Ecosystem Goods and Services in Production Landscapes in South-Eastern Australia

By

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ABSTRACT

Ecosystem goods and services (EGS), the benefits that humans obtain from ecosystems, are vital for human well-being. As human populations increase so do demands for almost all EGS. Managing changing landscapes for multiple EGS is therefore a key challenge for resource planners and decision makers. However, in many cases the supply of different types of goods and services can conflict. For example, the enhancement of provisioning services can lead to declines in regulating and cultural services, but there are few tools available for analysing these trade-offs in a spatially-explicit way. This thesis developed approaches and tools for spatially explicit measurement and management of multiple EGS provided by production landscapes. These were used to assess the impacts of land-use change and to provide a basis for managing these trade-offs using case studies in two contrasting production landscapes in south-eastern Australia. Both landscapes have been subject to extensive clearing of native vegetation, which is now present in remnant patches. One study landscape had a concentration of commercially-valuable hardwood and softwood plantations, and the other was dominated by land traditionally focused on agricultural production that is currently being re-configured to provide for more sustainable farming practices and to increase provision of multiple ecosystem services.

The study involved five components: (i) development of a novel, qualitative approach for rapid assessment of EGS in changing landscapes that was used to assess observed and potential changes in land use and land cover and their impact on the production of different EGS (Chapter 2); (ii) development and testing of an approach for assessing multiple EGS across space and time using a case study of six key EGS in a sub-catchment in Lower Glenelg Basin, south-western Victoria that demonstrated landscape-scale trade-offs between provisioning and many regulating services (Chapter 3); (iii) an economic valuation of EGS using market and non-market techniques to produce spatial economic value maps (Chapter 4); (iv) spatial assessment of the biodiversity values that underpin provision of many ecosystem services utilising a variety of readily available data and tools (Chapter 5); and (v) assessment of trade-offs and synergies among multiple EGS under current land use and realistic future land-use scenarios (Chapter 6).

Results indicate that EGS can be assessed and mapped in a variety of ways depending on the availability of data, time, and funding as well as level of detail and accuracy required. A qualitative assessment can be useful for an initial investigation (Chapter 2) while quantitative and monetary assessments may be required for detailed landscape-scale planning (Chapters 3, 4). In addition, the provision of EGS by production landscapes can vary considerably depending on land use and land cover, and management choices. The study demonstrates that landscapes dedicated mostly to

agricultural production have limited capacity to produce the range of ecosystem services required for human health and well-being, while landscapes with a mosaic of land uses can produce a wide range of services, although these are often subject to trade-offs between multiple EGS (Chapters 2, 3). Furthermore, the study demonstrated that spatial assessment and mapping of biodiversity value plays a vital role in identifying key areas for conservation and establishing conservation priorities to allocate limited resources (Chapter 5). There is potential for an improved balance of the multiple EGS required for human health and well-being at the landscape scale, although the economic incentive to adopt more sustainable land use practices that produce a wide range of services are compromised due to the lack of economic valuation of public ecosystem services (Chapter 6). High hopes have been placed by researchers on spatial assessment, mapping and economic valuations of ecosystem goods and services to influence policy makers for coping with the accelerating degradation of natural capital. The approaches and tools used in this thesis can potentially enhance our collective choices regarding the management of landscapes for multiple values and can help policy makers and land managers to enhance the total benefits that landscapes provide to societies through the provision of an optimal mix of goods and services.

DECLARATION

This is to certify that:

i. The thesis comprises only my original work.

ii. Due acknowledgement has been made in the text to all other material used.

iii. The thesis is less than 100,000 words in length, exclusive of tables, illustrations, bibliography, and appendices.

... ...

Himlal Baral

1 October 2013

PREFACE

This PhD thesis consists of seven chapters four of which have been published. I conducted the majority of research work for these publications while the co-authors contributed in the form of overall supervision from site selection, stakeholder consultation, resource supply and editorial support on manuscript writing. The citations for the published chapters and those in review are as follows:

Chapter 2

Baral, H., Keenan, R.J., Stork, N.E., Kasel, S., 2013. Measuring and managing ecosystem goods and services in changing landscapes: a south-east Australian perspective. *Journal of Environmental Planning and Management (in press)* http://dx.doi.org/10.1080/09640568.2013.824872

Chapter 3

Baral, H., Keenan, R.J., Fox, J.C., Stork, N.E., Kasel, S., 2013. Spatial assessment of ecosystem goods and services in complex production landscapes: A case study from south-eastern Australia. *Ecological Complexity* 13, 35–45.

Chapter 4

Baral, H., Kasel, S., Keenan, R. J., Fox, J., Stork, N., 2009. GIS-based classification, mapping and valuation of ecosystem services in production landscapes: A case study of the Green Triangle region of south-eastern Australia. In: Thistlethwaite, R., Lamb, D., Haines, R. (Eds.), *Forestry: a Climate of Change*. Caloundra, pp. 64–71.

Chapter 5

Baral, H., Keenan, R.J., Sharma, S.K., Stork, N.E., Kasel, S., (in press). Spatial assessment and mapping of biodiversity and conservation priorities in a heavily modified and fragmented production landscape in north-central Victoria, Australia. *Ecological Indicators* http://dx.doi.org/10.1016/j.ecolind.2013.09.022

Chapter 6

Baral, H., Keenan, R.J., Sharma, S.K., Stork, N.E., Kasel, S., (to be submitted). Economic evaluation of landscape management scenarios in north-central Victoria, Australia. *Land Use Policy*

Bibliographic style of citations and reference lists within each chapter follow those set by the publications in which each chapter was published or submitted for publication.

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Above all, I am really indebted to my dearest wife Biddya, son Avinab and daughter Alaka for patiently sharing all my pressure during the course of study and also deeply thankful to my family in Nepal for their love, care and moral support for pursuing higher study.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

1.1. PROBLEM STATEMENT

Worldwide, ecosystems are deteriorating with serious consequences for the ability of nature to provide crucial ecosystem goods and services (EGS) to human society (MEA, 2005). Many EGS are in decline due to ignorance of their value and inadequate social and economic mechanism to manage them sustainably (Cork et al., 2007; TEEB, 2012). One of the most persistent impacts of current global change is the rapid decline in species and habitat diversity (Perrings et al., 2010) and their replacement with biologically poorer and more homogenous human-dominated landscapes (Western, 2001).

In recent years, the impacts of human alteration on nature and its capacity to produce EGS are reflected at the local, regional and global scale (Vitousek et al., 1997; Foley et al., 2005). Due to the increasing human population and associated diverse demands of society, the gaps between the capacity of ecosystems to provide services and human needs are widening (DeFries et al., 2004; Foley et al., 2011). The strength of the ecosystem services concept is that by identifying and potentially quantifying resultant societal benefits and associated economic value, ecosystems are brought into planning and other decision-making processes (TEEB, 2010, 2012). This thesis focuses on identifying, assessing, mapping, valuing and analysing trade-offs and synergies among multiple EGS across production landscapes in south-eastern Australia. It does this by examining four case studies from two contrasting production landscapes in south-eastern Australia where there has been a significant and ongoing change in land use-land cover over the past two centuries. These case studies reflect similar changes in land use-land cover across most of the south-east Australian regional landscape.

1.2. RESEARCH AIM AND OBJECTIVES

This thesis aims to characterise and map EGS in production landscapes, assign associated values to selected services, and analyse trade-offs and synergies among them. Additional aims include modelling future land-use scenarios for the production landscape and analysis of the potential impacts on EGS and associated economic returns. The major research questions addressed are:

1. What are the current approaches for measuring EGS at the landscape scale? How can EGS be rapidly assessed in production landscapes? (Chapter 2)
2. How can EGS be characterised, assessed and mapped using readily available datasets and tools? How does the demand and supply of EGS change over time and space? (Chapter 3)
3. How can EGS be quantified, valued and mapped in economic terms? (Chapter 4)
4. How can biodiversity values be spatially assessed and represented? (Chapter 5)
5. What are the impacts of land use-land cover change over time on the provision of EGS? What are the effects of alternative future land-use scenarios? (Chapter 6)

To achieve these objectives the following conceptual and methodological framework is employed (Fig. 1-1). The framework combines the review and qualitative assessment from literature as well as quantitative assessment and monetary valuation of selected EGS. Both qualitative and quantitative assessments are analysed in this spatial, temporal and reversibility framework (Rodríguez et al., 2006).

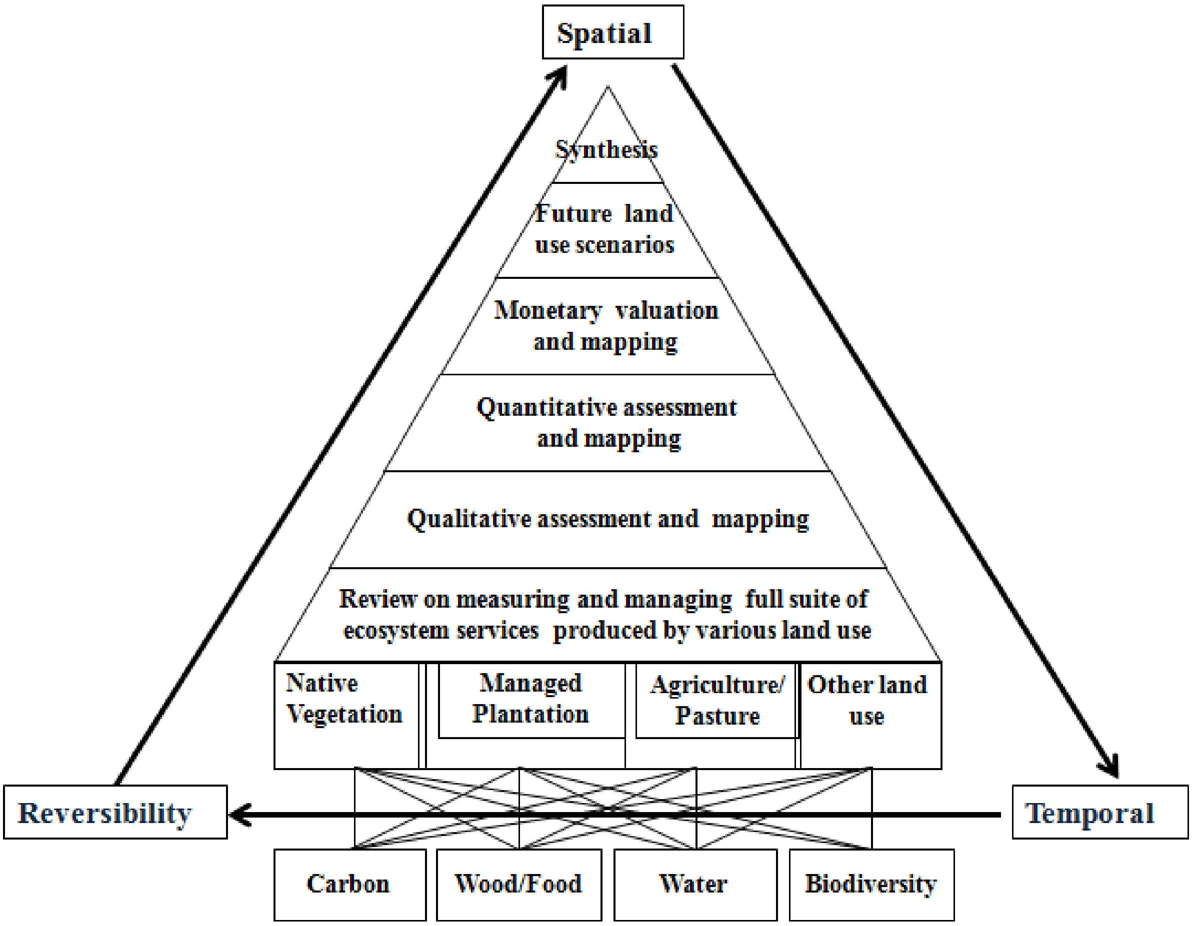

Figure 1-1 Overview of the main conceptual steps involved in this thesis. The foundation shows major land use /land cover types and key EGS in the study areas. Study progressed from review and synthesis, qualitative and quantitative assessment, monetary valuation, and evaluation of future land-use scenarios. Ecosystem services trade-offs are assessed in a spatial, temporal and reversibility framework (Figure inspired by Rodríguez et al., 2006)

1.3. BACKGROUND

Ecosystems and human well-being are inextricably linked. Ecosystems and the biological diversity contained within them provide a wide range of EGS and the continued delivery of these goods and services is essential to human survival (MEA, 2005; Balvanera et al., 2006) and economic prosperity (TEEB, 2010). The multitude of definitions and classification systems of EGS are well discussed in the literature (e. g., Wallace 2007, 2008; Costanza 2008; Fisher et al., 2009; Nahlik et al., 2012). In a broad sense, ecosystem services refer to the range of conditions and processes through which natural ecosystems, and the species that they contain, help sustain and fulfill human life (Daily, 1997). These services regulate the production of ecosystem goods, and the natural products harvested or used by humans such as timber, forage, natural fibres, game and medicine. More importantly, EGS support humanity by regulating essential processes, such as purification of air and water, nutrient cycling, decomposition of wastes, pollination of crops, and generation and renewal of soils, as well as by moderating environmental conditions by stabilising climate, reducing the risk of extreme weather events, mitigating droughts and floods, and protecting soils from erosion (MEA, 2005). This thesis addresses both ecosystem goods and services and utilises the definition of EGS offered by the UN Millennium Ecosystem Assessment, 'benefits people obtain from ecosystems' (MEA, 2005).

