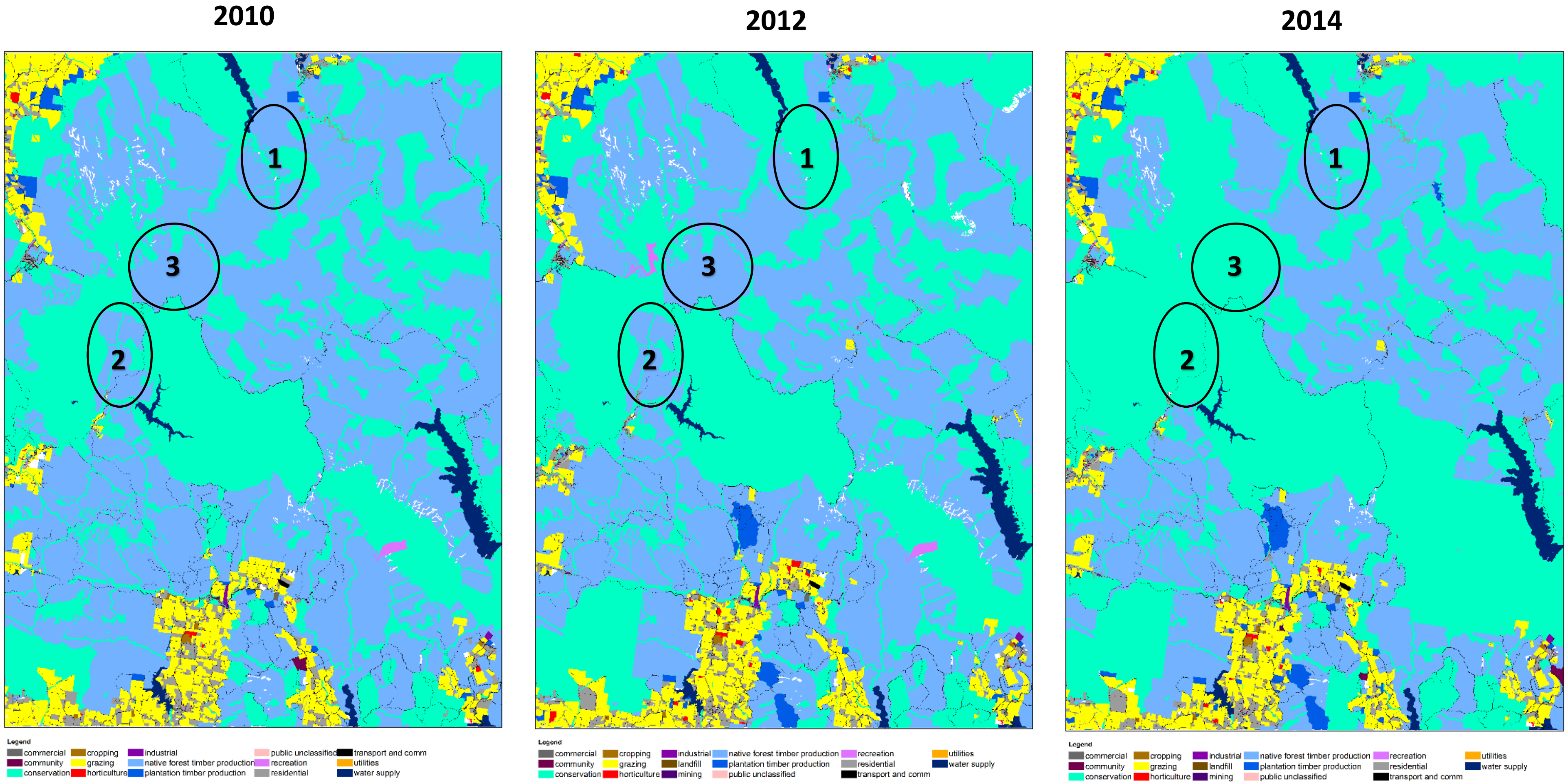
We assessed the 2009, post-fire, version of Modelled Old Growth Forest 'MOG2009' https://www.data.vic.gov.au/data/dataset/modelled-old-growth-boundaires

A3.5 Anomalies in land classification

Examples of anomalies in the land classification systems.

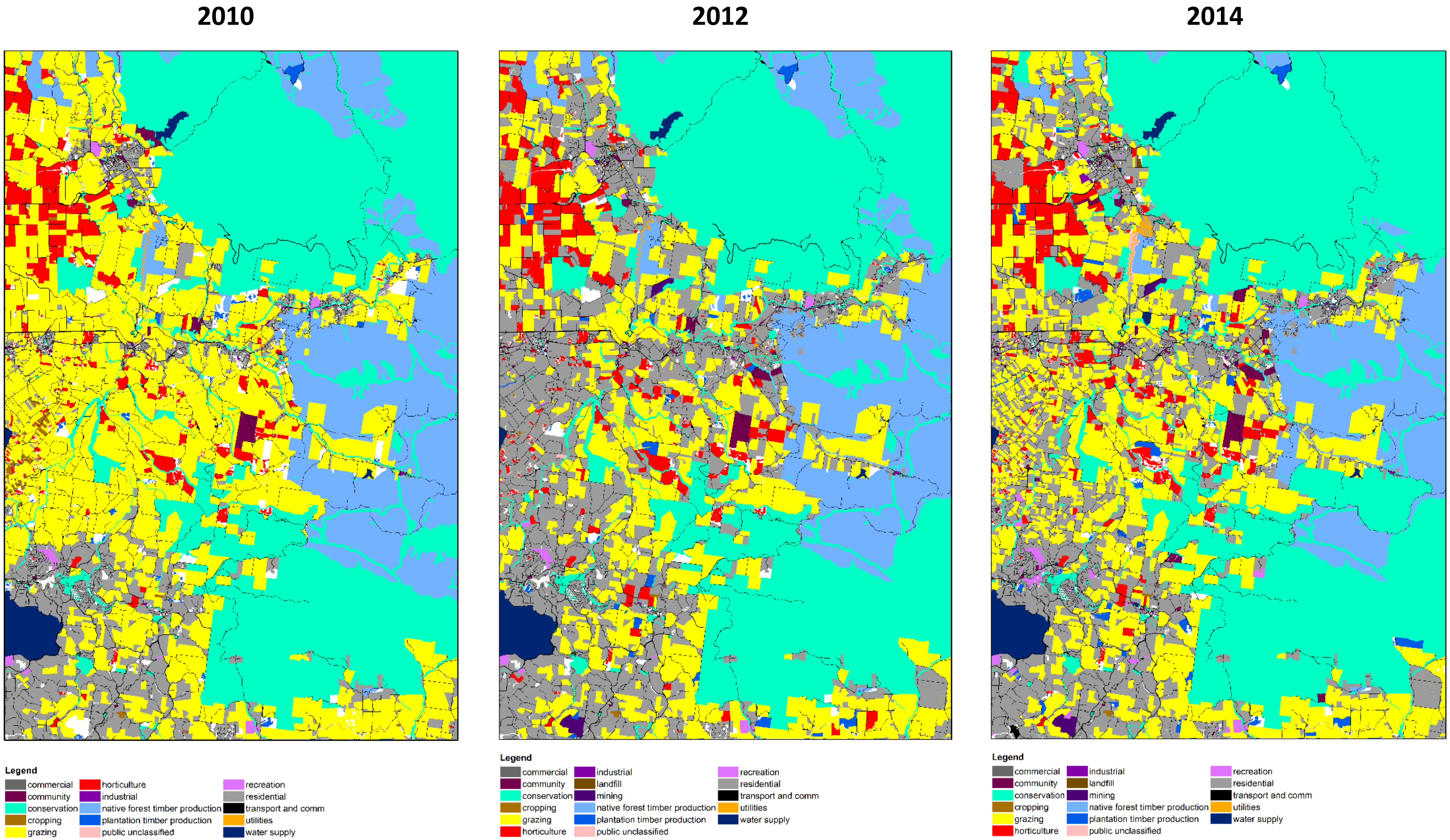
Example 1. Incorrect coding in one year.

Figure A3.1. Land use classification showing three anomalies in the coding for areas of 'conservation'. The areas marked as 'conservation' in only one year (1. in 2012, 2. and 3. in 2014) had not changed the land use category in reality, but had been coded incorrectly.



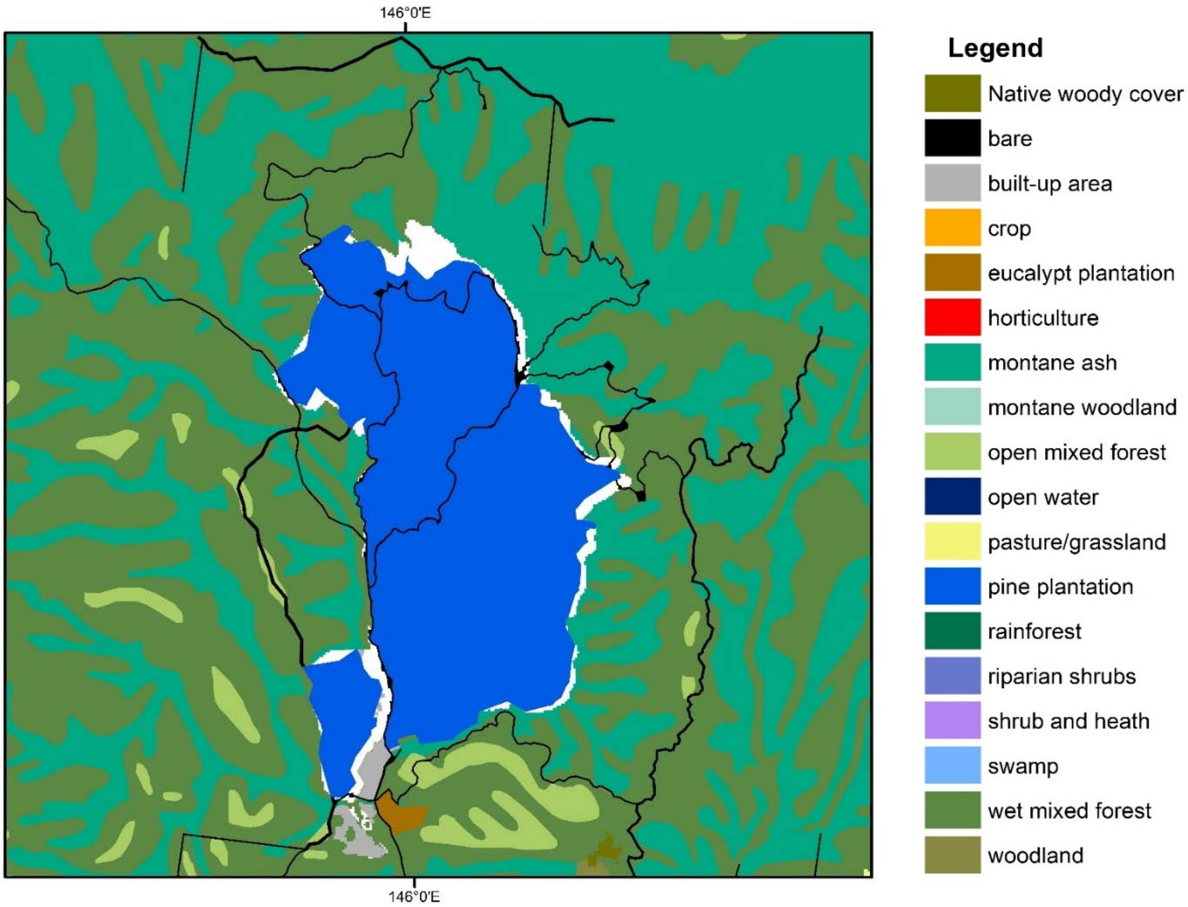
Example 2. **Change in definition of the classification criteria in one year.**

Figure A3.2. Land use classification showing an anomaly in the criteria for 'residential'. In 2012 there was a larger area of 'residential' than in 2010 or 2014, which would not have occurred in reality.



Example 3. Inconsistency in boundaries between different spatial layers of land cover.