Production landscapes are primarily managed for the production of ecosystem goods such as wood products, pasture, crops, horticulture and combination of these goods and services such as, water regulation, carbon storage, control of soil erosion and flood mitigation. In many production landscapes, there is a mosaic of landscape elements which includes areas of vegetation managed for biodiversity, aesthetic values and carbon storage benefits (Maher and Thackway, 2007). However, the magnitude and intensity of EGS can vary because EGS are heterogeneous in space and evolve through time, known as the spatio-temporal dynamic (Fisher et al., 2009).

A genuinely sustainable agro-ecosystem not only provides agricultural commodities but also helps to protect biodiversity, water and carbon storage benefits. Sustainable agriculture and biodiversity conservation are critically important issues for the balanced supply of ecosystem services from the Australian production environment (Maher and Thackway, 2007). However, managing production landscapes for multiple values requires trade-offs, given the realities of limited resources, the competing demands of modern society, and the intensive nature of modern agriculture and forestry (Faith and Walker, 2002). Trade-offs take place when there is a reduction in one good or service in favour of another – for example, reduced water yields for improved crop production in agricultural landscapes. However, if managed sustainably, production landscapes can provide a wide range of goods and services with enormous value to human beings (Belair et al., 2010; Power, 2010).

The contribution of production landscapes to biodiversity conservation, the global carbon cycle, soil conservation, water quality, salinity mitigation, landscape amenity values and other ecosystem services have not traditionally been valued in the commercial sense, although more recently a variety of mechanisms have been developed for valuing and trading ecosystem services (Brand, 2002; Harrison et al., 2003). These services are often overlooked or taken for granted and their economic value is implicitly set to zero in many environmental policy formulations and decision making processes (TEEB, 2010). Although climate change and its impact to the global ecosystem are finally receiving greater attention, the recent economic crisis in 2009 is pushing this most prominent issue to the background to be dealt with later or even ignored (Ruffo and Kareiva, 2009).

In south-eastern Australia, there has been a long history of changing vegetation cover over the last 180 years with extensive clearing for agriculture (Steffen et al., 2009). Native vegetation is now highly fragmented and generally degraded compared with the landscape condition that prevailed before European settlement in Australia (Cork et al., 2008; Pittock et al., 2012). Recently, agricultural lands have experienced significant land-use change as demonstrated by the rapid conversion of these lands from traditional farming use, to managed forest plantations, intensive agriculture, agro-forestry and alternate farming practices which impact on the provision of ecosystem services (Pittock et al., 2012; Baral et al., 2013). This is resulting in both positive and negative changes to a variety of ecosystem services at various spatial and temporal scales which need to be quantified in standard units (Crossman et al., 2009, 2010). Quantification of ecosystem services and dissemination of information to decision makers and relevant stakeholders is critical for the responsible and sustainable management of production landscapes.

1.4. MOTIVATION FOR THE RESEARCH

With increasing demands on, and growth of production landscapes, and accompanying decline in extent and quality of natural ecosystems, there is an increasing focus on the role of production landscapes in conserving biodiversity and ecosystem services (Belair et al., 2010; Power, 2010). Due to the lack of quantification and valuation, the relative importance of ecosystem services is poorly understood and analysis of trade-offs and synergies are often subjective (Kareiva et al., 2011). Failure to deal with necessary trade-offs not only creates uncertainties in resource management planning, but also create major sources of conflict among stakeholders (Brown, 2005). Clearly, there is an urgent need to characterise, quantify and map ecosystem services for an improved understanding of the relative benefits they provide, the assignment of associated values, and the analysis of trade-offs and synergies. This thesis aims to address this knowledge gap.

1.5. THESIS OVERVIEW

Chapter 2 (published in *Journal of Environmental Planning and Management*) provides a review on the measurement and management of ecosystem services in changing landscapes. The review is mainly focused on the nature and characteristics of ecosystem services in complex production landscapes where a mosaic of landscape elements such as remnant native vegetation is managed for biological diversity, and other modified areas are managed for cropping, grazing and the harvesting of wood products. Approaches and tools for measuring and managing EGS such as qualitative assessment, quantitative assessment, monetary valuation and social cultural valuation methods are discussed.

Chapter 3 (published in *Ecological Complexity*) focuses on spatial assessment and mapping of selected EGS in a sub-catchment in south-eastern Australia. Six key EGS (timber production, carbon stock, provision of water, water regulation, biodiversity, and forage production) are quantified and mapped using a wide range of readily available data and tools. This chapter also evaluates the trade-offs among EGS associated with observed land-use change.

Chapter 4 (peer reviewed paper published in the Biennial Conference of the Institute of Foresters of Australia, Caloundra, Queensland, 2009) deals with a spatial approach for classification, mapping and valuation of selected EGS using market and non-market valuation techniques. It first identifies and compiles a variety of spatial and non-spatial data and develops a land cover typology of the study area into a GIS environment. Secondly, it estimates the annual flow of economic value of each service using various economic valuation techniques. Finally, it produces an annual flow of total economic value of the study area using the spatial economic valuation technique.

Chapter 5 (accepted for publication in *Ecological Indicators*) explores the application of concepts and approaches for describing spatial assessment of biodiversity using readily available data and tools in a heavily modified agricultural landscape in north-central Victoria. The Chapter first assesses the landscape alteration states and the associated impact on biodiversity. Second, it identifies biodiversity hotspots and conservation priority sites. Third, it assesses the habitat quality and degradation across the landscape using readily available spatial data and evaluation tools. Finally, the chapter discusses the opportunities for reconnecting landscapes that have been cleared, modified and degraded in the past and that are being reconfigured to meet new landscape management objectives.

Chapter 6 (to be submitted to *Land Use Policy*) assess key EGS (carbon sequestration, timber production, provision of water, biodiversity and agricultural production) for five plausible future land-use scenarios (business as-usual, mosaic farming system, eco-centric, agro-centric and abandoned land use) in a heavily modified and fragmented production landscape in north-central Victoria, Australia.

Chapter 7 synthesises the trade-offs, synergies and interaction among multiple EGS within primary production landscapes. Potential impacts of land use-land cover and climate change on the ability of ecosystems to supply various EGS are discussed. The thesis concludes with the policy implications and future directions in the area of EGS mapping and valuation in production landscapes.

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CHAPTER 2: MEASURING AND MANAGING ECOSYSTEM GOODS AND SERVICES IN CHANGING LANDSCAPES: A SOUTH-EAST AUSTRALIAN PERSPECTIVE

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2.1. ABSTRACT

This paper reviews approaches to measuring and managing the multiple ecosystem goods and services (EGS) provided by production landscapes. A synthesis of these approaches was used to analyse changes in supply of EGS in heavily cleared and fragmented production landscapes in south-east Australia. This included analysis of spatial and temporal trade-offs and synergies among multiple EGS. Spatially explicit, up-to-date and reliable information can be used to assess EGS supplied from different types of land uses and land cover and from different parts of a landscape. This can support effective management and payment systems for EGS in production landscapes.

2.2. INTRODUCTION

Managing landscapes to fulfil multiple demands of society is becoming a major challenge to policy makers. Land use-land covers are also changing rapidly in line with increasing population and changing demands of society (Ramankutty et al. 2002; Acevedo et al. 2010). In many parts of the world natural vegetation is being cleared to agriculture (Zak et al. 2008) and elsewhere, agricultural land is being revegetated for wood production, carbon farming or water catchment protection. In many cases, changes in land use-land cover affect the ability of landscapes to continue providing the quality and quantity of ecosystem goods and services (EGS) required for human health and well-being (Foley et al. 2005; MEA 2005; Hector and Bagchi 2007). Predicting the effects of such land use-land cover changes on the provision of EGS has become an extremely active field of research (e.g., Foley et al. 2005; Zak et al. 2008; Polasky et al. 2011).

In recent years, there is increasing focus on EGS in primary production landscapes (Maynard, James, and Davidson 2010; Wilson et al. 2010). Production landscapes provide the food, fibre and energy that people need. Production landscapes also benefit society by providing services that are not currently bought and sold in the marketplace and support ecosystem function, such as water regulation, wildlife habitat and associated biodiversity value. These benefits are not always complementary and we must often choose between competing uses of the environment and a number of EGS provided by a healthy landscape (Foley et al. 2005; Nelson et al. 2009; Raudsepp-Hearne, Peterson, and Bennett 2010). EGS, by definition, contain all the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life (Daily 1997). Without efforts to classify, assess, quantify and value all the benefits associated with production landscapes, policy and managerial decisions will continue to be biased in favour of environmentally degrading practices. Furthermore, a lack of scientific understanding of the factors influencing provision of EGS and of their economic benefits limits their incorporation into land use planning and decision making (Daily et al. 2008; Kareiva et al. 2011).

The aim of this paper is to review approaches to identifying, quantifying, valuing, mapping and trade-off analysis for EGS. These approaches are considered in the context of two case study areas in changing landscapes in south-eastern Australia. These areas have been subject to long histories of land use change and provide potentially valuable insights into the changing patterns in the provision of EGS with changing land use. This area has been the subject of recent detailed study (Baral et al. 2009, 2013). We provide an analysis of definitions and associated classification systems for EGS, an overview of techniques used to map and measure EGS, including qualitative, quantitative, economic valuation and social value approaches and summarise a variety of relatively new tools and techniques associated with measuring EGS. Trade-offs and synergies among multiple EGS and the role of measuring and mapping EGS to support a market based instruments such as payments for ecosystem services in production landscapes are discussed.

2.3 DEFINING AND CLASSIFYING EGS

EGS are the aspects of nature that benefit people. Costanza et al. (1997) define EGS as the benefits human populations derive directly or indirectly from ecosystem functions. The Millennium Ecosystem Assessment (MEA 2005) categorised EGS into provisioning services, supporting services, regulating services and cultural services. Others have refined this definition to improve the applicability of EGS for decision-making, as outputs of ecological functions or processes that directly or indirectly relate to human well-being (Boyd and Banzhaf 2007; Wallace 2007; Fisher, Turner, and Morling 2009; TEEB 2009). EGS have been classified in a multitude of different ways (e.g. de Groot, Wilson, and Boumans 2002; MEA 2005; Wallace 2007; Costanza 2008; Fisher, Turner, and Morling 2009). Definition and classification system of EGS are well discussed in previous papers (e.g., Wallace 2007; Costanza 2008; Fisher and Turner 2008; Nahlik et al., 2012). Some influential definitions that are frequently cited in environmental literature and associated classification systems are listed in Table S2-1. For the purposes of this paper, we use the definition proposed by the MEA – the benefits people obtain from ecosystems (MEA 2005).