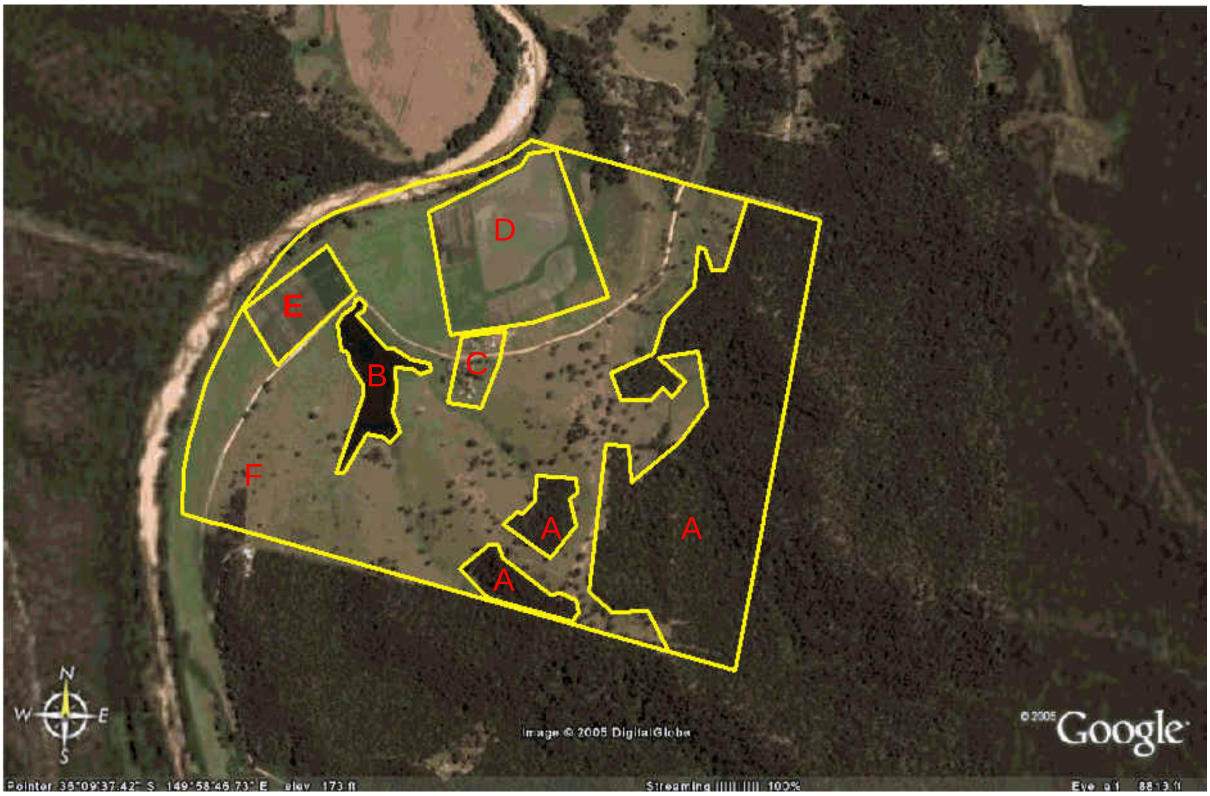
Figure A3.3. Native vegetation and managed vegetation area based on different spatial layers, and in this case the boundaries of the pine plantation do not match that of the native vegetation.



Example 4. Different sources of spatial data cause problems due to scale and aggregation.

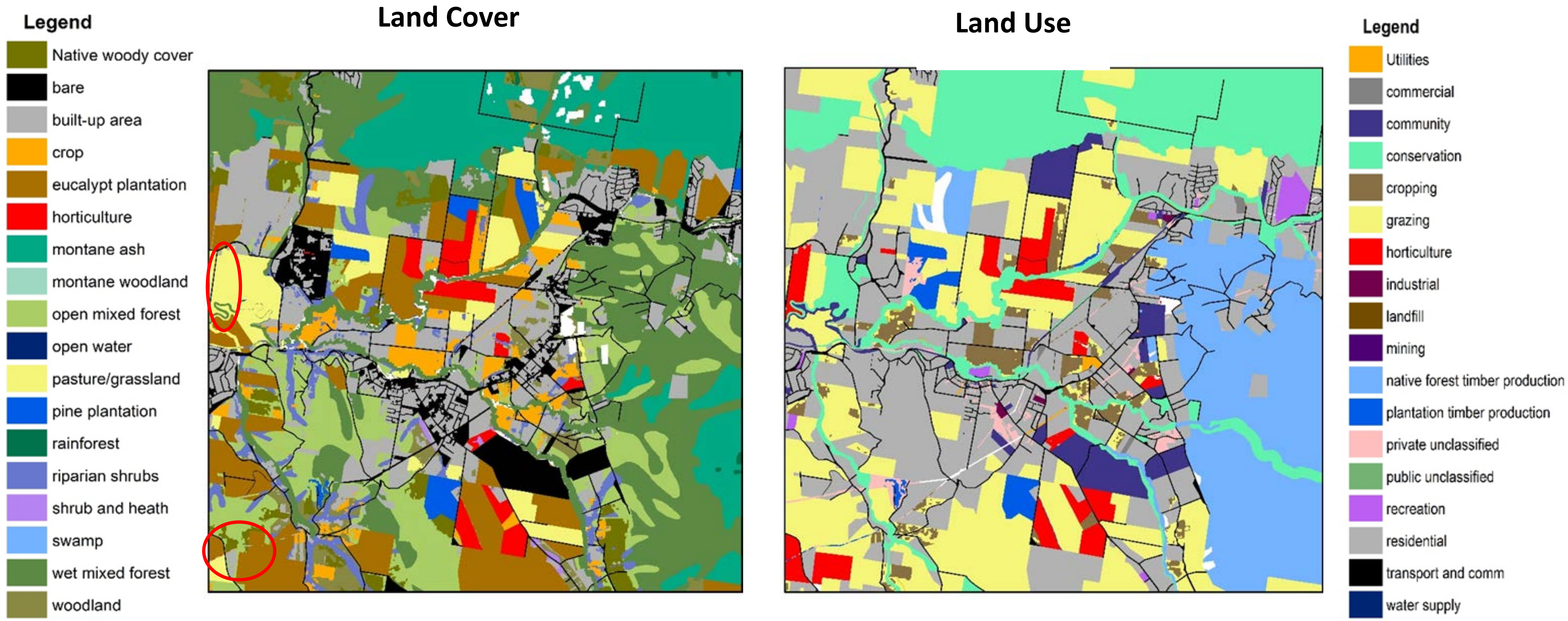
Figure A3.4. Land cover is assessed from satellite images whereas land use is mapped using administrative data.

Areas calculated for land cover and land use include:
Land cover: A: forest – 39.0 ha, B: water – 3.5 ha, C: residence – 1.8 ha, D: irrigated crop – 13.5 ha, E: other crop – 3.8 ha, F: grassland – 68.0 ha.
Land use: Agriculture (grazing) – 129.6 ha



Example 5. Anomalies between land cover and land use classifications.

Figure A3.5. Classes that should be the same in both the land cover and land use classification systems sometimes do not correspond.
‘Horticulture’ is the same class but there are two areas on the west boundary that show a ‘horticulture’ land use but not land cover (circled in red). ‘Built-up area’ land cover should correspond to ‘residential’ and ‘commercial’ land use, all shown in shades of grey. However, there is more grey area for land use than for land cover, particularly in the central section of the map.



A4. Water

A4.2 Water asset account

Table A4.1. Central Highlands water asset account for the reservoirs from 1990 – 2015.

Stocks are the water storage within the 10 reservoirs managed by Melbourne Water and sourced from runoff within the study area. Precipitation and evaporation refer to the transfers from the surface water of the reservoirs. Data are not available for all components of a full water asset account and these amounts are included in the unaccounted changes.

Volume of water (GL)	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Opening stock of reservoir water	1539	1599	1619	1577	1526	1502	1625	1470	1149	1089	981	980	969	854	969	1028	878	641	603	564	717	1045	1300	1372	1389	1300
Additions to stock																										
Returns																										
Inflows	698	628	760	712	527	667	826	232	433	317	560	426	324	509	508	389	163	374	287	369	559	634	658	416	421	306
Precipitation	61	62	67	67	45	62	68	37	54	49	56	51	41	53	54	52	35	51	47	45	65	65	58			
Inflows from other territories																										
Inflows from other water resources																										
Total additions	*758*	*690*	*827*	*778*	*571*	*729*	*894*	*269*	*487*	*366*	*616*	*477*	*365*	*562*	*562*	*441*	*198*	*425*	*335*	*414*	*625*	*699*	*716*	*416*	*421*	*306*
Reductions to stock																										
Abstraction	465	465	476	447	453	482	459	512	520	490	502	500	462	476	433	431	435	401	370	360	349	343	360	393	395	401
Evaporation	43	44	37	38	42	39	39	46	44	42	42	41	46	45	44	44	48	48	44	47	40	38	42			
Outflows to other territories																										
Outflows to sea																										
Outflows to other water resources																										
Total reductions	*508*	*509*	*513*	*485*	*495*	*521*	*498*	*558*	*564*	*532*	*544*	*541*	*508*	*521*	*477*	*475*	*483*	*449*	*414*	*407*	*389*	*381*	*402*	*393*	*395*	*401*
Net additions and reductions	250	181	314	293	77	208	396	-289	-77	-166	72	-63	-143	41	86	-34	-285	-24	-79	7	236	318	314	23	26	NA
Unaccounted changes	-191	-161	-356	-345	-101	-84	-551	-32	17	58	-73	52	28	74	-27	-116	49	-14	39	146	93	-64	-242	-6	-115	NA
Closing stock of reservoir water	1599	1619	1577	1526	1502	1625	1470	1149	1089	981	980	969	854	969	1028	878	641	603	564	717	1045	1300	1372	1389	1300	NA

A4.3 Water Yield

A4.3. Background

The response of water yield to forest age was derived from a synthesis of information from the literature. Disturbance within a forested catchment results in increased runoff due to loss of leaf area in the short-term of up to 1 to 5 years, until leaf area is restored. Reported increases in runoff after a range of disturbance events range from 25 to 100% (Jayasuriya et al. 1993; Vertessy et al. 1996, 2001; Watson et al. 1999a, 2001; Lane et al. 2006, 2010; Feikema et al. 2006, 2013). The water yield response immediately post-disturbance is highly dependent on the soil moisture conditions pre- and post-disturbance. Increased runoff post-fire is diminished if initial soil moisture stores are low and if subsequent rainfall is low. Such dry conditions typically occur prior to major fires and were particularly the case in 2009, where there was no clear evidence of an increase in post-fire runoff (Tan et al. 2011). This is also likely the reason that Kuczera (1987) did not report an increase in flow after the 1939 fire, which occurred during a prolonged dry period. A post-disturbance increase in streamflow is more likely after harvesting and if rainfall conditions and soil moisture storage are average or above average.

In many ecosystems, there is a gradual return of runoff to pre-disturbance levels as leaf area is restored. However, in the montane ash forest there is an additional factor; the regenerating forest with dense leaf growth results in high water use by transpiration and hence reduced runoff. The pattern of response of water yield is well established, but the parameters describing magnitude and timing are variable (Langford 1976; Kuczera 1985, 1987; Vertessy et al. 2001; Buckley et al. 2012). The hydrological effects of forest age have been related to the hydraulic and structural characteristics of ash stands, such as age-dependent trends in leaf area index, leaf conductance, interception and sapwood area index. Kuczera (1987) developed a model of the catchment level response of water yield to large-scale disturbance in ash forest, that is, a stand-replacing event. Reductions in water yield were projected to commence about 3 years post-disturbance, reach a maximum in 20 to 30-year-old stands, and then decline as the forest aged and transpiration and interception declined. The gradual recovery of water yield may take about 150 to 200 years (Vertessy et al. 1998, 2001). The Kuczera model provides a general response of water yield to disturbance over time that is appropriate to apply at the regional scale. The general relationship and the magnitude of the parameters have been verified by studies of smaller paired catchment silvicultural treatment experiments and re-analysis of longer time periods of the streamflow data (Vertessy et al 1998; Watson et al. 1999b; Brookhouse et al. 2013), and in other eucalypt forest types (Cornish and Vertessy 2001). At smaller scales, there are large variations in water yield between catchments with different site and forest characteristics and high levels of uncertainty in predictions of the recovery of water yield (Vertessy et al. 1998). Detailed prediction of impacts on water yield at the small catchment scale can be made using physically-based models that predict forest regrowth and its interactions with the water and energy balances given local site characteristics (Vertessy et al. 1996; Watson et al. 1999a, b).