2.4. ASSESSING AND MAPPING EGS

Since the publication of the Millennium Ecosystem Assessment's outcomes in 2005 (MEA 2005), there has been rapid growth in the science of assessing and mapping multiple EGS (Nelson et al. 2009; Braat and de Groot 2012; Crossman, Burkhard, and Nedkov 2012). The key reasons for assessing mapping and valuing are summarised in Table 2-1. However, scientists have struggled to assess EGS using consistent and comparable approaches (Crossman, Burkhard, and Nedkov 2012; Martinez-Harms and Balvanera 2012). EGS can be assessed at different spatial and temporal scales, in relation to their potential supply or production potential, demand and consumption, and using an array of indicators or metrics which usually involves three approaches, (i) judgement of potential capacity or qualitative assessment (Cork et al. 2001; Shelton et al. 2001; Burkhard et al. 2012), (ii) measurement of biophysical outcomes or quantitative assessment (Nelson et al. 2009; Raudsepp-Hearne, Peterson, and Bennett 2010; Egoh et al. 2011), and (iii) economic valuation of these EGS (Costanza et al. 1997; TEEB 2010; de Groot et al. 2012) (Fig. 2-1).

These approaches are being applied either separately or in combination. The assessed values are often transferred into a GIS environment and then displayed into EGS flow maps to produce spatially explicit results and analyse trade-offs and synergies among multiple EGS (see Nelson et al. 2009; Raudsepp-Hearne, Peterson, and Bennett 2010; Egoh et al. 2011).

Table 2-1. Key reasons for assessing, mapping and valuing ecosystem goods and services (EGS).

Benefits of assessing, mapping and valuing EGS	Reference
Helps to make decisions about allocating resources between competing uses.	Farley (2008)
Raises awareness and conveys the relative importance of EGS to policy makers.	De Groot et al. (2012)
Improves the efficient use of limited funds by identifying where protection and restoration is economically most important and can be provided at lowest cost.	Crossman and Bryan (2009); Crossman, Bryan, and King (2011)
Determines the extent to which compensation should be paid for the loss of EGS in liability regimes.	Payne and Sand (2011)
Provides guidance in understanding user preferences and the relative value current generations place on ecosystem services.	De Groot et al. (2012)
Improves incentives and generates expenditures needed for the conservation and sustainable use of EGS.	Farley and Costanza (2010)

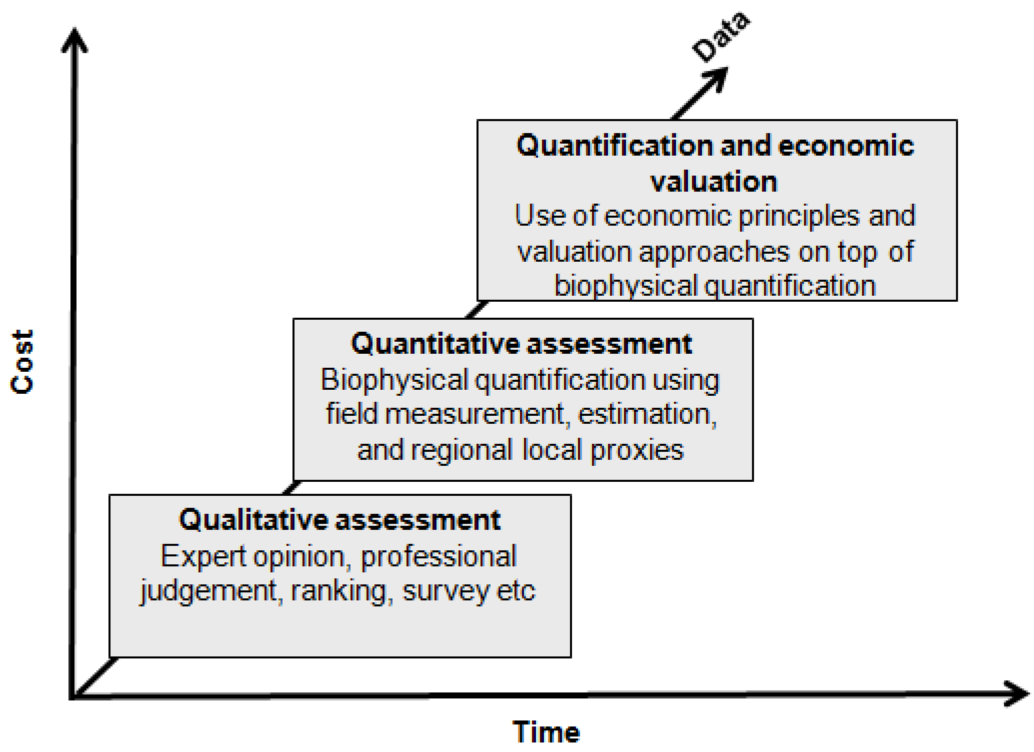

Figure 2-1. Common approaches to assessing ecosystem goods and services, and associated time, data and cost requirement. The time, cost and data requirement depends on the number of services assessed and the size of the landscape and is indicative only. An alternative economic valuation approach commonly known as 'benefit-transfer' can be done quickly and cheaply although it is not an economic valuation methodology itself, but rather a procedure that uses valuation estimates from other 'study sites' to a given 'policy site'(see Jensen and Bourgeron 2001)

2.4.1. QUALITATIVE ASSESSMENT

Lack of quantitative data has been cited as one of the major barriers in ecosystem management (Grantham et al. 2009; Burkhard et al. 2012) and ecosystems and their associated EGS will deteriorate further while we wait for improved data and delayed conservation actions (Grantham et al. 2009). Qualitative assessment approaches, such as participatory mapping tools, expert view or professional judgment, questionnaire and surveys can be utilised to assess the condition and trend of EGS (MEA 2005; Burkhard et al. 2012b; Busch et al. 2012; Scolozzi and Geneletti 2012). Numerous authors have used these approaches using qualitative indicators such as high, moderate or low provision of EGS and increasing, decreasing or stable trends. Such qualitative assessment or value classes are often transferred into GIS to produce spatially explicit distribution maps (e.g. Burkhard et al. 2012b; Haines-Young, Potschin, and Kienast 2012; Vihervaara et al. 2010, 2012). However, these approaches are still debated among scholars and practitioners (Krueger et al. 2012). The results of such analysis are often subjective and error prone and the accuracy depend on the knowledge and experience of the expert or professional for a particular landscape.

2.4.2. QUANTITATIVE ASSESSMENT

Many authors have attempted to quantify the EGS in biophysical units using approaches such as field sampling and measurements, models, and extraction of regional or global data and reports (Luck, Chan, and Fay 2009; Nelson et al. 2009; Egoh et al. 2011). The key reasons for quantifying EGS in biophysical units are, (i) relative ease in assessing temporal changes in EGS (Burkhard et al. 2012a), (ii) relative ease in converting to monetary value for payment and compensation (Nelson et al. 2009), (iii) allocation of resources between competing uses (Nelson et al. 2009), (iv) trade-off analysis (Egoh et al. 2011), and (v) identifying conservation priority sites (Chen et al. 2006; Naidoo et al. 2008). However, quantitative assessment based on proxies and models has its own challenges including poor correlation between primary data sources where the proxies are generated and applied (Eigenbrod et al. 2010).

2.4.3. ECONOMIC VALUATION

There are a number of reasons and associated methodologies for economic valuation of EGS. Several economic valuation methods focusing on utilitarian values are often used to quantify the benefits of EGS. In the past, many of these EGS have been traditionally viewed as free gifts from nature to society or ‘public goods’, including landscape amenity, watershed services and carbon storage. For this reason there was little attention to measuring and valuing such EGS. In addition, due to the lack of a monetary value and a formal market, these EGS are often overlooked in public and private resource planning and decision making. Recent developments in valuing EGS provide a basis for estimating economic benefits (Kareiva et al. 2011). Many EGS can be given monetary value using a range of economic approaches (Farber et al. 2006). A crucial aspect of monetary analysis is the discount rates used to assess the present value of future benefits and/or future value of current benefits (Bullock et al. 2011) because different rates can produce highly contrasting economic outcomes (Currie, Milton, and Steenkamp 2009). Key ecological and economic reasons for valuing EGS include: (i) economic incentives for conservation, (ii) improvements in the use and management of EGS, (iii) justification for allocation of public funding, and (iv) a useful step towards institutional innovation such as Payment for Ecosystem Services (PES) (Farber 2002; Barbier and Heal 2006; Turner, Morse-Jones, and Fisher 2010; Salles 2011).

2.4.4. SOCIAL AND CULTURAL VALUE OF EGS

Some ecosystem services cannot be monetised, such as the many cultural services that reflect societal values (Gee and Burkhard 2010), cultural and religious beliefs such as sacred groves (Bhagwat and Rutti 2006; Of 2008). Although many cultural values are consistently recognised throughout the world, they are not adequately defined or integrated within the EGS framework (Daniel et al. 2012). In Australia, many parts of the landscape have important cultural values to Indigenous Australians and the protection of these values is seen as important to Traditional Owners. In such cases 'non-monetising' approaches have been suggested, which involve analysing the choices and preferences of stakeholders (Farber et al. 2006). A non-monetised social value of EGS provides a standardised, quantitative indicator which can express relative value across geographic extents and within survey subgroups without relying on dollar-value terms (Sherrouse et al. 2011). In many cases, biophysical and economic values are included in spatial planning for conservation and environmental management and social values are ignored (Bryan et al. 2010). Psycho-social and cultural research perspectives suggest that value be considered as a psychological and cultural concept related to human perception (Nijkamp et al. 2008). The values perceived by society are often inadequately captured by conventional utilitarian valuation methods, which neglect the value of the psychological well-being derived from an individual's relationship with nature (Kumar and Kumar 2008). Sherrouse et al. (2011) developed a GIS application to calculate and map the relative social values of EGS as perceived by diverse groups of ecosystem stakeholders that provides and alternative way to assess and map EGS.

2.4.5. MAPPING EGS

Maps are a powerful tool for processing complex spatial and temporal data to support resource and environmental management as well as landscape planning (Burkhard et al. 2012a, 2012b; Crossman, Burkhard, and Nedkov 2012). Therefore, identifying key areas for EGS supply and displaying on map is increasing rapidly in recent years (Martinez-Harms and Balvanera 2012). A wide range of EGS are mapped using various methods in different geographic scales (Martinez-Harms and Balvanera 2012). Recently, Martinez-Harms and Balvanera (2012) identified 70 publications that mapped EGS between 1995 to 2011 by searching on the ISI Web of Science, ScienceDirect and Google Scholar. They found that carbon storage/sequestration, food production, recreation and water quality/provision are most commonly mapped EGS whereas timber production is least mapped. Most of the reviewed studies used secondary data and focused on the regional scale (Martinez-Harms and Balvanera 2012). Depending on the extent and resolution, they provide better understanding of what EGS are provided by a given piece of land, landscape, region, state, continent and even globally, so that the level of provision of EGS can be monitored and managed efficiently (Burkhard et al. 2012a; Crossman, Burkhard, and Nedkov 2012).

2.4.6. TOOLS AND TECHNIQUES TO ASSESS MULTIPLE EGS

A number of tools have been developed for assessing, mapping, and analysing trade-offs among multiple EGS. Some widely used and influential tools are – Integrated Valuation of Ecosystem Services and Trade-offs (InVEST; Tallis et al. 2011), the Multi-scale Integrated Models of Ecosystem Services (MIMES; Boumans and Costanza 2008), and Artificial Intelligence for Ecosystem Services (ARIES; Villa et al. 2009, 2011).

2.4.6.1. INVEST - INTEGRATED VALUATION OF EGS AND TRADE-OFFS

In 2006, three key authors of the Millennium Ecosystem Assessment (MEA) took an initiative to take the next step forward by forming the Natural Capital Project which is dedicated to bring EGS science into practice (Kareiva et al. 2011). InVEST is a key outcome of the Natural Capital Project and it is currently being applied and validated worldwide (Kareiva et al. 2011). The tool and series of associated models can be used to analyse the effect of different land use and management scenarios on the provision of biodiversity habitat and a wide range of EGS (Polasky et al. 2011).

2.4.6.2. THE MULTI-SCALE INTEGRATED MODELS OF ECOSYSTEM SERVICES (MIMES)

MIMES is a suite of models for land-use change and marine spatial planning decision making. The models quantify the effects of land and sea use change on EGS and can be run at global, regional, and local levels (Grigg et al. 2009). MIMES use input data from GIS sources and time series to simulate ecosystem components under different scenarios defined by stakeholder input. These simulations can help stakeholders evaluate how development, management and land use decisions will affect natural, human and built capital (Grigg et al. 2009).

2.4.6.3. ARTIFICIAL INTELLIGENCE FOR ECOSYSTEM SERVICES (ARIES)

ARIES is a new methodology and web application designed to assess EGS and illuminate their values to humans in order to make environmental decisions easier and more effective (Villa et al. 2009). ARIES and the corresponding rapid assessment software toolkit can currently handle a sizable cross-section of the EGS problem area; the methods and models are being fine-tuned in case studies in Madagascar, USA, Mexico, Spain, and elsewhere (Villa et al. 2011).

2.5. EGS ASSESSMENT IN CHANGING LANDSCAPES: A SOUTH-EAST AUSTRALIAN PERSPECTIVE

Since European settlement from 1788, large parts of the south-eastern Australian landscape have been intensively modified to provide food and fibre (Steffen et al. 2009). There is some debate that most parts of south-eastern Australia were burnt more or less on an annual basis by the aboriginal people prior to European settlement (Flannery 1994, 1998; Ryan et al. 1995; Benson and Redpath 1997). However there is no clear evidence regarding pre-European fire regimes and associated impacts on vegetation communities and it is commonly believed that the south-east Australian landscape was covered with intact native vegetation. The effect of large-scale vegetation clearing has commonly resulted in widespread environmental changes including the degradation of land and water resources (Walker et al. 2009; Pittock, Cork, and Maynard 2012) and biodiversity (Steffen et al. 2009). Production of food by growing crops and raising stock enhanced private goods or provisioning services at the expense of regulating and cultural services such as biodiversity, water quality, gas regulation and recreation (Cork, Stoneham, and Lowe 2007; Steffen et al. 2009; Pittock, Cork, and Maynard 2012). Similar land-use changes and trade-offs among EGS has been reported elsewhere (e.g., Falcucci, Maiorano, and Boitani 2007; Rudel et al. 2009; Acevedo et al. 2010; Vihervaara et al. 2011) although the magnitude of change and associated impact may vary.

The state of Victoria is the most extensively cleared Australian state and has also been subject to the longest history of land use by European settlers (Pittock, Cork, and Maynard 2012). Victoria comprises a rich variety of terrestrial ecosystems which result from a diversity of terrain, climate, geology and soil types (MacEwan et al. 2008). Over recent decades, land use practices have changed significantly and landscapes have been modified to suit this diversity of climate and soil. While the value of commodities produced from production landscapes has been recognised since the beginning of settled agriculture, it is becoming increasingly important to understand the wider uses and benefits that rapidly changing production landscapes provide society (Dale and Polasky 2007; Bennett et al. 2009; DSE, 2009). Key EGS in the south-eastern Australia area (Cork, Stoneham, and Lowe 2007;

Steffen et al. 2009; Baral et al. 2013) are provided in Table 2-2 with further details of some recent studies on EGS assessment and mapping in south-eastern Australia summarised in Table 2-3.

A rapid qualitative assessment of EGS from two contrasting landscapes in Victoria that are representative of the range of production landscapes across most of south-eastern Australian provides an understanding of land use-land cover change and associated impacts on EGS. For both case studies we used peer reviewed papers, published reports and expert opinion for qualitative assessment and ranking. In spite of some limitations discussed in Section 2.4.1, we employed a qualitative approach to demonstrate the observed and potential impact of land use-land cover change on EGS with limited data, time and resources. In addition, the four authors involved in this study have substantial experience and prior knowledge of this study landscape and feedback from other stakeholders and agencies has also been incorporated.

Table 2-2. Important ecosystem goods and services (EGS) in south-eastern Australia. Letters in brackets represent MEA ecosystem service categories: provisioning (P), regulating (R), cultural (C) and supporting (S) services. EGS description and beneficiary types are adapted from Baral et al. (2013) and criteria range and codes for scale and time lag are adapted from Bennett et al. (2010): 'O' on-site (*in situ* delivery), 'L' local (off-site, 100 m – 10 km), 'R' regional (10-1000 km), 'G' global (>1000 km), time lag 'I' immediate (<1 year), 'F' fast (1 year to ≤10 years), 'M' medium (11 to ≤30 years), 'S' slow (31 to ≤50 years), 'VS' very slow (>50 years). Unit of measurement 'm^3' cubic metre, 'ML' mega litre, 'DSE' Dry Sheep Equivalent which is equivalent to 0.125 Large Stock Unit, 'Mg' mega gram, 'kg' kilogram.

EGS	Description	Beneficiary/use	Scale	Time lag	Unit of measurement
Timber production (P)	Provision of timber, pulp from managed plantations and native production forests	Private	O	M	m^3 or tons ha^{-1}
Provision of Water (P)	Filtering, retention and storage of freshwater available for human consumption or industrial use	Public	O-R	F-VS	ML ha^{-1} yr^{-1}
Forage production (P)	Production of forage for domestic livestock mainly from pasture and grazing land	Private	O	I-F	DSE ha^{-1*}
Carbon sequestration (R)	Capture atmospheric carbon dioxide in trees, shrubs and other vegetation	Public	O-G	F-VS	Mg ha^{-1} yr^{-1}
Nutrient regulation (R)	Internal cycling, processing and acquisition of nutrients by vegetation and microorganisms	Private	O-L	I-VS	kg ha^{-1} yr^{-1}
Pollination (R)	Pollination of wild plant species and harvested crops	Private/Public	O-R	I-S	Number of, or impact of pollinating species
Carbon stock (R)	Stock of carbon in wood, other biomass and soil and keep CO_2 out of the atmosphere	Public/Private	O-R	F-VS	Mg ha^{-1}
Water regulation (R)	Role of land cover in regulating hydrological flows by vegetation	Public /Private	O-R	M-VS	m^3 ha^{-1}
Salinity water disposal (R)	Storage of saline water	Private/Public	O-L	I-S	
Flood control (R)	Control of floods	Private/Public	O-R	M-S	Number of prevented flood events
Aesthetic beauty (C)	Attractive landscape features helps enjoyments of scenery	Private/Public	O-R	F-S	Presence of landscape features
Recreation (C)	Travel to natural ecosystems for eco-tourism, outdoor sport etc	Public	L-R	I-VS	N° of visitors yr^{-1}, \$ ha^{-1} yr^{-1}
Soil protection (S)	Promotes agricultural productivity and the integrity of natural ecosystems	Private/Public	O-R	F-VS	ha yr^{-1}
Biodiversity (S)	Landscapes capacity to hold naturally functioning ecosystems support a diversity of plant and animal life	Public/Private	O-R	I-VS	

Table 2-3. A summary of recent studies on assessment and mapping of ecosystem goods and services (EGS) in south-eastern Australia

Study location	Method and objectives	EGS measured and/or mapped	Reference
South Australian Murray Darling Basin region	social value of EGS mapped into GIS environment in order to indentify focal areas for high priority sites for environmental conservation and management	31 EGS based on MEA categories	Bryan et al. (2011)
Torrumbarry Irrigation area in northern Victoria	spatial targeting within a cost-benefit framework to reconfigure irrigated agricultural landscapes to reduce the water use and enhance provision of EGS	salinity mitigation, climate regulation, water, agricultural production, recreation and amenity	Crossman et al. (2010)
North-west Victoria	use of readily available data on vegetation classes, conditions and associated characteristics to manipulate the EGS at landscape scale	climate regulation, water regulation, disturbance regulation, controlling contaminants, supply of raw materials, habitat protection and cultural and amenity values	Yapp, Walker, and Thackway (2010)
South-east Queensland	ecosystem-based framework and the process that produces matrices and maps to identify and illustrate the linkages between EGS and the community well-being	28 EGS under MEA categories	Maynard, James, and Davidson (2010)
South Australian Murray Darling Basin	use of mathematical programming to support cost-effective environmental investment decisions under uncertainty	23 EGS under MEA categories	Bryn (2010)
Lower Murray region	integration of disparate landscape-scale biophysical and economic data and models to identify cost-effective hotspots for restoring EGS and enhancing landscape multi-functionality	agricultural production, soil conservation, water, carbon sequestration, biodiversity benefits	Crossman and Bryan (2009)
The Goulburn Broken Catchment, North-central Victoria	a multi-phase interactive process among various stakeholders for mutual understanding and participatory decision making about ecosystem services and identification of more sustainable land management options	12 EGS, mainly regulating, and cultural services ranked based on landowners preferences	Cork and Proctor (2005)
The Goulburn Broken Catchment, North-central Victoria	use of multi-criteria evaluation to identify key natural resource management issues and assess various scenarios for the study region in terms of ecosystem services	wide range of regulating services – such as, water flow regulation, erosion control, maintenance of soil health, pest control	Proctor et al. (2002)

2.5.1. CASE I: LOWER GLENELG BASIN, SOUTH-WESTERN VICTORIA

Sub-catchment G8 of the Glenelg Hopkins Catchment is located in the Green Triangle region of south-western Victoria spanning over 300 km^2 (8-198 m asl, 37º 50' S, 141º 30' E). This area was selected because of its concentration of commercially valuable hardwood and softwood plantations where the focus is on production forestry with the provision of a variety of EGS. Further details about this study site can be found in Baral et al. (2009).

To assess the impacts of land use-land cover changes we used three temporal reference points, (i) pre-European condition from modelled vegetation data (it was assumed that the native vegetation of the study area was intact until European settlement), (ii) pre-1970s or conversion to pasture: a large proportion of native vegetation was converted to pasture by this time with very limited plantation establishment or other afforestation activity, and (iii) recent condition or post-1970s: in recent years a large proportion of pasture and some native vegetation has been converted to managed forestry plantations. The effects of these land use-land cover changes on potential supply of EGS were assessed according to the relative capacity of a particular land cover to provide various EGS and represented using flower diagrams for the different time periods (Fig. 2-2). Similarly, the changes in the demand and associated value of EGS over time was assessed qualitatively using changes in population or EGS beneficiaries at the local, state and the national scale (Fig. 2-2).

Total EGS from land with intact native vegetation was significantly reduced after conversion to pasture. In contrast, more recent conversion of pasture to managed plantation increased the provision of most EGS. On the other hand the demand for most of the EGS has increased due to the number of user or beneficiaries of EGS since European settlement in Australia while supply is diminishing.