A4.3.2 Calculations

Water yield with and without disturbance and resulting changes in forest age was calculated for each grid cell in the study area. Alpine Ash, Mountain Ash and rainforest forest types that were clearfell logged or burnt (fire severity class 1 or 2 assessed in 2009) had an initial increase in runoff followed by a decrease related to forest age. Mixed species forest types that were clearfell logged had an initial increase in runoff, but then, were assumed to have constant leaf area (Feikema et al. 2006; Lane et al. 2010). Percent changes in water yield in relation to forest age of ash were applied to the annual runoff calculated from the water balance model. Two equations were used to describe the relationship between reduction in water yield and forest age, depending on the assumed initial or pre-disturbance forest age of either old growth or regrowth. The Kuczera (1987) model assumed the initial forest was old growth and was calibrated before the 1939 fire. Whereas, the current forest is mostly regrowth since the 1939 fire, and hence, is assumed to be experiencing reduced water yield. The water balance model was calibrated for the current forest, and hence, at the time of each disturbance event in the current calculations, the modelled water yield would have been less than maximum and the corresponding reduction in the regenerating forest would be less than that modelled.

The following functions were used in the calculation of water yield (shown in Figure A4.1):

Initial increase in water yield following disturbance as a proportion of the baseline calculation for constant age: Year 1 = +0.5; Year 2 = + 0.25; Year 3 = 0.

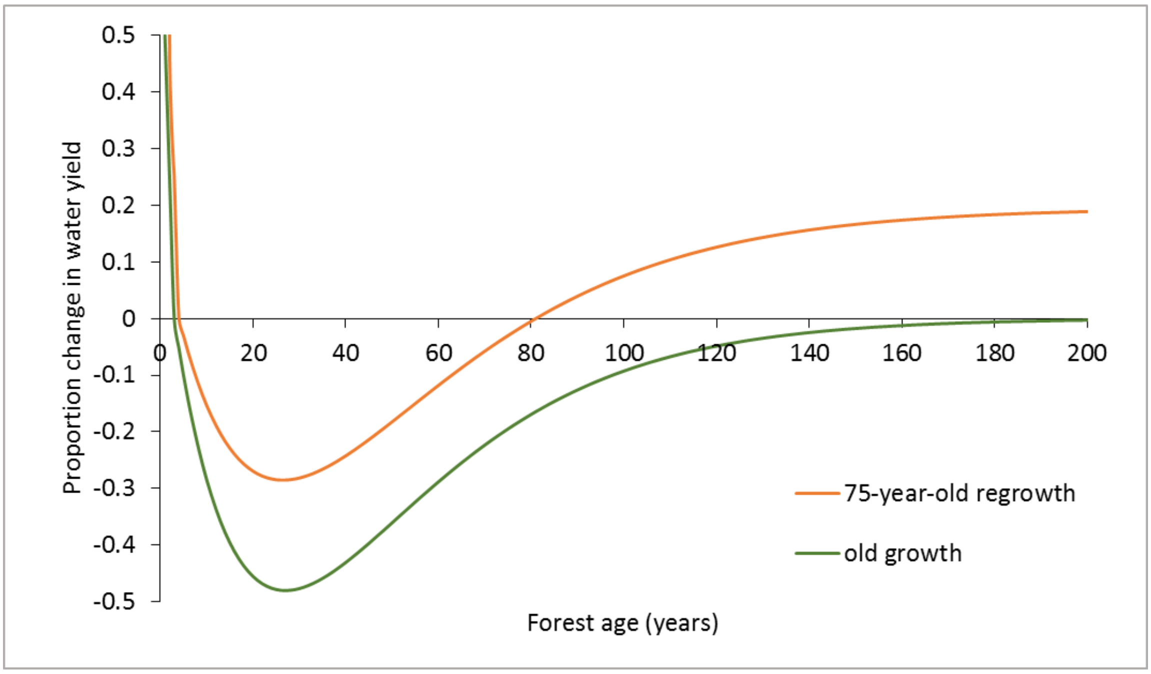
Reduction in water yield as a proportion of the baseline calculation for constant age:
Pre-disturbance forest of old growth:

reduction proportion = 0.48 * 0.04167 * (t -3) * exp(1 - 0.04167 * (t - 3))

Pre-disturbance forest of regrowth:

reduction proportion = 0.48 * 0.03667 * (t - 3 + 4.82) * exp(1 - 0.03665 * (t - 3 + 4.82)) + 0.1949

Figure A4.1. Change in water yield following stand-replacing disturbance

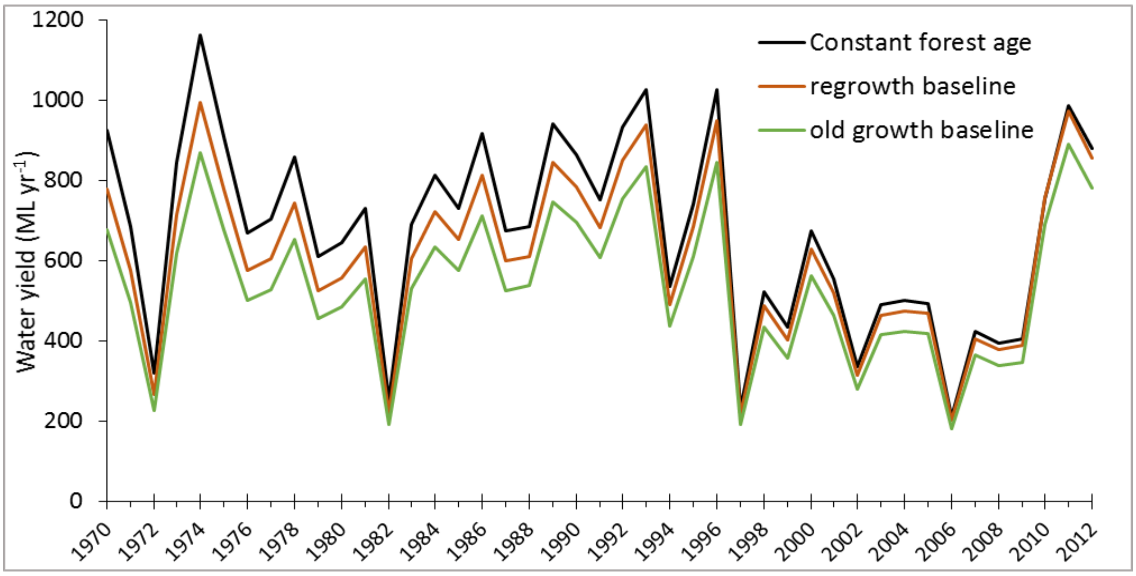


An initial increase in water yield occurs and then a decrease over time under the regrowing forest. Pre-disturbance conditions of 75-year-old regrowth and old growth forest are compared.

A4.3.3 Results

The water yield for the combined catchments within in the study area is shown in Figure A4.2, together with the difference in yield due to the reduction resulting from forest age using conditions of the initial forest being old growth or regrowth. Using a pre-disturbance vegetation condition of the 75-year old regrowth is probably the most realistic scenario for this region because the majority of the forest was burnt in 1939. Pre-disturbance condition of regrowth produces a lesser reduction because the catchment was not at maximum water yield at the time that the disturbances occurred. The difference between constant forest age and the regrowth and old growth conditions are reduced over time as the forest increases in age.

Figure A4.2. Total annual water yield for the reservoirs in the Central Highlands showing the difference in yield resulting from different initial conditions of forest age, being either constant, old growth or regrowth



Water yield reflects the area of the catchment, but also the water balance between precipitation and evaporation, and the effect of vegetation type and slope on runoff. For example, the O'Shannassy, Maroondah and Tarago catchments are similar sizes (Table A4.2), but the water yield is greatest in the O'Shannassy and least in the Tarago. The catchments differ greatly in their proportions of the land cover types (Table A4.2 and Figure A4.2), and this influences the response of water yield because the reduction due to forest age is applied to the Mountain and Alpine Ash and rainforest land cover types, but not to the mixed forest and woodland types. The proportion of each catchment that has regenerating forest following disturbance by wildfire or logging over the period 1970 – 2012 is shown in Figure A4.3. The largest catchment, the Thomson, had 9% of the area logged in ash forest but this represented 4300 ha, nearly as large an area as that burnt in 2009 in the O'Shannassy catchment.

Table A4.2. Area (ha) of each land cover class in the catchments

	Land Cover Class						
Reservoir catchment	**Mountain & Alpine Ash, Rainforest**		**Open & wet mixed forest, woodland, montane woodland**		**Other**		**Total**
	area (ha)	%	area (ha)	%	area (ha)	%	area (ha)
Upper Yarra	16,271	48	16,853	50	910	3	34,034
Maroondah	7,473	73	2,461	24	250	2	10,184
O'Shannassy	11,394	96	444	4	43	0	11,881
Thomson	16,781	35	27,380	58	3 386	7	47,548
Tarago	4,949	43	3,798	33	2755	24	11,502
Total							115,149

Figure A4.3. Proportion of the catchment area that is regenerating forest following wildfire or logging in ash forest, and logging in mixed species forest, over the period 1970 to 2012

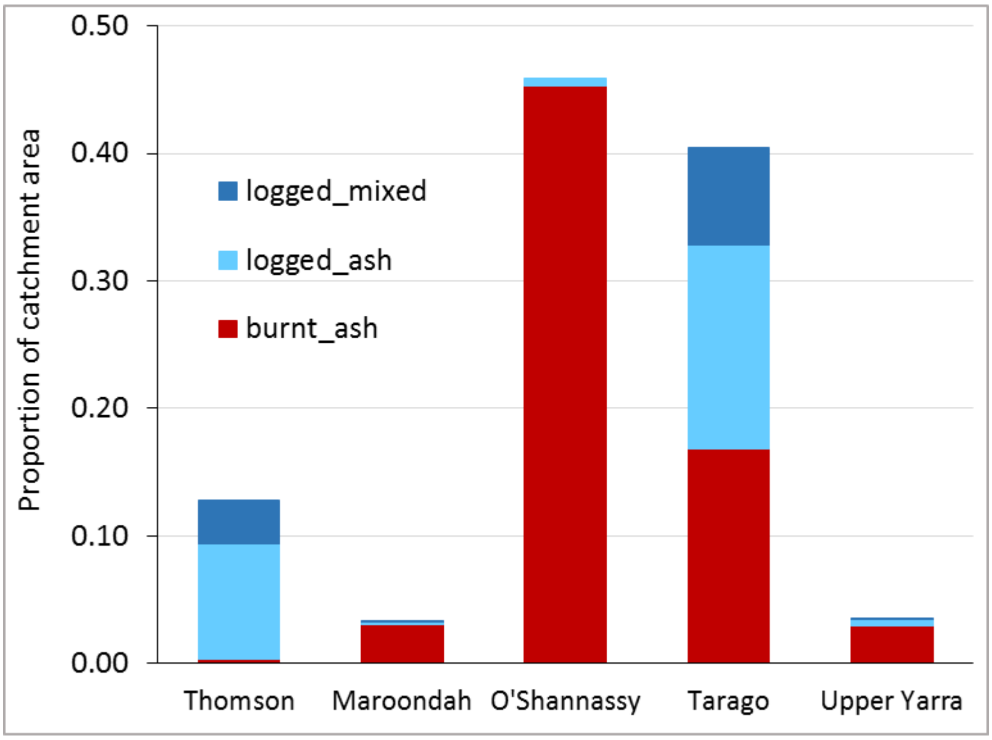
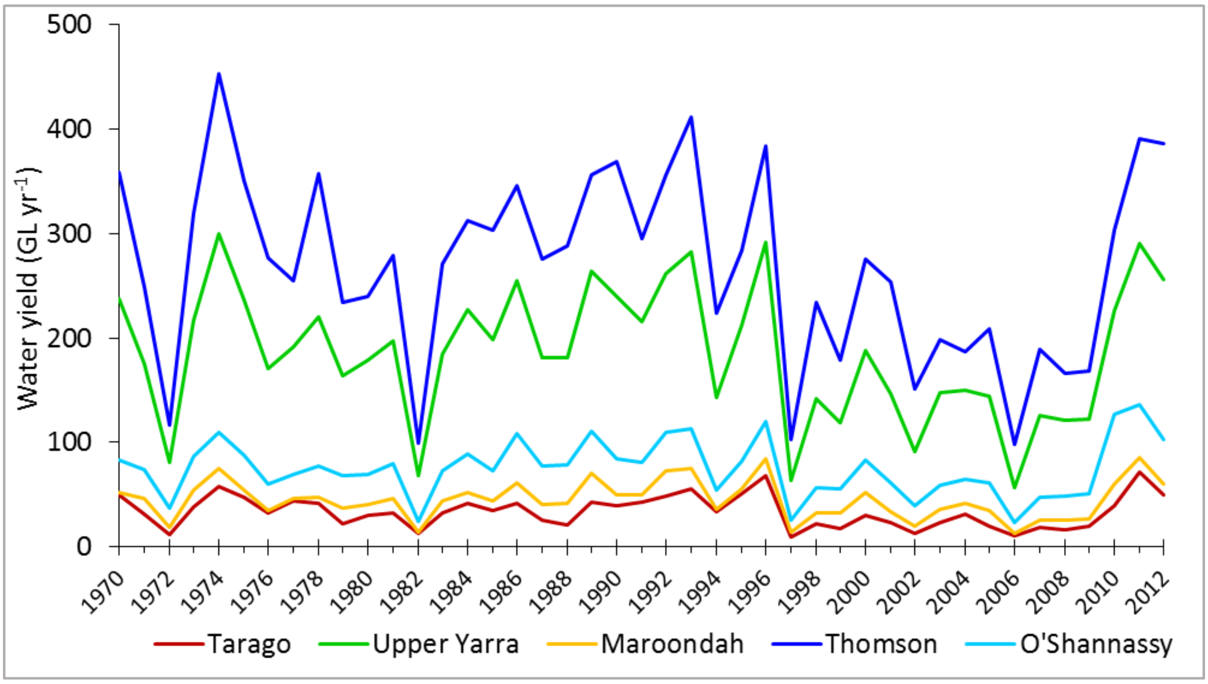