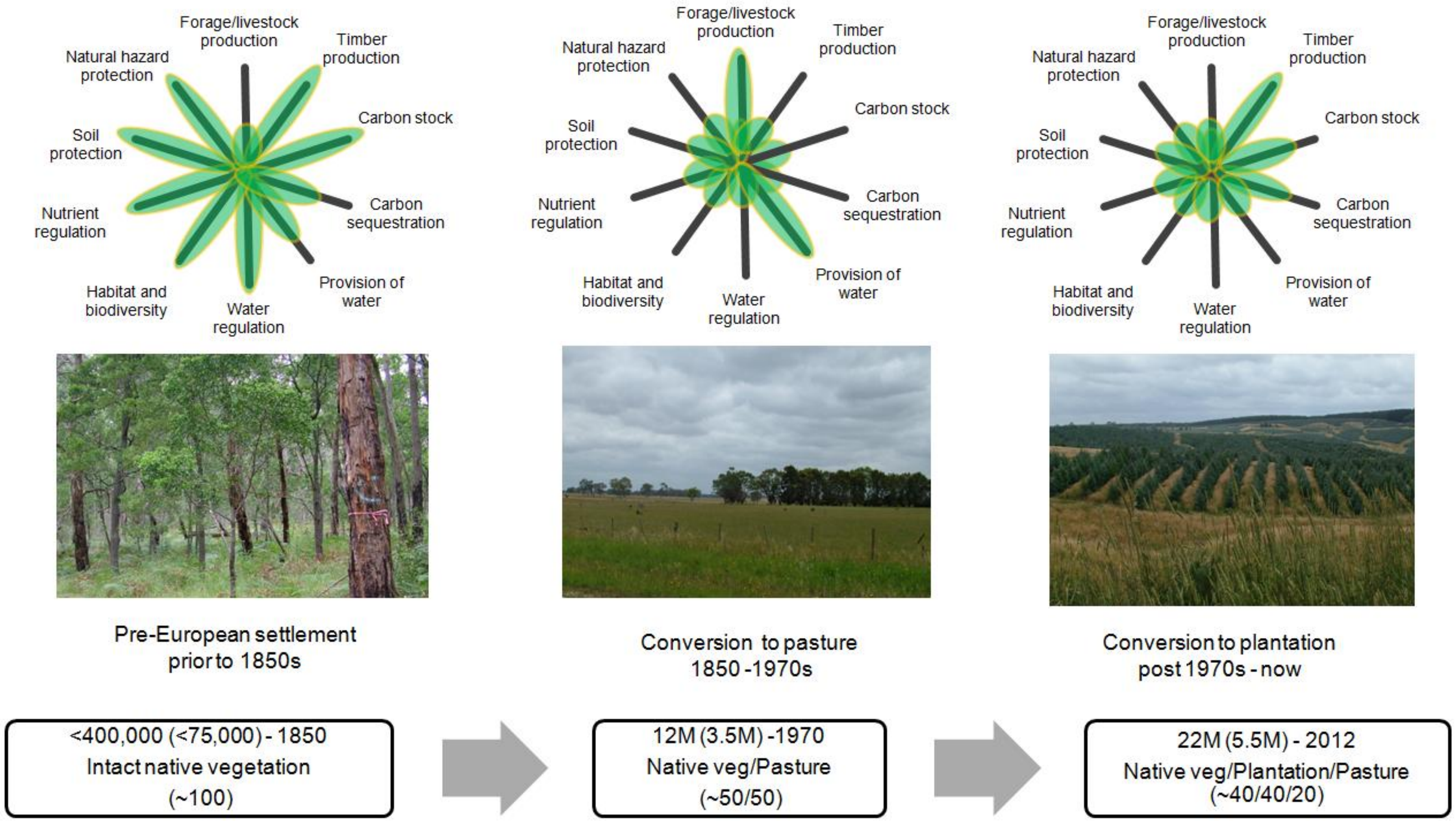

Figure 2-2. Typical land use transition in the Green triangle region of south-eastern Australia and potential trade-offs among multiple ecosystem goods and services. Text in the box represents the population in Australia (and Victoria in brackets) at different points in time (top row) and the approximate proportion of native vegetation pasture and plantation (bottom row). The provision of ecosystem goods and services are applicable to particular transitions and are indicative only (figure inspired by Foley et al. 2005).

2.5.2. CASE II: REEDY LAKES AND WINLATON, NORTH-CENTRAL VICTORIA

The study site between Kerang and Lake Boga is located in north-central Victoria, Australia, approximately 320 km north-west of Melbourne (35.972º S, 143.228º E). The total area spans about 30,000 ha, essentially defined by the boundaries of the Little Murray and Lower Loddon Rivers in the North, West and South and the Murray Valley Highway in the West. Further details about this study area can be found in Mansergh (2010). This area has been extensively cleared for agriculture and is now highly fragmented and often degraded. More recently, Kilter Pty Ltd (an asset management group servicing the superannuation sector), has been selecting land in this region and managing it under a long-term program (Future Farming Landscapes, FFL) that aims to restore landscapes to their most sustainable configurations.

Similar to the Lower Glenelg basin case study, three temporal reference points were used to assess the impact of land use land cover changes – (i) pre-European condition from modelled historical vegetation data: it was assumed that the study area remained with intact native vegetation until European settlement and vegetation modification in the early 1850s, (ii) current or intensive agricultural focus: a large proportion of native vegetation converted to agriculture since the 1850s, and (iii) future farming landscape: proposed landscape reconfiguration through the FFL program which comprises a mixture of irrigated cropping, biodiversity, grazing, perennial horticulture, and agroforestry, spanning 25% of the study area. The effects of these land use-land cover changes on EGS were assessed based on their relative capacity using available literature relevant to south-eastern Australia (Table 2-4, Fig. 2-3).

Results indicated mixed outcomes of land use-land cover changes for the provision of EGS. However spatially targeted proposed land-use changes in this study landscape could result in an increase in supply of a number of EGS. This is primarily due to conversion of intensively managed agriculture and pasture land to environmental plantings, low intensity grazing and agroforestry activities.

Table 2-4. Potential effects of future land-use change (conversion of irrigated and dryland farming to future land uses under the Future Farming Landscapes program) on various ecosystem goods and services. Qualitative scale based on that used by others (Shelton et al. 2001; MEA 2005; Bullock et al. 2007, 2011; Dowsan and Smith 2007; Cao, Chen, and Yu 2009; Ostle et al. 2009; de Groot and van der Meer 2010a): '+' positive, '++' strongly positive, '0' neutral or no change, '-' negative, '- -' strongly negative, '?' not known. Letters in brackets represent Millennium Ecosystem Assessment categories: provisioning (P), Regulating (R), Cultural (C) and Supporting (S) services.

Ecosystem Goods and Services	Future Land Use			
	Environmental planting	Agroforestry	Grazing	Agriculture
Forage production (P)	--	--	+	--
Food production (P)	0	0	0	++
Wood production (P)	0	++	0	0
Carbon stock (R)	++	++	+	0
Carbon sequestration (R)	++	++	+	0
Water supply (P)	-	--	+	0
Water regulation (R)	++	+	+	0
Flood control (R)	++	+	+	0
Nutrient regulation (R)	++	+	+	0
Wildlife habitat (S)	++	+	+	0
Pollination (R)	+	?	+	0
Aesthetic beauty (C)	?	?	?	0
Recreation (C)	+	+	?	0
Soil protection (S)	++	+	+	0
Salinity mitigation (R)	+	+	+	0

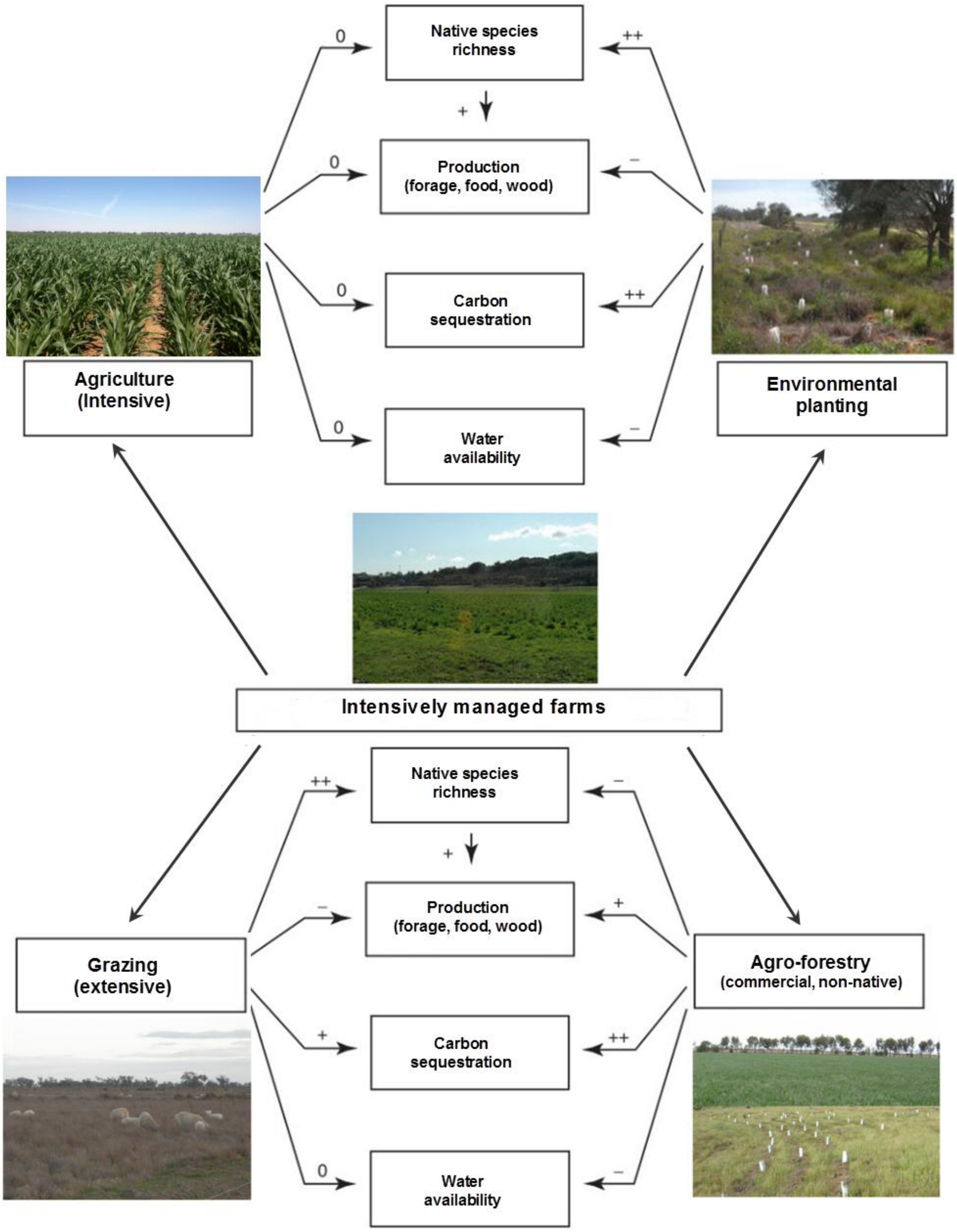

Figure 2-3. Possible land-use changes in the study area and associated trade-offs among ecosystem services. Intensively managed croplands can potentially be converted to four different land uses which produces different response to various EGS, (i) intensive agriculture relative to recent past intensive pasture will have no effect on major EGS with this land-use change simply replacing forage production with food production, (ii) environmental planting with native tree species will have a positive effect on native species richness and carbon sequestration but reduce water availability, (iii) grazing (extensive) – an extensive form of grazing with biodiversity consideration will potentially enhance native species richness and some carbon sequestration but will reduce forage production and have no effect on water availability, and (iv) commercial agroforestry systems will enhance wood production and carbon sequestration but have negative effects on native species richness and water availability (figure inspired by Bullock et al. 2011).

2.5.3. LESSONS FROM TWO CASES STUDIES

The two examples presented here show that anthropogenic driven land-use change can alter the ecosystem's capacity to provide various EGS required for human well-being. In our study clearing of native vegetation provided important benefits for early settlers, as provided for production of ecosystem goods (e.g., timber, food production). However, replacement of deep-rooted perennial woody vegetation for shallow rooted annual crop or modified pasture reduced the supply of many regulating services, such as water regulation, soil protection and climate regulation (Jones et al. 2007; Yapp, Walker, and Thackway 2010) and reduced habitat and conservation services. When assessing EGS consumed by humans we have to delineate between the ends and means (Fisher and Turner 2008). Some EGS are considered to be intermediate services while others generate final benefit or end. In our case, for example, timber production can provide intermediate benefits for carbon sequestration/stock which depend on the use of the timber. However, timber itself can be used for human benefits and becomes a final EGS (see Boyd and Banzhaf 2007; Fisher and Turner 2008). Results also demonstrated that commercial plantations and restoration efforts can enhance the provision of different EGS but the results are not always complementary and trade-offs are inevitable (Bullock et al. 2011). Demands for many EGS are increasing due to the population growth, market trend, and changes on societal preferences (MEA 2005; FAO 2007; Baral et al. 2013). The value of different EGS to society also changes over time. As more basic needs for subsistence are met, or as the knowledge of the importance of different services for longer-term survival increases, societies have begun to place more value on services such as water quality or carbon sequestration (Baral et al. 2013).

Qualitative assessment of EGS benefits supplied from different types of land uses and land cover from different parts of a landscape can be useful for initial assessment and scoping study. To this end, our results presented here are indicative only and more rigorous assessment such as quantitative and economic valuation are required for final assessment (see Baral et al. 2009; 2013).

2.6. KEY ISSUES ASSOCIATED WITH EGS IN CHANGING LANDSCAPES

2.6.1. TRADE-OFFS, AND SYNERGIES

Trade-offs among EGS occur when an increase in one service leads to a decrease in one or more other services, and represent important externalities in current approaches to EGS management (Rodriguez et al. 2006; Bennett et al. 2009). Trade-offs in EGS can be classified along three axes: (a) spatial scale – location of trade-offs, (b) temporal scale – timing of trade-offs, and (c) reversibility – the possibility of perturbed EGS returning to an improved state (MEA 2005; Rodriguez et al. 2006). Typically, trade-offs among EGS arise from management choices and specific management practices made by human society that can change the nature, magnitude and direction of services provided by ecosystems (MEA 2005; Rodriguez et al. 2006).

Synergies occur when services either increase or decrease due to simultaneous response to the same driver or due to true interactions among services (Bennett et al. 2009; Chattere and Agrawal 2009). For example, a synergistic relationship exists among wildlife habitat and recreation opportunities in protected areas such as national parks and wildlife reserves. The protected areas provide better habitat for wildlife and also enhance opportunities for recreation and ecotourism (Lindsey et al. 2007). In assessing trade-offs and synergies between alternative uses of ecosystems, the total bundle of EGS provided by different conversion and management states need to be considered (Braat and de Groot 2012).

A number of researchers have studied the trade-off between two products and services provided by forested ecosystems such as timber production and carbon sequestration (Seidl et al. 2007) and, multiple EGS (Nelson et al. 2009; Raudsepp-Hearne, Peterson, and Bennett 2010). They found that trade-offs are inevitable in many cases. Chattere and Agrawal (2009) analysed the relationships between institutional factors and multiple benefits such as carbon storage and livelihood options using original data for 10 countries across Asia, Africa, and Latin America. They found that larger forest size and greater rule-making autonomy at the local level are associated with high carbon storage and livelihood benefits and differences in ownership of forest are associated with trade-offs between livelihood benefits and carbon storage.

2.6.2. PAYMENTS FOR ECOSYSTEM SERVICES

Payments for private ecosystem goods (e.g., food and timber) have commonly occurred in markets throughout human history. However public services (e.g., fresh air, recreation) do not receive price signals in markets and hence there are little financial incentives for landowners to produce them (Ribaudo et al. 2010). Payments for ecosystem services (PES) are part of a new and more direct conservation paradigm, explicitly recognising, (i) the need to bridge the interests of landowners and the broader society, (ii) the costs of providing different ecosystem services, and (iii) that those that benefit from these services to pay these costs. The underlying idea of PES is that EGS beneficiaries (which may include individuals elsewhere, firms or broader community through the government) make direct, contractual and conditional payments to local landholders in return for adopting practices that provide increased services, for example through ecosystem conservation and restoration. A number of financial incentives or PES type payment mechanisms are in place and have been practiced in south-eastern Australia for some time. These have been generally described as market-based instruments (MBIs) and include approaches such as Eco-Tender (Eigenraam et al. 2006), Bush Tender (Stoneham et al. 2003) and Bio-banking (Burgin 2008). Such financial incentives can have both synergies and tensions for land use and management practices which ultimately results in a range of trade-offs and co-benefits across multiple EGS (see Bryn 2013).

Establishing a baseline and a quantified measure of EGS following the payment or credit transaction are key requirement for any successful PES or MBIs (Patterson and Coelho 2009).

2.7. CONCLUDING COMMENTS

This review and initial analysis for two case study areas indicated that measuring EGS is a vital step for valuation to guide management and for payments to provide incentives for the maintenance or enhanced provision of currently unpriced ecosystem services such as water quality, carbon sequestration or biodiversity conservation. However, multiple and complex definitions and classification systems for EGS are often confusing for decision and policy makers. This confusion is likely to be counterproductive in building the case for investment in measures to reduce land or vegetation degradation and enhance the provision of ecosystem services (Wallace 2008). In addition, the inconsistency in methods to assess and map EGS is a challenge for their inclusion in national accounts and broader policy and natural resource management decision making (Crossman, Burkhard, and Nedkov 2012). Furthermore, ongoing land use-land cover and climate change place further complexity on future measurement and management of multiple EGS.

The case studies highlight the impact of land-use change on provision of EGS in south-eastern Australia. Such land-use changes are similar to those occurring elsewhere, particularly in sub-tropical or temperate developing regions. Our findings therefore have broader relevance, although we recognise that the impacts of land-use changes on EGS will depend on local circumstances. Assessing EGS supplied from different types of land uses and land cover from different parts of a landscape, and identifying who benefits from these services, are critical steps in the development of effective land use policy and decision-making. Spatially explicit, up-to-date and reliable information about EGS are required to support this assessment.

2.8. REFERENCES

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Table S2-1. Major classification systems of ecosystem goods and services.

Costanza et al. (1997)	Daily (1997)	Cork et al. (2001)	MEA (2005)	Wallace (2007)	TEEB (2009)	de Groot et al. (2010b)
Definition						
the benefits human populations derive, directly or indirectly, from ecosystem functions	the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life	use Daily (1997)	the benefits people obtain from ecosystems	use MEA (2005)	the direct and indirect contributions of ecosystems to human well-being	use MEA (2005)
Classification system						
food production (e.g. fish, game, fruit)	food	pollination	food	food	food	food
raw materials	durable materials (natural fibre, timber)	life-fulfilling services	fibre	oxygen	raw materials	fibre, fuel other raw materials
water supply	energy (biomass fuels)	regulation of climate	fuel	water	water	biochemical products and medicinal resources
gas regulation	industrial products	pest control	genetic resources	energy	genetic resources	ornamental species and/or resources
waste treatment	pharmaceuticals	genetic resources	biochemicals, natural medicines	dispersal aids	medicinal resources	genetic materials
erosion control and sediment retention	genetic resources	maintenance and regeneration of habitat	ornamental resources	protection from predators	ornamental resources	water
pollination	genetic resources	provision of shade and shelter	freshwater	protection from disease and parasites	air quality regulation	air quality regulation
disturbance regulation	cycling and filtration processes	filtration and erosion control	air quality regulation	temperature	climate regulation	water regulation
climate regulation	translocation processes (dispersal of seeds, pollination)	maintenance of soil health	climate regulation	moisture	moderation of extreme events	waste treatment
biological control	regulation of hydrological cycle	regulation of river flows and groundwater levels	water regulation	chemical	waste treatment	erosion protection

nutrient cycling	river channel stability	waste absorption and breakdown	erosion regulation	spiritual and philosophical contentment	erosion prevention	pollination
soil formation	moderation of weather extremes		water purification and waste removal	benign social group	maintenance of soil fertility	natural hazard mitigation
refugia	partial stabilization of climate		disease regulation	recreation/leisure	pollination	climate regulation
recreation	control of pest species		pest regulation	meaningful occupation	biological control	biological regulation
cultural	aesthetic beauty		pollination	aesthetics	maintenance of life cycles of migratory species	soil formation and regeneration
	cultural, intellectual and spiritual inspiration		natural hazard regulation	opportunity values	maintenance of genetic diversity	genepol protection
	scientific discovery		cultural diversity		aesthetic information	nursery habitat
	serenity		spiritual and religious values		opportunities for recreation & tourism	recreation and tourism
	existence value		knowledge systems		inspiration for culture, art and design	cultural heritage and identity
	maintenance of the ecological components and systems needed for future supply		educational values		spiritual experience	aesthetic
			inspiration		information for cognitive development	inspiration for culture art and design
			aesthetic values			spiritual and religious inspiration
			social relations			education and science

CHAPTER 3: SPATIAL ASSESSMENT OF ECOSYSTEM GOODS AND SERVICES IN COMPLEX PRODUCTION LANDSCAPES: A CASE STUDY FROM SOUTH-EASTERN AUSTRALIA

This chapter has been published as follows:

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3.1. ABSTRACT

Many production landscapes are complex human-environment systems operating at various spatio-temporal scales and provide a variety of ecosystem goods and services (EGS) vital to human well-being. EGS change over space and time as a result of changing patterns of land use or changes in the composition and structure of different vegetation types. Spatio-temporal assessment of EGS can provide valuable information on the consequences of changing land use and land cover for EGS and helps to deal with this complexity. We carried out a quantitative and qualitative appraisal of selected EGS (timber production, carbon stock, provision of water, water regulation, biodiversity, and forage production) to understand how these have altered in a complex mosaic of landscape that has undergone significant change over the past 200 years.

Land use and land cover types and their associated EGS were assessed and mapped using a wide range of readily available data and tools. We also evaluated the trade-offs among services associated with observed land use change. In contrast to work elsewhere, we found the recent changes in land use and land cover have an overall positive impact on various EGS due mainly to the conversion of pasture to managed plantations which are connected to the larger areas of remnant vegetation. Results also indicate that there was a high level of variation in the distribution of the EGS across the landscape. Relatively intact native vegetation provide mainly regulating services whereas the modified landscapes provides provisioning services such as timber and forage production at the cost

of regulating services. Rapidly changing demand and supply of certain goods and services (e.g., timber, pulp or carbon) may also have positive and negative impact on other services. For example, increasing plantation rotation has positive impacts for biodiversity and carbon stock but reduces stream flow and water yield.

3.2. INTRODUCTION

In recent years, understanding the value of ecosystem goods and services (EGS), through their description and quantification, particularly in rapidly changing landscapes, has become widely recognised as important areas of study (Fisher et al., 2009). The Millennium Ecosystem Assessment (MEA) strongly linked ecosystem health with human welfare and identified that at the global scale 15 out of 24 recognised EGS are in a state of decline (MEA, 2005). The MEA looked at four possible future scenarios on how EGS (under four categories: provisioning, regulating, cultural and supporting services) might change in the future and their implications for human well-being (Burkhard et al., 2010; Carpenter et al., 2006; MEA, 2005). Elsewhere, other modelled scenarios consistently indicate that EGS will continue to decline in the 21st century with likely negative impacts on human welfare (Pereira et al., 2010). However, most such analyses have focused on intact natural vegetation and there has been less attention to the assessment of EGS in the more complex production landscapes that support dynamic mosaics of agriculture, pastures, managed plantations and native remnant vegetation.

If planned and managed appropriately, production landscapes can support not only the production of food and fibre but also a wide variety of non-market services such as biodiversity conservation, water regulation, and landscape amenity (Eigenbrod et al., 2009; Lovell and Johnston, 2009a, 2009b; Power, 2010; Verburg et al., 2009). Quantification, mapping and valuation of multiple EGS in production landscapes are therefore of considerable interest for environmental policy and land management as different configurations of landscapes and mixtures of production versus conservation may be more productive than others (Bennett and Balvanera, 2007; Cork et al., 2007; O'Farrell et al., 2010; Petrosillo et al., 2009). Assessment and mapping of EGS are considered essential prerequisites to subsequent quantification and valuation (Burkhard et al., 2010, 2012; de Groot et al., 2010; Kareiva et al., 2011). Importantly, spatially explicit assessment of EGS can be helpful in analysing trade-offs and synergies among EGS in a particular landscape (Naidoo et al., 2008; Nelson et al., 2009; Raudsepp-Hearne et al., 2010).