Figure A4.4. Annual water yield in the five catchments of the Central Highlands study area over the period 1970 to 2012, using a baseline of regrowth forest



The effect of the water yield reduction depends on the age of the ash forest and rainforest, and the area of these forest types within each catchment. The shift in age categories over time due to fire or logging is shown in the following graphs and maps. The age categories were selected to coincide with similar proportions of water yield reduction, with the greatest reduction occurring between ages of 13 – 49 years and peaking at 25 years. Forest age is determined from the last stand-replacing event, which refers to fire or clearfell logging for ash, and clearfell logging for mixed species forest.

Figure A4.5. Distribution of forest types across the catchments, where ash type forest is affected by reduction in water yield and mixed forest is not affected

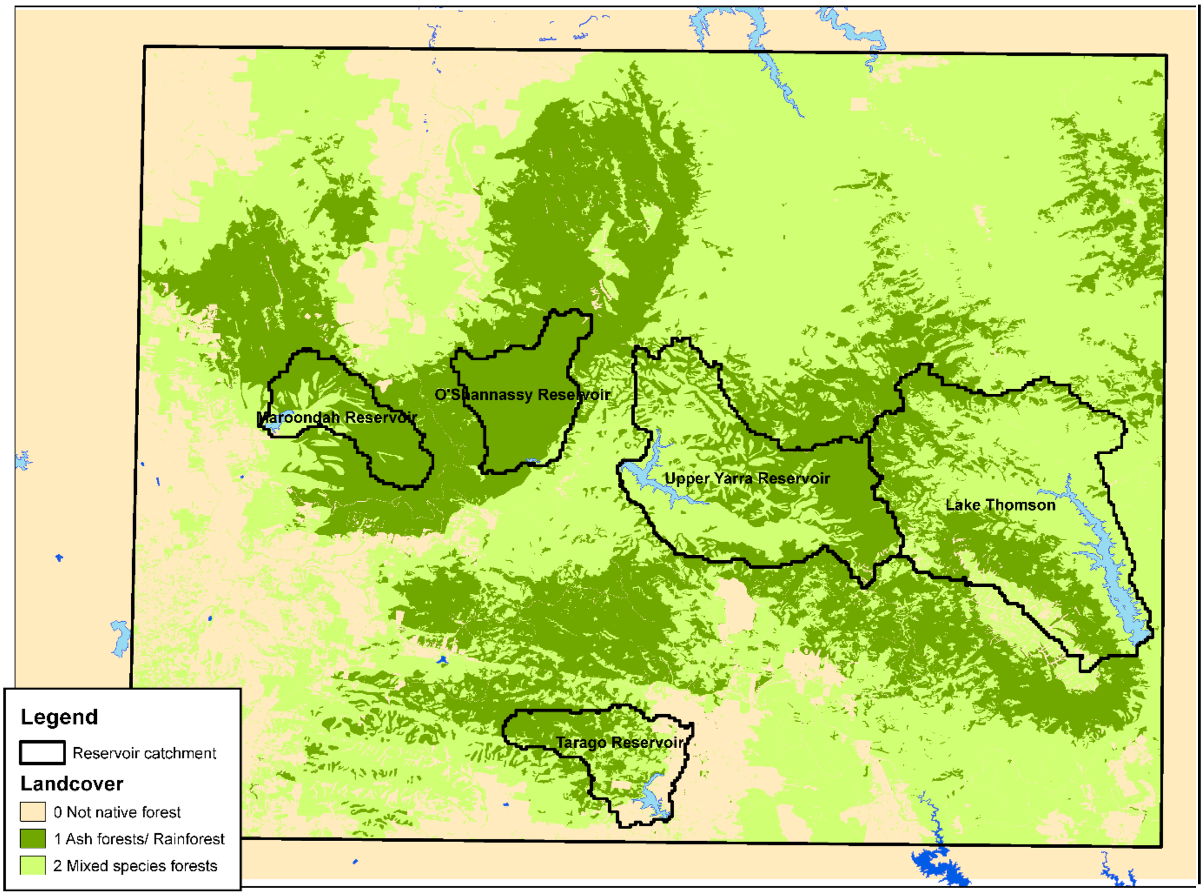


Figure A4.6. The proportion of catchment area in each forest type and age category, which determine the reduction in the water yield function

Shown at time intervals of 1974, 1980, 1999 and 2012 to provide an estimate of change over time.

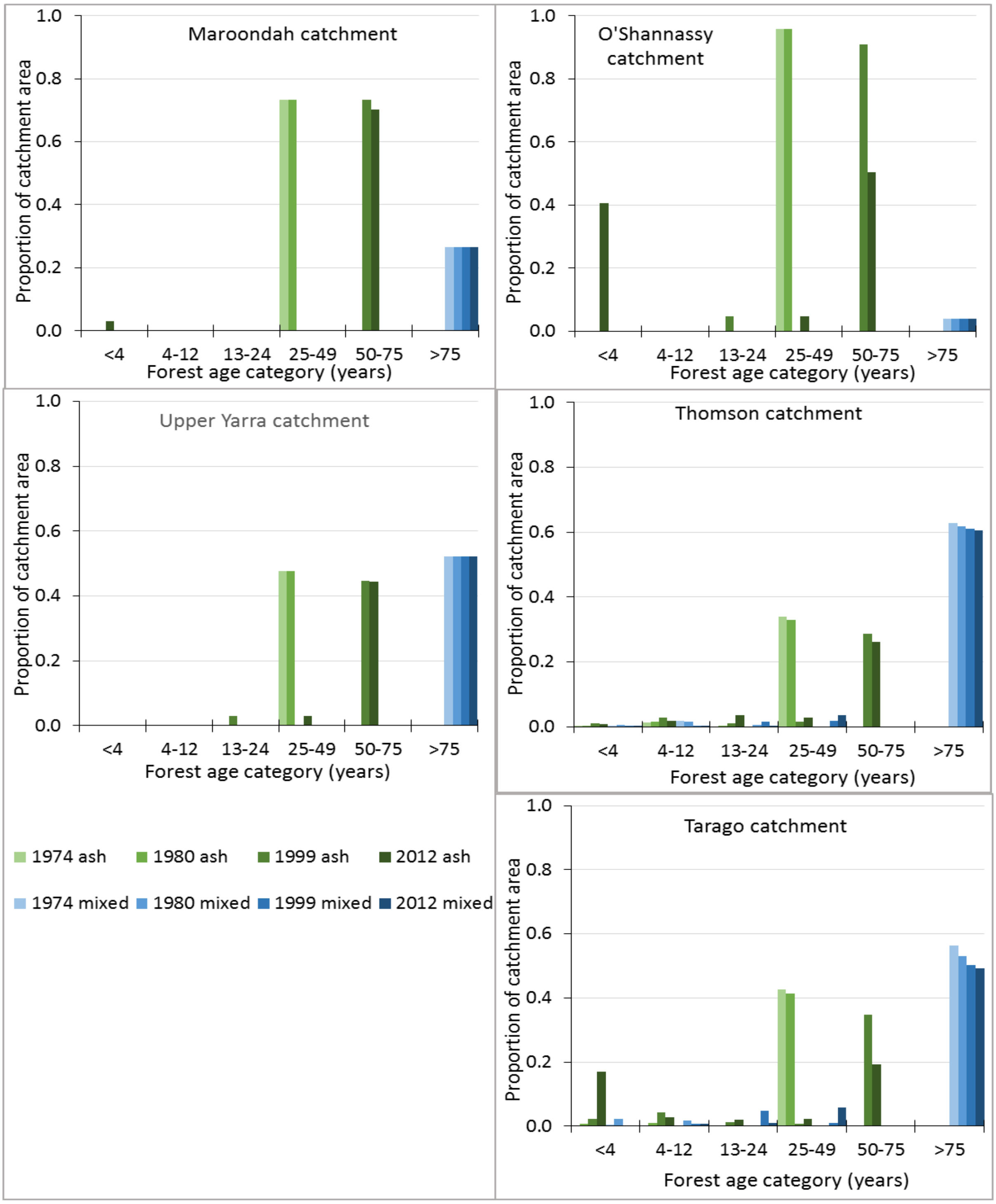
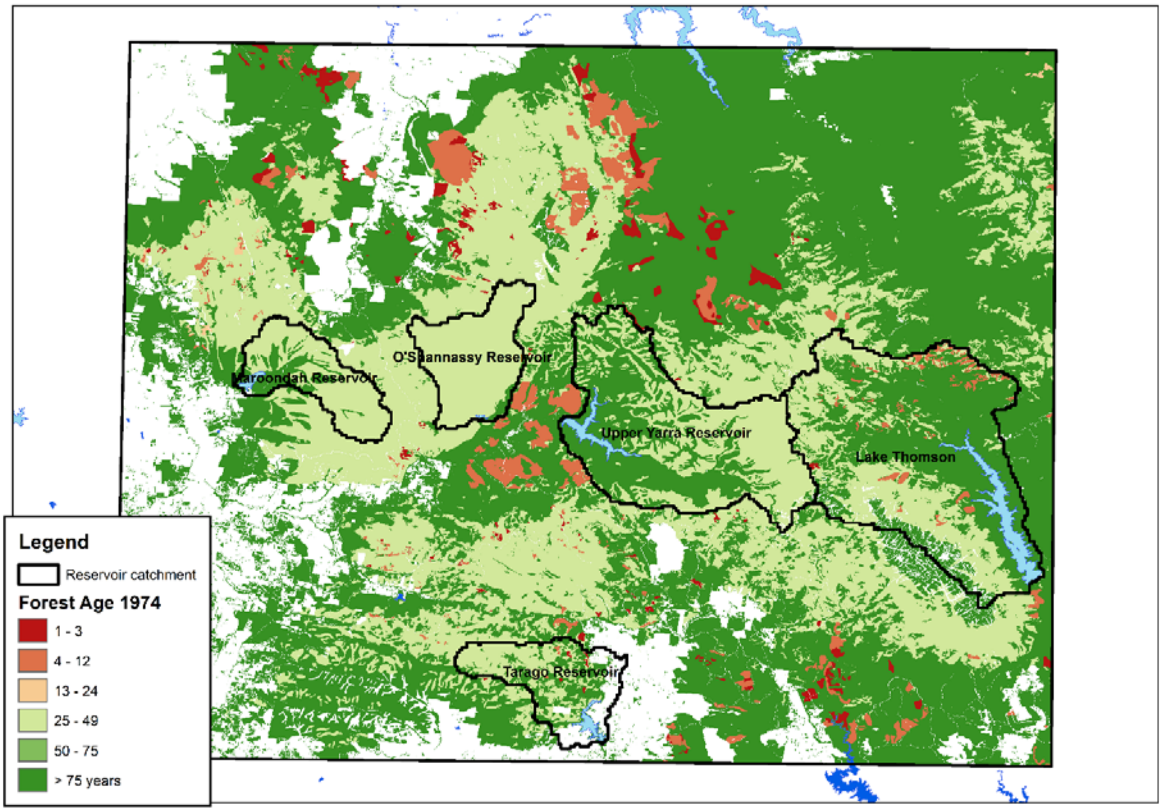
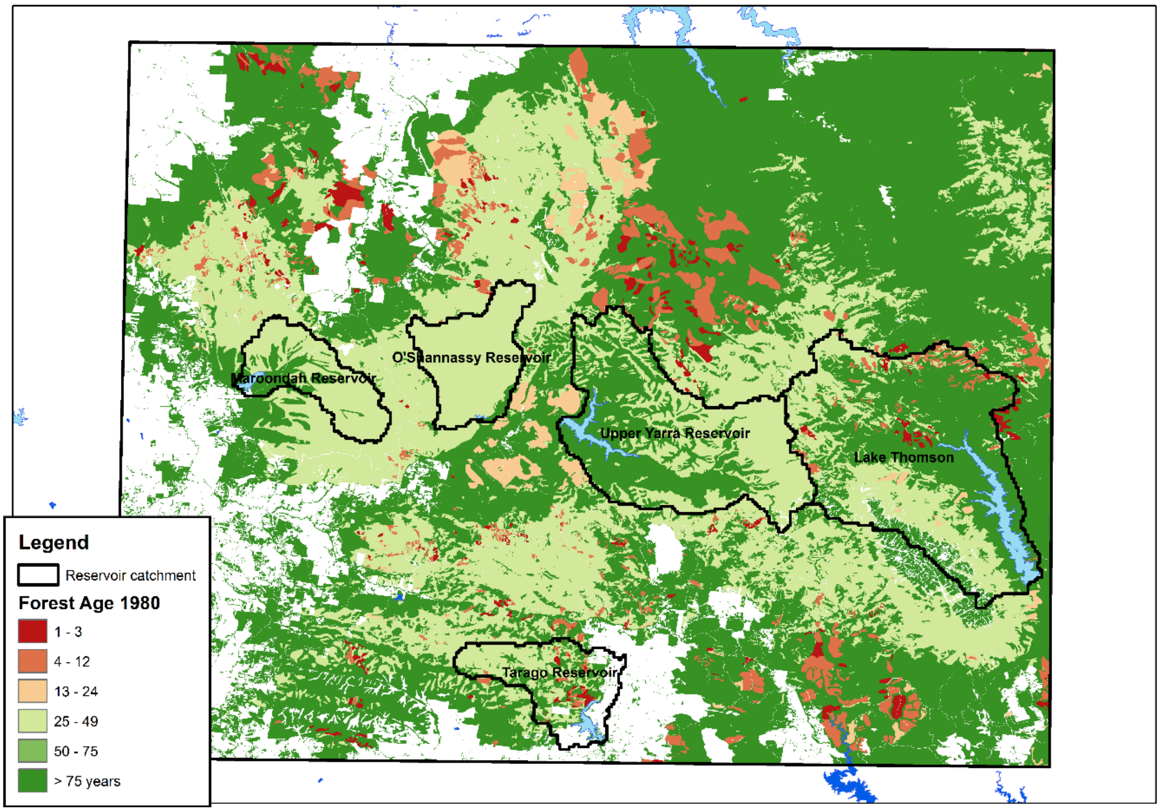
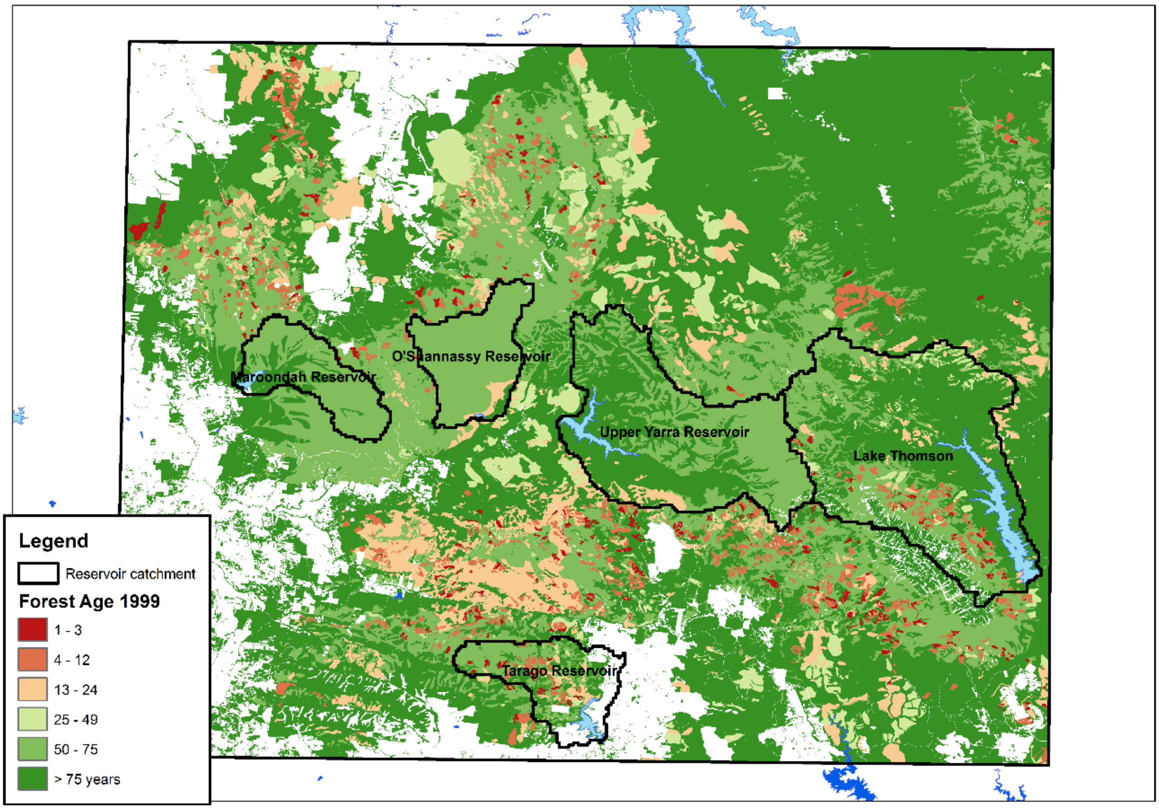
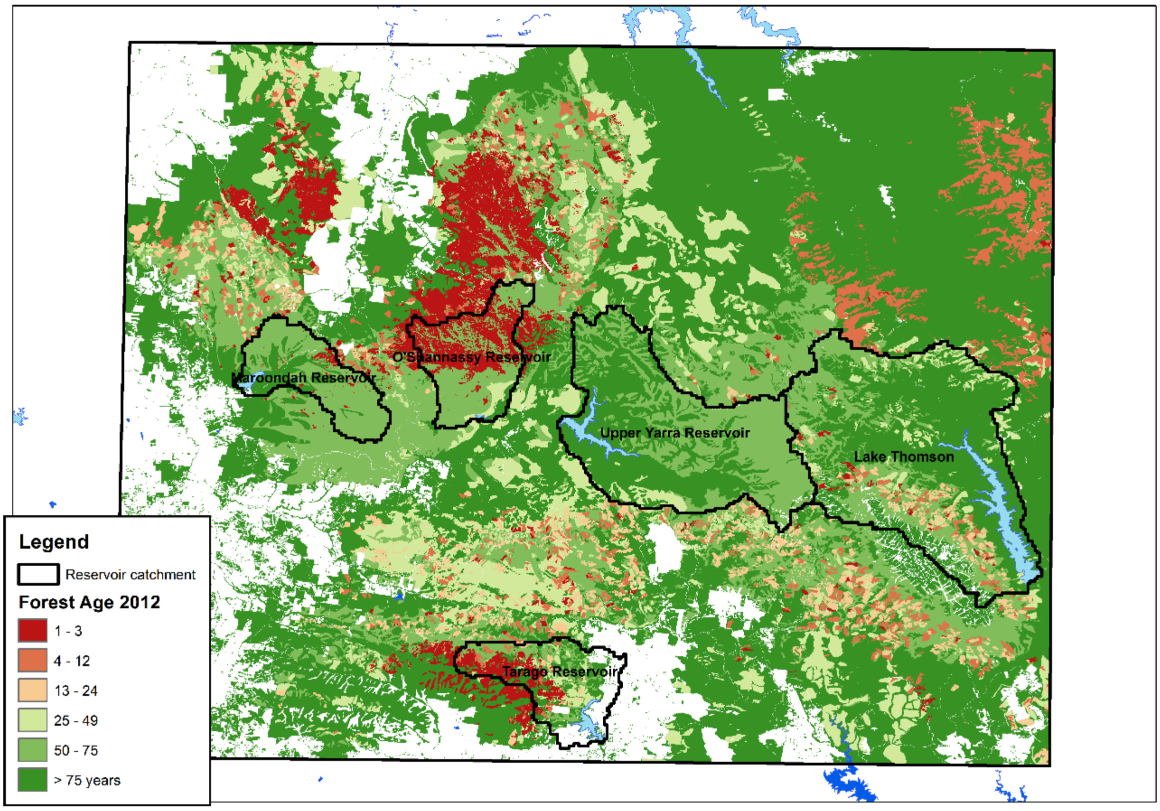


Figure A4.7. Spatial distribution of forest age categories shown for a selection of years to illustrate the change over time, both as forests increase in age and disturbance results in regeneration of young forest






O'Shannassy Reservoir
Maroondah Reservoir
Upper Yarra Reservoir
Lake Thomson
Tarago Reservoir
Legend
Reservoir catchment
Forest Age 1999
1 - 3
4 - 12
13 - 24
25 - 49
50 - 75
> 75 years


O'Shannassy Reservoir
Maroondah Reservoir
Upper Yarra Reservoir
Lake Thomson
Tarago Reservoir
Legend
Reservoir catchment
Forest Age 2012
1 - 3
4 - 12
13 - 24
25 - 49
50 - 75
> 75 years

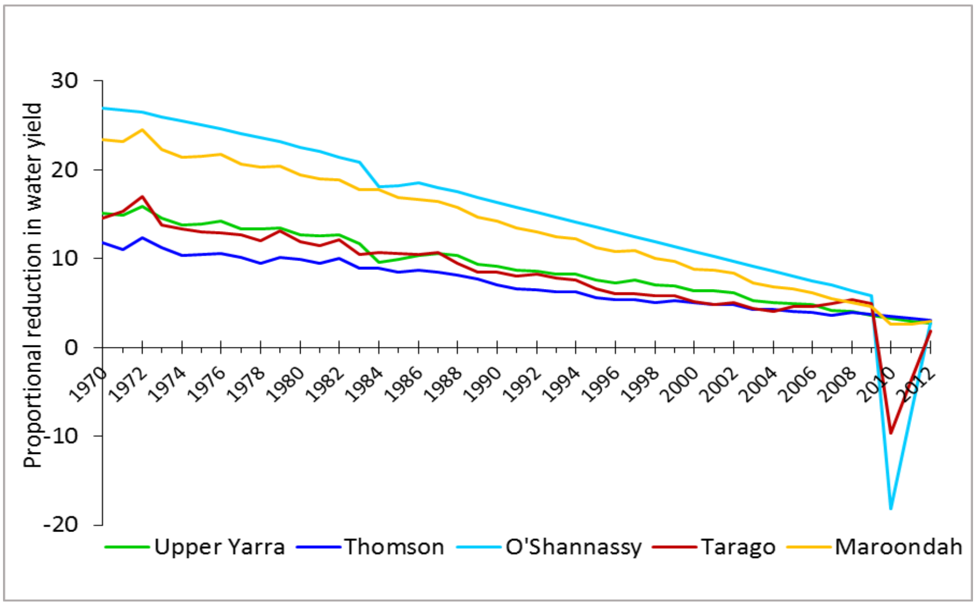
The reduction in water yield due to forest age is declining in all catchments as the majority of the forest that is 1939 regeneration is increasing in age (Figure A4.8). Differences between the catchments in their rate of change reflect the factors that reduce water yield. The greatest rate of decline in the reduction of water yield, that is, the greatest rate of return of water yield to pre-disturbance levels, occurs in the O'Shannassy catchment. This catchment has the highest proportion of montane ash forest and had no stand-replacing disturbances, until the 2009 fire. The Maroondah catchment is similar but with a lower proportion of ash forest.