Production landscapes are characterised by complex inter-relations between biophysical, socio-economic, and culturally heterogeneous components that interact at several spatio-temporal scales (Cadenasso et al., 2006; Petrosillo et al., 2010). Moreover, they are subject to regular human intervention as well as natural disturbances (Bennett and Balvanera, 2007; Burkhard et al., 2012; Carpenter et al., 2006) and present different challenges to assessing EGS than intact natural systems.

Over the past 200 years large parts of the Australian landscapes have been intensively modified to provide food and fibre (Steffen et al., 2009). The effect of this modification and large-scale clearing has commonly resulted in the degradation of land and water resources (de Groot, 2006) which has affected other EGS such as biodiversity, water quality and gas regulation (Steffen et al., 2009). Victoria is the most extensively cleared Australian state and has also been subject to the longest history of human use (Beeton et al., 2006). Victoria comprises a rich variety of terrestrial ecosystems which result from a diversity of terrain, climate, geology and soil types (MacEwan et al., 2008). Over recent decades, land use practices have changed significantly and have been modified to suit this diversity of climate and soil. While the value of commodities produced from production landscapes has been recognised since the beginning of settled agriculture, it is becoming increasingly important to understand the wider uses and benefits that production landscapes provide society (Bennett et al., 2009; Dale and Polasky, 2007).

The value of EGS is determined by the beneficiaries of the particular EGS (Bennett et al., 2010; Fisher et al., 2009). These can vary from local land owners and communities to purchasers or users of EGS in other parts of a catchment, or in national or global markets. The nature of the benefit also varies. Those purchasing goods are generally receiving a private benefit resulting from their personal use of these goods. For services such as water regulation, carbon stock or biodiversity, there are shared or public benefits associated with the potentially wide access to these benefits from a range of different beneficiaries. Beneficiaries may also extend to future generations. In some cases there are market-based processes developing to facilitate investment in the provision of services such as increased carbon sequestration or improved water quality (DPI, 2005). The value that the local and global communities place on different types of EGS also changes over time (Costanza, 2008; Daily et al., 2009; Fisher et al., 2009). As more basic needs for subsistence are met, or as the knowledge of the importance of different services for longer-term survival increases, societies have begun to place more value on services such as water quality or carbon sequestration.

This study aimed to characterise EGS produced from various land use/cover types within a production landscape and to assess the change in supply of these over time as a result of land use change. We carried out a quantitative and qualitative appraisal for selected EGS (timber production, carbon stock, provision of water, water regulation, biodiversity, and forage production) and developed a quantitative framework to evaluate the effects of land use and land cover change in the past 200 years on these EGS. We chose a study area subject to a relatively high rate of change in land use and land cover, primarily in recent years through conversion of agricultural land to intensively-managed forest plantations. These changes can have both positive and negative impacts on different types of EGS at local and regional scales over time (Brockerhoff et al., 2008). This 'spatio-temporal dynamic' presents a further challenge in understanding and classifying EGS produced from complex landscapes (Cadenasso et al., 2006; Fisher et al., 2009).

3.3. METHODS

3.3.1. REVIEW – ASSESSMENT AND MAPPING OF EGS

Methodologies used for identifying, assessing and mapping EGS are diverse and often inconsistent. Similarly the spatial representation, objective of mapping, and number of EGS assessed and mapped varied widely. Some recent examples of EGS assessment and mapping are summarised in Table 3-1.

Assessing and mapping the distribution of multiple EGS is difficult due to lack of data (Naidoo et al., 2008; Seppelt et al., 2011) and two possible solutions identified from a number of recent studies are to either; (i) use expert opinion to rank the relative capacity of EGS (e.g. Burkhard et al., 2009, 2012; Nedkov and Burkhard, 2012; Vihervaara et al., 2010; Yapp et al., 2010) or (ii) estimate values using proxies (e.g., Luck et al., 2009; Turner et al., 2007). In this study, we assess and map six important EGS provided by a production landscape using a mixed approach (Fig. 1-1).

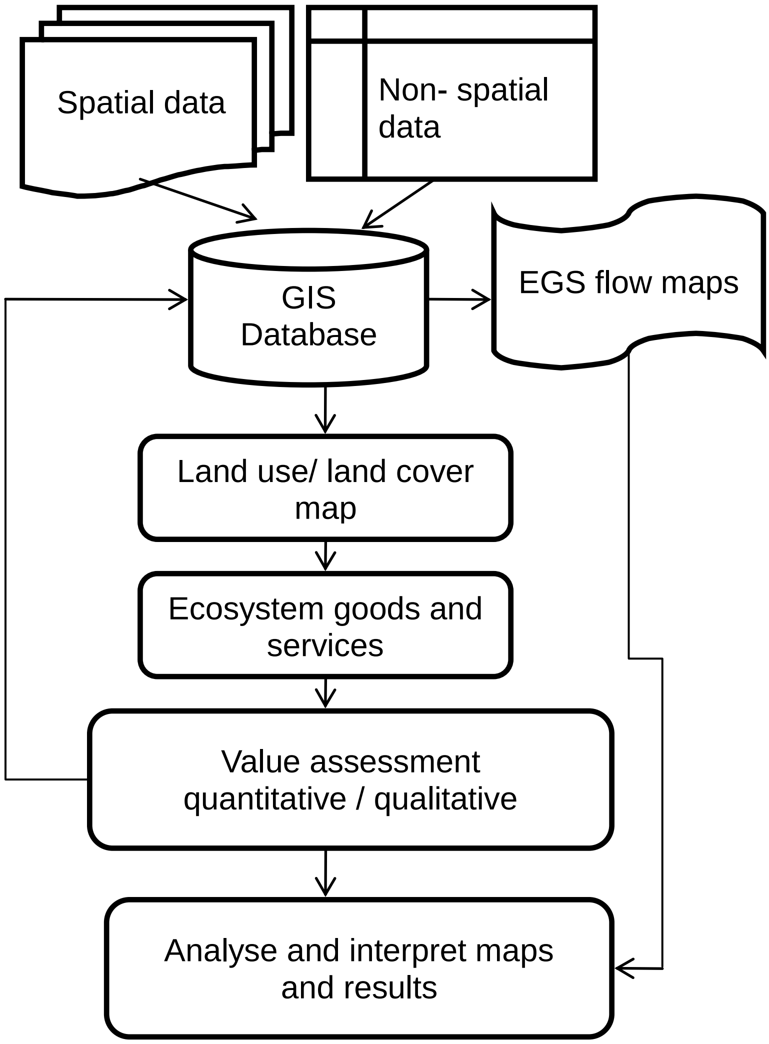

Figure 3-1. The methodological approach for spatial assessment and mapping of ecosystem goods and services employed in this study

Table 3-1. A summary of recent studies on assessment and mapping of ecosystem goods and services (EGS)

Location	Method and objectives	EGS assessed and mapped	Reference
Leipzig-Halle, Germany	easy-to-apply concept based on a matrix linking spatially explicit biophysical landscape to EGS for appropriate quantification and spatial visualisation of EGS	22 EGS based on MEA categories	Burkhard et al. (2012)
Central Coast ecoregion, California, USA	use of spatially explicit conservation planning framework to explore the trade-offs and opportunities for aligning conservation goal for biodiversity and EGS	carbon stock, flood control, forage production, outdoor recreation, crop pollination, water provision	Chan et al. (2006)
South Africa	use of statistical distribution of proxy indicators to quantify the amount an distribution of EGS across the landscape and spatial congruence	water supply, water flow regulation, soil accumulation, soil retention, carbon stock	Egoh et al. (2008)
Ewaso Ngiro Catchment, Kenya	mapping bundles of EGS at the land use scale for land use planning and management in data-poor regions	carbon, wildlife species, timber, livestock, crops, freshwater, flood regulation, cultural value	Erickson et al. (2012)
Global watersheds	spatial distribution of multiple ecosystem services for reconciling conservation and human development goals	water provision, flood mitigation, carbon storage, biodiversity priorities	Luck et al. (2009)
Willamette Basin, Oregon, USA	combination of land use and land cover classification with a suite of models to map EGS	water quality, soil conservation, storm peak management, carbon sequestration, biodiversity conservation, commodity production	Nelson et al. (2009)
Quebec, Canada	mapped spatial distribution of proxy indicators for selected EGS and identified bundles using spatial location	crops, pork, drinking water, maple syrup, deer hunting, nature appreciation, carbon sequestration, soil retention, soil organic matter	Raudsepp-Hearne et al. (2010)
Little Karoo Region, South Africa	use of land cover data as the basis for identifying EGS and mapped the overlap in provision of EGS	forage production, carbon stock, erosion control, tourism, water regulation	Reyers et al. (2009)
Finish Forest Lapland, Finland	effect of various land uses on provision of EGS using GIS techniques	27 EGS based on MEA categories	Vihervaara et al. (2010)

3.3.2. STUDY SITE

The study area was the 300 km^2 sub-catchment G8 of the Lower Glenelg Basin, in the Green Triangle region of south-western Victoria (8-198 m asl, 37º 50’ S, 141º 30’ E; Fig. 3-2). It was selected because of its concentration of commercially valuable hardwood *(Eucalyptus globulus*) and softwood (*Pinus radiata*) plantations (37% cover) within a mix of other land cover and land use types including native vegetation (44%) and pasture (17%). Most of the softwood plantations have been established since 1970s for sawlog production with a rotation of about 30 to 40 years. A large proportion of the softwood plantation (67%) is matured or semi-matured (>20 years) and remaining is either mid-rotation (16%; 5-20 years) or young (17%; <5 years). Hardwood plantations were established since 1990 and are nearly all *Eucalyptus globulus* grown for pulpwood on a rotation of 10 to 12 years. Similar to softwood, large proportion of hardwood plantations (70%) is matured or semi-matured (8-12 years), 28% is mid-rotation (4-8 years) and small proportion (2%) is young (<4 years). Other land uses such as residential development, roads and mining comprise a small proportion of the landscape and were not assessed in this study. The study area has a mean annual rainfall of approximately 700 mm and mean annual temperature of 8 ºC (min) to 19 ºC (max).

Since European settlement in the early 1850s, 50% (15,800 ha) of native vegetation in the study area has been cleared. The proportion of remnant native vegetation is slightly higher than for Victoria as a whole (46.2%) of the original extent (VEAC, 2010). Most remnant native vegetation is on public land, including State Forests or other protected areas. The majority of remaining native vegetation (classification follows DSE, 2011) and proportion of the area occupied within the study area are – heathy woodlands (27%), plain woodlands (19%), herb-rich woodlands (9%), lowland forests(4%), riparian or swampy scrubs (2%), heathlands (2%), riverine grassy woodlands (<1%) and wetlands (<1%). The vegetation types that had the largest areas cleared are mainly eucalypt woodlands, and eucalypt tall open forests. In contrast, large proportions of heathlands, riparian scrubs or swampy scrubs remain (Fig. 3-2).

According to the Victorian Department of Sustainability and Environment's (DSE) threatened flora and fauna databases, 15 species of threatened flora and 26 different species of threatened fauna are recorded for the study area, including 15 birds, five mammals, three amphibians and one reptile. Seven species are classified as endangered, 11 as vulnerable and nine species are classified as near threatened. Almost all threatened species are confined to the native vegetation except for one plant species (*Theymitra mucida*), three faunal species recorded in managed plantation, and four faunal species (two species of arboreal mammals and two species of waterbirds) recorded in pastures.