The Tarago and Thomson catchments have a smaller proportional reduction in water yield than other catchments, because they have more mixed species forest where the regrowth does not cause the reduction in water yield. These two catchments have more logged areas and hence younger forest, but less of this forest is ash, than in the other catchments. The Tarago catchment does not show a decline from 2004 to 2009, which may indicate reductions in yield due to younger forest regenerating from logging.

The increases in water yield in 2010 and 2011 in the O'Shannassy and Tarago catchments reflect the large areas burnt in 2009 and the short-term increase in runoff after fire. This result may be an over-estimate of the increase in runoff after disturbance, because the increase may not have be as large as the standard function during the dry conditions before and after the fire.

Our estimated reduction in water yield after disturbance at a grid cell scale, which was then aggregated to the catchment scale, provided similar results to that from a physically-based model (Lane et al. 2010). Model results included a maximum decline of 55% from a landscape unit, a decline of 20% at the catchment scale after mortality of 34% of the ash forest area, a return over more than 200 years (Lane et al. 2010), and a 42% decline in a catchment completely burnt (Feikema et al. 2013).

Figure A4.8. Reduction in water yield from constant forest age assuming regrowth forest baseline



A5. Carbon

A5.2 Carbon stock assets

A5.2.1.1 Carbon stocks in land cover types

The biomass carbon stock model was derived for montane ash forest, but the carbon stock in mixed species wet temperate forest is less than for the ash forest. This adjustment in the modelled carbon stock was estimated using existing allometric volume equations and wood density for the other species compared with the ash species (Keith et al. 1997, 2000; Bi et al. 2004; Illic et al. 2000). Estimates of biomass carbon stock density for other land cover types were derived from the best available information in the literature, and were applied as constant values. Carbon stocks in eucalypt and pine plantations were calculated using the FullCAM model with standard plot values for the region (DotE 2015).

Table A5.1 Estimates of biomass carbon stock density for all land cover types in the study area

Land cover	Average carbon stock (tC ha^{-1})	Proportion of modelled ash	Source
Rocky / bare	0		1
Riparian shrubs	40		1
Rainforest	325		2
Wet mixed forest		0.6	3, 4, 5, 6, 7
Montane ash		1.0	8
Open mixed forest		0.5	5, 6, 7
Woodlands	150		9
Shrub and heath	30		1
Swamp	20		1
Montane woodland	150		10
Grazing	4		1
Cropping	4		1
Horticulture	8		1
Plantation softwood	56		7
Plantation hardwood	152		7
Residential	15		1
Reservoirs	0		1

1. Ajani and Comisari (2014); 2. May et al. (2012); 3. Keith unpubl.; 4. West and Mattay (1996); 5. Grierson et al. (1992); 6. Borough (1984); 7. DotE (2015a); 8. Keith et al. (2014a); 9. Berry et al. (2010); 10. Keith et al. (1997)

A5.2.1.2 Carbon accumulation functions

Table A4.2. Carbon accumulation functions based on forest growth for each forest type

t is the time since the last stand-replacing disturbance event

Forest type	Carbon accumulation function	Reference
Montane ash	$1200 \times (1-\exp(-0.0045\ t)^{0.7}$	1
Wet mixed species	$450 \times (1-\exp(-0.015\ t)^{1.05}$	3, 4, 5, 6, 7
Open mixed species	$310 \times (1-\exp(-0.025\ t)^{1.1}$	5, 6, 7
Rainforest	$800 \times (1 - \exp(-0.002\ t)^{1.2}$	11, 12
Pine plantation	$130 \times (1 - \exp(-0.15\ t)^{6}$	7
Eucalypt plantation	$500 \times (1-\exp(-0.35\ t)^{1.25}$	7
Woodland	$C_{t-1} + 0.23$	11

1. Keith et al. (2014a); 3. Keith unpubl.; 4. West and Mattay (1996), 5. Grierson et al. (1992); 6. Borough (1984); 7. DotE (2015a); 11. DotE (2015b); 12. Wood et al. (2010).

A5.2.1.3 Change in carbon stock due to logging

Equations describing the reduction in carbon stock due to logging, based on Keith et al. (2014a).

Amount of biomass remaining on-site after product removal from logging:

$$C_{slash} = 0.6 \times C_{initial}$$

Amount of biomass remaining on-site after slash burning:

$$C_{residual(0)} = 0.5 \times C_{slash}$$

Decomposition of the residual biomass remaining after harvesting and slash burning:

$$C_{residual(t)} = C_{residual(0)} \times \exp(-0.07\ t)$$

A5.2.1.4 Change in carbon stock due to fire

Equations describing the change over time in dead biomass components after fire, based on Keith et al. (2014b).

Dead standing trees remain after fire, but slowly collapse and fall to the ground.

$$C_{dead\_standing\ (t+1)} = C_{dead\_standing\ (t0)} / (1 + \exp(0.1\ t - 5))$$

Fallen trees become input to the coarse woody debris (CWD).

$$C_{dead\_standing\ (t)} - C_{dead\_standing\ (t+1)} = C_{CWD\_input}$$

Coarse woody debris on the ground decomposes over time.

$$C_{CWD\ (t)} = C_{CWD\ (0)} \times \exp(-0.07\ t) + C_{CWD\_input}$$

Table A4.3. Loss in biomass carbon stock (%) due to emissions under different fire severities

Forest age (yrs)	Fire severity	
	Low (classes 3 ,4 ,5)	High (classes 1, 2)
0 - 30	6	14
31 – 72	7	11
> 72	7	9

If fire severity was not known, an average of 10% carbon stock loss due to emissions was used. (Keith et al. 2014b).

A7. Agriculture

Table A7.1. Australian agriculture, estimated resource rent, 2006-07 to 2013-14

SUBDIVISION 01 Agriculture									
		2006-07	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**	**2012-13**	**2013-14**
	Total industry output (Australian production)	48,366	57,293	58,109	54,033	62,732	66,887	70,665	71,895
less	Intermediate consumption	27,895	33,253	32,187	28,505	33,401	36,242	37,197	39,665
	Compensation of employees	4,655	5,034	4,967	4,570	4,887	5,093	5,249	5,634
	Net taxes on production	368	394	484	421	512	646	680	713
equals	Gross operating surplus & mixed income	15,448	18,612	20,471	20,537	23,932	24,906	27,539	25,883
less	Consumption of fixed capital	8,028	9,013	8,941	9,287	9,532	9,762	10,039	10,145
	Return to fixed Capital	5,424	6,080	5,370	5,081	5,593	3,417	4,575	4,512
equals	**Resource rent**	**1,996**	**3,519**	**6,160**	**6,169**	**8,808**	**11,727**	**12,924**	**11,226**
	NPV								
	Net Capital Stock at beginning of year	86,646	94,265	97,290	99,631	107,343	112,406	121,678	127,452
	Rate of Return on capital (RBA 10yr Bond-Rate)	6.26%	6.45%	5.52%	5.10%	5.21%	3.04%	3.76%	3.54%

A9. Biodiversity

Table A9.1. List of threatened species in the Central Highlands study area classified under IUCN, EPBC, FFG and Victorian Advisory lists

Species	Common name	IUCN Red List	EPBC category	FFG Act	Vic Advisory List
Mammals					
Antechinus minimus maritimus	Swamp Antechinus			Listed	Near Threatened
Bettongia gaimardi	Eastern Bettong	Near Threatened 2008; Lower Risk 1996	Extinct on mainland	Listed	Regionally Extinct
Burramys parvus	Mountain Pygmy-possum	Critically Endangered 2000; Endangered 1994	Endangered 2000	Listed	Critically Endangered
Dasyurus maculatus maculatus	Spotted-tailed Quoll	Near Threatened 2008; Vulnerable 1996	Endangered 2004	Listed	Endangered
Dasyurus viverrinus	Eastern Quoll	Near Threatened 2008; Lower Risk 1996	Extinct on mainland. Not endangered in Tasmania	Listed	Regionally Extinct
Gymnobelideus leadbeateri	Leadbeater's Possum	Endangered 2008, 1994; Vulnerable 1990	Critically Endangered 2015	Listed	Endangered
Isoodon obesulus obesulus	Southern Brown Bandicoot		Endangered 2001	Listed	Near Threatened
Miniopterus schreibersii	Common Bent-wing Bat	Near Threatened 2008; Least Concern 2004; Lower Risk 1996		Listed	
Miniopterus schreibersii oceanensis	Eastern Bent-wing Bat			Listed	Vulnerable
Perameles gunnii	Eastern Barred Bandicoot (mainland form)	Near Threatened 2008; Vulnerable 1996	Endangered 2000	Listed	Regionally Extinct
Petaurus norfolcensis	Squirrel Glider	Least concern 1996, 2008		Listed	Endangered
Petaurus volans	Greater Glider				Vulnerable

Species	Common name	IUCN Red List	EPBC category	FFG Act	Vic Advisory List
Phascogale tapoatafa	Brush-tailed Phascogale	Near Threatened 1996, 2008		Listed	Vulnerable
Pseudomys fumeus	Smoky Mouse	Endangered 2008; Vulnerable 1996; Rare 1990	Endangered 2000	Listed	Endangered
Rhinolophus megaphyllus megaphyllus	Eastern Horseshoe Bat			Listed	Vulnerable
Sminthopsis leucopus	White-footed Dunnart	Vulnerable 2008; Data Deficient 1996		Listed	Near Threatened
Reptiles					
Delma impar	Striped Legless Lizard	Vulnerable 1996, 1994	Vulnerable 2007	Listed	Endangered
Lissolepis (Egernia) coventryi	Eastern Mourning Skink			Listed	Vulnerable
Pseudemoia cryodroma	Alpine Bog Skink			Listed	Endangered
Pseudemoia rawlinsoni	Glossy Grass Skink				Vulnerable
Vermicella annulata	Bandy-bandy Snake			Listed	Vulnerable
Amphibians					
Litoria raniformis	Southern Bell Frog	Endangered 1996, 2002, 2004; Insufficiently Known 1994	Vulnerable 2000	Listed	Endangered
Litoria spenceri	Spotted Tree Frog	Critically Endangered 2002; Vulnerable 1996; Endangered 1994	Endangered 2000	Listed	Critically Endangered
Litoria verreauxii alpina	Alpine Tree Frog		Vulnerable 2000	Listed	Critically Endangered
Philoria frosti	Baw Baw Frog	Critically Endangered 2002, Endangered 1996, Vulnerable 1994, Rare 1986	Endangered 2000	Listed	Critically Endangered

Species	Common name	IUCN Red List	EPBC category	FFG Act	Vic Advisory List
Pseudophryne bibronii	Brown Toadlet	Near Threatened 2004, Data Deficient 2002, Lower Risk 1996, Insufficiently Known 1994		Listed	Endangered
Pseudophryne semimarmorata	Southern Toadlet				Vulnerable
Fish					
Gadopsis marmoratus	River Blackfish				Critically Endangered
Galaxias fuscus	Barred Galaxia	Critically Endangered 1996, Endangered 1994	Endangered 2000	Listed	Critically Endangered
Galaxias rostratus	Flathead Galaxias	Vulnerable 1996, Rare 1994			Vulnerable
Galaxiella pusilla	Dwarf Galaxias	Vulnerable 1996, 1994	Vulnerable 2000	Listed	Endangered
Nannoperca (Edelia) obscura	Yarra Pygmy Perch	Vulnerable 1996, 1994	Vulnerable 2010	Listed	Vulnerable
Prototroctes maraena	Australian Grayling	Near Threatened 2009, Vulnerable 1996, 1990	Vulnerable 2000	Listed	Vulnerable
Birds					
Actitis hypoleucos	Common Sandpiper				Vulnerable
Anas (Spatula) rhynchotis rhynchotis	Australasian Shoveler				Vulnerable
Anseranas semipalmata	Magpie Goose			Listed	Near Threatened
Anthochaera (Xanthomyza) phrygia	Regent Honeyeater	Critically Endangered 2013, 2012; Endangered 2008, 1994; Threatened 1988	Critically Endangered 2015	Listed	Critically Endangered
Ardea (Casmerodius) modesta	Eastern Great Egret				Vulnerable
Ardea (Mesophoyx) intermedia	Intermediate Egret	Least Concern 2014		Listed	Endangered
Aythya (Nyroca) australis	Hardhead Duck				Vulnerable

Species	Common name	IUCN Red List	EPBC category	FFG Act	Vic Advisory List
Biziura lobata	Musk Duck				Vulnerable
Botaurus poiciloptilus	Australasian Bittern	Endangered 2014, 2004; Vulnerable 2000; Endangered 1996, 1994; Lower Risk 1988	Endangered 2011	Listed	Endangered
Burhinus (Burhinus) grallarius	Bush Stone Curlew	Least Concern 2012; Near Threatened 2008, 2004; Lower Risk 2000, 1988		Listed	Endangered
Calamanthus pyrrhopygius	Chestnut-rumped Heathwren			Listed	Vulnerable
Chthonicola sagittata	Speckeld Warbler			Listed	Vulnerable
Egretta garzetta nigripes	Little Egret			Listed	Endangered
Excalfactoria (Coturnix) chinensis victoriae	King Quail			Listed	Endangered
Falco (Hierofalco) subniger	Black Falcon				Vulnerable
Geopelia cuneata	Diamond Dove			Listed	Near Threatened
Grantiella picta	Painted Honeyeater	Vulnerable 2012, 2009; Near Threatened 2008, 2004; Lower Risk 2000; Vulnerable 1996, 1994; Lower Risk 1988		Listed	Vulnerable
Grus (Mathewsia) rubicunda	Brolga	Least Concern 2012, 2004; Lower Risk 2000, 1988		Listed	Vulnerable
Ixobrychus dubius	Little Bittern			Listed	Endangered
Lewinia (Rallus Dryolimnas) pectoralis	Lewin’s Rail			Listed	Vulnerable
Lichenostomus melanops cassidix	Yellow-tufted (Helmeted) Honeyeater		Critically Endangered 2014	Listed	Critically Endangered

Species	Common name	IUCN Red List	EPBC category	FFG Act	Vic Advisory List
Lophoictinia isura	Square-tailed Kite	Least Concern 2012, 2004; Lower Risk 2000; Vulnerable 1996, 1994; Lower risk 1988		Listed	Vulnerable
Melanodryas (Melanodryas) cucullata cucullata	Hooded Robin			Listed	Near Threatened
Neophema pulchella	Turquoise Parrot	Least Concern 2012, 2004; Lower Risk 2000, 1994, 1988		Listed	Near Threatened
Ninox (Hieracoglaux) connivens connivens	Barking Owl			Listed	Endangered
Ninox strenua	Powerful Owl	Least Concern 2012, 2004; Lower Risk 2000; Vulnerable 1996, 1994; Lower Risk 1988		Listed	Vulnerable
Oxyura australis	Blue-billed Duck	Near Threatened 2012, 2004; Lower risk 2000, 1988		Listed	Endangered
Porzana pusilla palustris	Baillon's Crane			Listed	Vulnerable
Rostratula (benghalensis) australis	Australian Painted Snipe	Endangered 2012, 2010; Not Recognised 2008, 1988	Endangered 2013; Vulnerable 2003	Listed	Critically Endangered
Stagonopleura guttata	Diamond Firetail Finch	Least Concern 2012; Near Threatened 2008, 2004; Lower Risk 2000, 1988		Listed	Near Threatened
Stictonetta naevosa	Freckled Duck	Least Concern 2012, 2004; Lower Risk 2000; Vulnerable 1996, 1994; Threatened 1988		Listed	Endangered

Species	Common name	IUCN Red List	EPBC category	FFG Act	Vic Advisory List
Turnix pyrrhothorax	Red-chested Button Quail	Least Concern 2012, 2004; Lower Risk 2000, 1994, 1988		Listed	Vulnerable
Tyto (Megastrix) novaehollandiae novaehollandiae	Masked Owl			Listed	Endangered
Invertebrates					
Acrodipsas myrmecophila	Small Ant-blue Butterfly			Listed	Critically Endangered
Archaeophylax canarus	Caddisfly			Listed	
Austroaeschna flavomaculata	Alpine Darner				Vulnerable
Austrogammarus australis	Dandenong Freshwater Amphipod	Critically Endangered 2014; Extinct 1994		Listed	Endangered
Austrogammarus haasei	Sherbrooke Amphipod			Listed	Vulnerable
Austropyrgus grampianensis	Dairy Creek Austropyrgus Snail			Listed	Critically Endangered
Caliagrion billinghursti	Large River Damsel				Endangered
Canthocamptus dedeckkeri	Harpactacoid Copepod	Vulnerable 1996; Insufficiently Known 1994			Vulnerable
Canthocamptus mammillifurca	Harpactacoid Copepod	Vulnerable 1996; Insufficiently Known 1994			
Colubotelson searlei	Phreatoicid Isopod				Vulnerable
Ecnomus nibbor	Caddisfly				Vulnerable
Engaeus curvisuturus	Curve-tail Burrowing Cray	Data Deficient 2010; Endangered 1996		Listed	Endangered
Engaeus hemicirratulus	Gippsland Burrowing Cray	Least Concern 2010			Endangered

Species	Common name	IUCN Red List	EPBC category	FFG Act	Vic Advisory List
Engaeus sternalis	Warragul Burrowing Cray	Critically Endangered 2010; Endangered 1996; Vulnerable 1994		Listed	Critically Endangered
Engaeus tuberculatus	Tubercle Burrowing Cray				Endangered
Engaeus urostrictus	Dandenong Burrowing Cray	Vulnerable 2010; Endangered 1996		Listed	Critically Endangered
Engaeus victoriensis	Foothill Burrowing Cray				Endangered
Euastacus armatus	Murray Cray	Data Deficient 2010; Vulnerable 1996; Indeterminate 1994		Listed	Near Threatened
Hemiphlebia mirabilis	Ancient Greenling Damselfly	Endangered 2008; Vulnerable 1996; Rare 1994; Endangered 1990		Listed	Endangered
Leptocerus souta	Caddisfly				Vulnerable
Pasma tasmanica	Tasmanica Skipper Butterfly				Vulnerable
Plectrotarsus gravenhorstii	Caddisfly				Vulnerable
Pseudalmenus chlorinda zephyrus	Silky Hairstreak Butterfly				Vulnerable
Riekoperla darlingtoni	Mount Donna Buang Wingless Stonefly	Critically Endangered 2014; Vulnerable 1996; Rare 1994, 1990		Listed	Critically Endangered
Riekoperla intermedia	Stonefly			Listed	Endangered
Riekoperla isosceles	Stonefly			Listed	Critically Endangered
Synemon plana	Golden Sun Moth		Critically Endangered 2002	Listed	Critically Endangered

Species	Common name	IUCN Red List	EPBC category	FFG Act	Vic Advisory List
Tanjistomella verna	Caddisfly				Critically Endangered
Themognatha sanguinipennis	Jewel Beetle				Vulnerable
Vascular plants					
Acacia daviesii	Timbertop wattle			Listed	Vulnerable
Acacia sporadica	Pale Hickory-wattle				Vulnerable
Acacia verniciflua	Stinkwood Bush				Vulnerable
Actinotus bellidioides	Tiny Flannel-flower				Regionally Extinct
Adiantum capillus-veneris	Dainty-Maiden-hair Fern	Least Concern 2013		Listed	Endangered
Adiantum diaphanum	Filmy Maidenhair			Listed	Endangered
Astelia australiana	Tall Astelia		Vulnerable 2000	Listed	Vulnerable
Asterolasia asteriscophora subsp. albiflora	White Star-bush			Listed	Endangered
Boronia citrata	Lemon Boronia				Vulnerable
Botrychium australe	Austral Moonwort			Listed	Vulnerable
Caladenia concolor	Crimson Spider Orchid			Listed	Endangered
Caladenia maritima	Angahook Pink-fingers			Listed	Endangered
Caladenia oenochila	Wine-lipped Spider-orchid				Vulnerable
Caladenia ornata	Ornate Pink Finger Orchid		Vulnerable 2008	Listed	Vulnerable
Caladenia reticulata	Veined Caladenia				Vulnerable
Caladenia versicolor	Candy Spider-orchid		Vulnerable 2000	Listed	Endangered
Callistemon nyallingensis	Boggy Creek Bottlebrush			Listed	Vulnerable
Callitriche umbonata (cyclocarpa)	Water Starwort				Rare
Cardamine astoniae	Spreading Bitter-cress				Vulnerable
Cardamine gunnii	Spade-leaf Bitter-cress			Listed	Regionally Extinct

Species	Common name	IUCN Red List	EPBC category	FFG Act	Vic Advisory List
Cardamine lilacina	Lilac Bitter-cress				Vulnerable
Cassinia ozothamnoides	Cottony Haeckeria				Vulnerable
Correa reflexa var. lobata	Powelltown Correa				Rare
Craspedia lamicola	Bog Billy-buttons				Vulnerable
Cullen parvum	Small Scurf-pea			Listed	Endangered
Cyathea cunninghamii	Slender Tree Fern			Listed	Vulnerable
Cyathea x marcescens	Skirted Tree-fern				Vulnerable
Dianella amoena	Grassland Flaxlily		Endangered 2000	Listed	Endangered
Dianella revoluta	Black-anthered Flaxlily				Vulnerable
Discaria pubescens	Australian Anchor Plant			Listed	Rare
Diuris behrii	Golden cowslip				Vulnerable
Diuris palustris	Swamp Diuris			Listed	Vulnerable
Erigeron tasmanicus	Tasmanian Fleabane				Vulnerable
Eucalyptus crenulata	Buxton Gum		Endangered 2015	Listed	Endangered
Eucalyptus splendens	Apple Jack				Endangered
Eucalyptus strzeleckii	Strzeleckii Gum		Vulnerable 2000	Listed	Vulnerable
Euphrasia collina ssp. muelleri	Purple Eyebright		Endangered 2000	Listed	Endangered
Euphrasia scabra	Rough Eyebright			Listed	Endangered
Ficus coronata	Sandpaper Fig			Listed	Vulnerable
Gahnia grandis	Brickmakers Sedge				Vulnerable
Gaultheria hispida	Snow Berry			Listed	Endangered
Glycine latrobeana	Clover Glycine		Vulnerable 2000	Listed	Vulnerable
Grammitis magellanica subsp. nothofageti	Beech Finger-fern				Vulnerable
Grevillea barklyana ssp barklyana	Gully Grevillea			Listed	Vulnerable

Species	Common name	IUCN Red List	EPBC category	FFG Act	Vic Advisory List
Grevillea parvula	Genoa Grevillea				Vulnerable
Grevillea polychroma	Royal Grevillea				Vulnerable
Hovea asperifolia	Rosemary Hovea				Rare
Huperzia varia	Long Clubmoss				Vulnerable
Isolepis gaudichaudiana	Benambra Club-sedge				Vulnerable
Lastreopsis decomposita	Trim Shield-fern				Vulnerable
Leptorhynchos elongatus	Lanky Buttons				Endangered
Nematolepis squamea	Harsh Nematolepis		Vulnerable 2000	Listed	Vulnerable
Nematolepis wilsonii	Shiny Nematolepis		Vulnerable 2000	Listed	Vulnerable
Olearia pannosa subsp. cardiophylla	Velvet Daisy-bush			Listed	Vulnerable
Olearia rugosa	Wrinkled Diasy-bush				Vulnerable
Persoonia arborea	Tree Geebung				Vulnerable
Plantago muelleri	Star Plantain				Vulnerable
Pomaderris vacciniifolia	Round-leaf Pomaderis		Critically Endangered 2014	Listed	Endangered
Prasophyllum frenchii	French's Leek Orchid		Endangered 2015	Listed	Endangered
Prasophyllum lindleyanum	Green Leek Orchid				Vulnerable
Prasophyllum pyriforme	Graceful Leek Orchid				Endangered
Pterostylis chlorogramma	Green-striped Greenhood		Vulnerable 2000	Listed	Vulnerable
Pterostylis cucullata	Leafy Greenhood		Vulnerable 2000	Listed	Endangered
Pterostylis lustra	Forked Greenhood			Listed	Endangered
Pterostylis truncata	Brittle Greenhood			Listed	Endangered
Pultenaea blakelyi	Blakely's Bush-pea				Endangered
Senecio psilocarpus	Smooth-fruited Groundsel		Vulnerable 2000		Vulnerable
Thelymitra circumsepta	Naked Sun Orchid				Vulnerable

Species	Common name	IUCN Red List	EPBC category	FFG Act	Vic Advisory List
Thelymitra gregaria	Basalt Sun-orchid			Listed	Endangered
Thelymitra hiemalis	Winter Sun-orchid			Listed	Endangered
Thelymitra longiloba	Marsh Sun-orchid				Endangered
Thismia rodwayi	Fairy Lantern			Listed	Vulnerable
Tmesipteris elongata	Elongate Fork-Fern				Vulnerable
Uncinia compacta	Compact Hook-sedge				Vulnerable
Zieria cytisoides	Downy Zieria				Rare
Non-vascular plants					
Acrobolbus cinerascens	Grey Pouchwort				Vulnerable
Anoectangium bellii	Kiwi Cave-moss			Listed	Vulnerable
Braithwaitea sulcata	Giant Fern-moss				Regionally Extinct
Dinckleria (Plagiochila) pleurata	Delicate Featherwort			Listed	Endangered
Distichium capillaceum	Fine Fringe-moss				Vulnerable
Orthotrichum hortense	Gardner's Bristle-moss			Listed	Endangered
Pedinophyllum monoicum	Southern Pedinophyllum			Listed	Vulnerable
Pseudocephalozia paludicola	Alpine Leafy Liverwort		Vulnerable 2000	Listed	Vulnerable
Tetraphidopsis pusilla	Arc Moss				Vulnerable
Thuidium laeviusculum	Forest Weft-moss				Vulnerable
Triandrophyllum subtrifidum	Variable Gondwanawort			Listed	Endangered
Treubia tasmanica	Treubia			Listed	Endangered
Xanthoparmelia suberadicata	Foliose Lichen			Listed	Endangered

A10. Ecosystem accounts

Table A10.1 Ecosystem services – physical supply. Average values over 5-year time periods

2011-2015 — **Land cover**

Ecosystem services	Units	unclass-ified	bare	open water	swamp	built-up area	crop	crop/ pasture	pasture grass	horticul-ture	pine plantation	eucalypt plantation	shrub /heath	riparian shrubs	woodland	montane woodland	open mixed forest	wet mixed forest	alpine ash	mountain ash	rain-forest	**total**
Area	Ha	4,064	11,832	4,361	4	16,907	1,143	8,421	44,582	4,067	11,025	25,310	4,397	4,812	6,577	13,835	151,951	213,081	64,476	140,583	5,646	737,072
Provisioning services																						
Water	ML yr^{-1}	4,454	42,066	13,827	61	52,559	2,321	25,711	97,546	11,271	37,258	79,598	26,668	28,507	17,273	144,984	675,159	1,062,748	624,202	969,954	54,648	3,970,818
Timber - sawlogs	m^3 yr^{-1}																6,079	25,808	139,907	133,126		
Residual logs	m^3 yr^{-1}																15,151	64,327	227,803	216,764		
Regulating services																						
Water storage	GL			1,281																		
Carbon sequestration	Mt yr^{-1}		0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.02	0.03	0.00	0.00	0.00	0.00	0.18	0.46	0.23	0.70	0.00	1.64
Carbon storage	Mt		0.00	0.00	0.00	0.26	0.01		0.18	0.03	0.58	3.95	0.13	0.19	0.96	2.08	10.66	29.16	39.51	56.63	1.82	146.16

2006-2010 — **Land cover**

Ecosystem services	Units	unclass-ified	bare	open water	swamp	built-up area	crop	crop/ pasture	pasture grass	horticul-ture	pine plantation	eucalypt plantation	shrub /heath	riparian shrubs	woodland	montane woodland	open mixed forest	wet mixed forest	alpine ash	mountain ash	rain-forest	**total**
Area	Ha	4,064	11,832	4,361	4	16,907	1,143	8,421	44,582	4,067	11,025	25,310	4,397	4,812	6,577	13,835	151,951	213,081	64,476	140,583	5,646	737,072
Provisioning services																						
Water	ML yr^{-1}	1,412	13,019	4,391	38	14,052	510	6,822	24,376	2,752	11,129	21,848	13,077	13,079	4,357	72,876	228,955	387,057	268,102	377,444	22,159	1,487,455
Timber - sawlogs	m^3 yr^{-1}																6,012	9,458	78,555	206,247		
Residual logs	m^3 yr^{-1}																21,786	34,272	145,218	381,270		
Regulating services																						
Water storage	GL			680																		
Carbon sequestration	Mt yr^{-1}		0.00	0.00	0.00	0.00	0.00		0.00	0.00	-0.02	-0.03	0.00	0.00	0.00	-0.02	0.12	0.33	0.01	0.20	0.00	0.58
Carbon storage	Mt		0.00	0.00	0.00	0.26	0.01		0.18	0.03	0.49	3.79	0.12	0.18	0.95	2.06	9.74	26.87	38.38	53.12	1.80	137.99

2001-2005 — Land cover

Ecosystem services	Units	unclass-ified	bare	open water	swamp	built-up area	crop	crop/ pasture	pasture grass	horticul-ture	pine plantation	eucalypt plantation	shrub /heath	riparian shrubs	woodland	montane woodland	open mixed forest	wet mixed forest	alpine ash	mountain ash	rain-forest	**total**
Area	Ha	4,064	11,832	4,361	4	16,907	1,143	8,421	44,582	4,067	11,025	25,310	4,397	4,812	6,577	13,835	151,951	213,081	64,476	140,583	5,646	737,072
Provisioning services																						
Water	ML yr^{-1}	2,362	21,435	6,493	47	25,923	1,142	12,635	48,903	5,506	18,987	38,892	17,505	18,250	8,184	96,688	353,956	550,497	349,860	511,585	29,381	2,118,232
Timber - sawlogs	m^3 yr^{-1}																9,833	15,338	66,184	272,762		
Residual logs	m^3 yr^{-1}																50,950	79,476	106,912	440,615		
Regulating services																						
Water storage	GL			960																		
Carbon sequestration	Mt yr^{-1}		0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.46	0.18	0.27	0.01	1.10
Carbon storage	Mt		0.00	0.00	0.00	0.26	0.01		0.18	0.03	0.58	3.95	0.13	0.19	0.97	2.16	9.14	25.21	38.35	52.12	1.81	135.08

1996-2000 — Land cover

Ecosystem services	Units	unclass-ified	bare	open water	swamp	built-up area	crop	crop/ pasture	pasture grass	horticul-ture	pine plantation	eucalypt plantation	shrub /heath	riparian shrubs	woodland	montane woodland	open mixed forest	wet mixed forest	alpine ash	mountain ash	rain-forest	**total**
Area	Ha	4,064	11,832	4,361	4	16,907	1,143	8,421	44,582	4,067	11,025	25,310	4,397	4,812	6,577	13,835	151,951	213,081	64,476	140,583	5,646	737,072
Provisioning services																						
Water	ML yr^{-1}	3,047	28,870	8,699	48	36,572	1,497	17,973	67,224	7,946	25,282	54,654	19,669	20,912	11,949	103,426	440,591	708,858	378,299	606,153	32,632	2,574,300
Timber - sawlogs	m^3 yr^{-1}																8,342	12,235	69,407	290,687		
Residual logs	m^3 yr^{-1}																66,600	97,684	153,122	641,297		
Regulating services																						
Water storage	GL			1,263																		
Carbon sequestration	Mt yr^{-1}		0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.44	0.17	0.31	0.01	1.10
Carbon storage	Mt		0.00	0.00	0.00	0.26	0.01		0.18	0.03	0.58	3.95	0.13	0.19	0.97	2.14	8.22	22.92	37.44	50.79	1.78	129.59

1991-1995		Land cover																			
Ecosystem services	Units	unclass-ified	bare	open water	swamp	built-up area	crop	crop/ pasture	pasture grass	horticul-ture	pine plantation	eucalypt plantation	shrub /heath	riparian shrubs	woodland	montane woodland	open mixed forest	wet mixed forest	alpine ash	mountain ash	rain-forest	**total**
Area	Ha	4,064	11,832	4,361	4	16,907	1,143	8,421	44,582	4,067	11,025	25,310	4,397	4,812	6,577	13,835	151,951	213,081	64,476	140,583	5,646	737,072
Provisioning services																						
Water	ML yr^{-1}	4,294	38,820	13,413	59	47,497	1,945	23,408	88,391	10,289	34,382	72,314	25,108	26,687	15,260	137,990	643,267	1,000,743	502,009	807,288	42,162	3,535,325
Timber - sawlogs	m^3 yr^{-1}																5,723	8,176	49,835	236,060		
Residual logs	m^3 yr^{-1}																47,132	67,331	116,281	550,807		
Regulating services																						
Water storage	GL			1,564																		
Carbon sequestration	Mt yr^{-1}		0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.39	0.20	0.34	0.01	1.10
Carbon storage	Mt		0.00	0.00	0.00	0.26	0.01		0.18	0.03	0.58	3.95	0.13	0.19	0.96	2.13	7.40	20.72	36.57	49.27	1.75	124.15

1990		Land cover																			
Ecosystem services	Units	unclass-ified	bare	open water	swamp	built-up area	crop	crop/ pasture	pasture grass	horticul-ture	pine plantation	eucalypt plantation	shrub /heath	riparian shrubs	woodland	montane woodland	open mixed forest	wet mixed forest	alpine ash	mountain ash	rain-forest	**total**
Area	Ha	4,064	11,832	4,361	4	16,907	1,143	8,421	44,582	4,067	11,025	25,310	4,397	4,812	6,577	13,835	151,951	213,081	64,476	140,583	5,646	737,072
Provisioning services																						
Water	ML yr^{-1}	3,914	33,522	11,210	61	40,237	1,964	19,729	81,576	8,755	30,794	61,455	24,470	26,189	12,712	140,066	594,173	904,808	500,190	750,495	41,651	3,287,971
Timber - sawlogs	m^3 yr^{-1}																2,226	16,723	47,406	223,921		
Residual logs	m^3 yr^{-1}																18,336	137,722	110,615	522,482		
Regulating services																						
Water storage	GL			1,275																		
Carbon sequestration	Mt yr^{-1}																					
Carbon storage	Mt		0.00	0.00	0.00	0.26	0.01		0.18	0.03	0.58	3.95	0.13	0.19	0.96	2.12	6.63	18.76	35.56	47.54	1.72	118.62