3.3.3. APPROACH

A general list of EGS applicable to the study area was derived based on those identified by Cork et al. (2007), Costanza (2008), de Groot et al. (2002, 2010), and MEA (2005), (Table 3-2). For this study we focused on selected EGS which are considered to be most important to this region but that are also of wider national and international significance – timber production, carbon stock, provision of water, water regulation, biodiversity, and forage production (Carpenter et al., 2009; Naidoo et al., 2008). Rationales and a brief description of each EGS are provided below with further details on quantitative and qualitative assessment criteria, beneficiary and associated spatial and temporal scales summarised in Table 3-2 (see also Appendix 3-1 for further details).

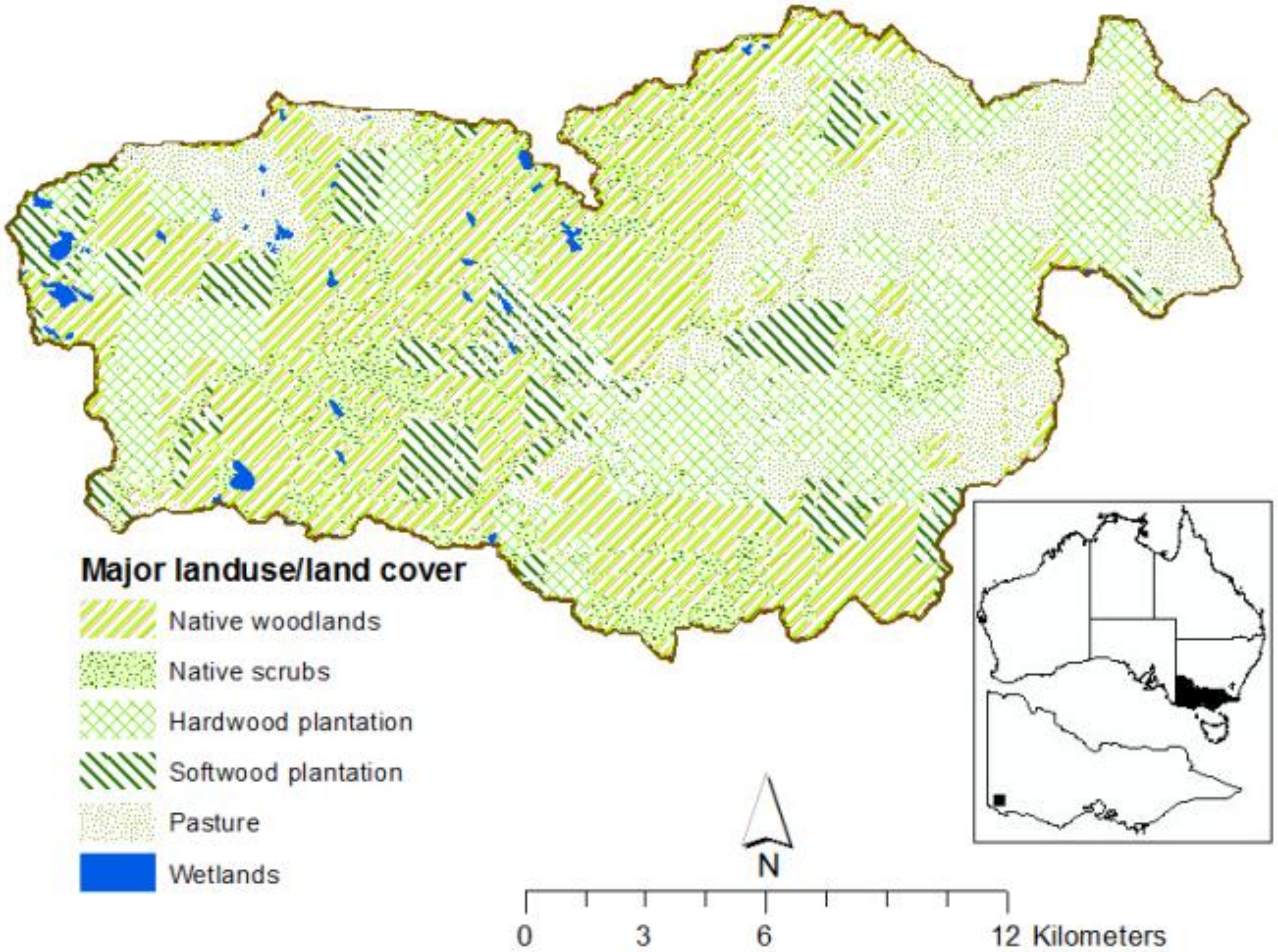

Figure 3-2. Location of the study area in Victoria, Australia with major land use and land cover types in Sub-catchment G8 of the Lower Glenelg Basin. Native woodlands comprise heathy woodlands, herb-rich woodlands and lowland forests with at least 15 large trees (dbh >60 cm) ha^{-1}. Native scrubs comprise riparian scrubs or swampy scrubs and heathlands up to 6 m tall. Wetlands are seasonal wetlands containing generally treeless vegetation dominated by sedges. Hardwood plantations are *Eucalyptus globulus* and softwood plantations are *Pinus radiata*. Pastures include both agriculture and pasture.

Table 3-2. Key ecosystem goods and services (EGS) identified for sub-catchment G8, Lower Glenelg basin. Letters in brackets represent MEA ecosystem service categories: provisioning (P), regulating (R), cultural (C) and supporting (S) services. Criteria range and codes for scale and time lag are adapted from Bennett et al. (2010): 'O' on-site (*in situ* delivery), 'L' local (off-site, 100 m – 10 km), 'R' regional (10-1000 km), 'G' global (>1000 km) and time lag 'I' immediate (<1 year), 'F' fast (1 year to ≤10 years), 'M' medium (11 to ≤30 years), 'S' slow (31 to ≤50 years), 'VS' very slow (>50 years). Only the selected EGS in bold are assessed and mapped in this study. 'DSE' Dry Sheep Equivalent which is equivalent to 0.125 Large Stock Unit (LSU)

EGS	Description	Beneficiary/use	Scale	Time lag	Unit of measurement
Timber production (P)	Provision of timber, pulp from managed plantations and native production forests	Private	O	M	m^3 or tons ha^{-1}
Carbon stock (R)	Stock of carbon in wood, other biomass and soil and keep CO_2 out of the atmosphere	Public/Private	O-R	F-VS	Mg ha^{-1}
Provision of Water (P)	Filtering, retention and storage of freshwater available for human consumption or industrial use	Public	O-R	F-VS	ML ha^{-1} yr^{-1}
Water regulation (R)	Role of land cover in regulating hydrological flows by vegetation	Public /Private	O-R	M-VS	m^3 ha^{-1}
Biodiversity (S)	Landscapes capacity to hold naturally functioning ecosystems support a diversity of plant and animal life	Public/Private	O-R	I-VS	
Forage production (P)	Production of forage for domestic livestock mainly from pasture and grazing land	Private	O	I-F	DSE ha^{-1*}
Carbon sequestration (R)	Capture atmospheric carbon dioxide in trees, shrubs and other vegetation	Public	O-G	F-VS	Mg ha^{-1} yr^{-1}
Nutrient regulation (R)	Internal cycling, processing and acquisition of nutrients by vegetation and microorganisms	Private	O-L	I-VS	kg ha^{-1} yr^{-1}
Pollination (R)	Pollination of wild plant species and harvested crops	Private/Public	O-R	I-S	Number of, or impact of pollinating species
Aesthetic beauty (C)	Attractive landscape features helps enjoyments of scenery	Private/Public	O-R	F-S	Presence of landscape features
Recreation (C)	Travel to natural ecosystems for eco-tourism, outdoor sport etc	Public	L-R	I-VS	N° of visitors yr^{-1}, \$ ha^{-1} yr^{-1}
Soil protection (S)	Promotes agricultural productivity and the integrity of natural ecosystems	Private/Public	O-R	F-VS	ha yr^{-1}

3.3.3.1. TIMBER PRODUCTION

Timber and other wood fibre are commercial products provided by forest plantations (Tallis et al., 2010) that generate a significant revenue and employment to this region (ABARES, 2011). The value of timber is realised at the time of commercial thinning or final clear fell but we used mean annual increment (MAI) as an estimate of capacity to supply timber or wood fibre for hardwood and softwood plantations. MAI was estimated using CABALA (Bhattaglia et al., 2004) and Farm Forestry Toolbox (FFT) (Version 5.0, Private Forests Tasmania, 2009) with associated data/parameter sets calibrated to the study region, and then classified this into three classes of timber production (see Table 3-3). For native woodlands we used the average increment for these forest types derived from the Victorian Forest Resource Inventory (Hamilton et al., 1999).

3.3.3.2. CARBON STOCK

Forest and grassland ecosystems store carbon in living vegetation, dead organic material and soils and are an important part of the global carbon cycle (Tallis et al., 2010). Conversion of woody vegetation to other forms of land cover results in carbon emissions to the atmosphere and increasing carbon stocks in woody vegetation can reduce net emissions and contribute to climate change mitigation objectives (DCC, 2008). Therefore carbon storage and sequestration are important ecosystem services in Australia and globally (Carpenter et al., 2009). Following a number of previous studies (e.g., Chan et al., 2006; Egoh et al., 2008, 2010; Reyers et al., 2009; Kareiva et al., 2011) this study mapped carbon storage a service because maintaining vegetation in a natural state provides a service to society. This has been recognised in recent legislation in Australia for the Carbon Farming Initiative and the Clean Energy Future package that provides the framework for a trading scheme to reduce greenhouse gas emissions (DCCEE, 2011a). In this study, carbon stock was estimated and mapped as Mg ha^{-1} for each land use/cover type. For managed plantations we used CABALA (Battaglia et al., 2004) and the Carbon Farming Initiative (CFI) reforestation tool (DCCEE, 2011b) using GIS data available from forestry companies. For native vegetation and pastures we derived proxy values from relevant studies (Grierson et al., 1992; IPCC, 2006; Norris et al., 2010; Paul et al., 2008, 2013).

3.3.3.3. PROVISION OF WATER

Provision of clean water is a vital service provided by healthy streams and landscapes in south-eastern Australia. However, estimating accurate water use by forest plantations and various vegetation types is a difficult undertaking. It is generally agreed that for a given rainfall, a forest uses more water than pasture and agricultural land (Keenan et al., 2006, Zhang et al., 1999, 2001). The deeper roots of trees give them greater access to water and also with the lower albedo and greater height and roughness, trees tend to absorb more energy than pastures and other land uses (Benyon et al., 2007; van Dijk and Keenan, 2007).

Woody vegetation can remove nutrient pollutants applied to agricultural systems from runoff and reduce salinity input to streams where salts are stored in the landscape. However, woody vegetation also uses a large proportion of rainfall compared to other land uses and reduce inflow to streams and rivers compared with other forms of land cover (Zhang et al., 1999, 2001). In this study we assessed only potential water supply as defined by de Groot et al. (2002) filtering, retention and storage of freshwater (e.g. in aquifers) in each land use and land cover type. Water yield from different forms of land cover was assessed based on the potential ground water recharge (mm yr^{-1}) for given rainfall conditions from the studies within this study area (Benyon et al., 2007, 2009). The estimated values (Table S3-1) were transferred to land use and land cover types into GIS environment and then assigned to three classes (see Table 3-3).

Table 3-3. Quantitative and qualitative assessment criteria for ecosystem EGS ranking.

EGS	Value classes	Description	Data source/Tools	Confidence level**
Timber production	High	High mean annual increment potential, >10 ha^{-1} yr^{-1}	CABALA (Battaglia et al., 2004), Farm Forestry Toolbox, existing data/reports	High
	Medium	Moderate mean annual increment, 2-10 ha^{-1} yr^{-1}		
	Low	Low mean annual increment, <2 ha^{-1} yr^{-1}		
Carbon stock	High	High carbon stock potential, >250 Mg ha^{-1}	CABALA (Battaglia et al., 2004), IPCC 2006; DCC 2008; URS Forestry 2008; CFI reforestation tool (DCCEE, 2011b), Grierson et al. (1992)	High
	Medium	Moderate carbon stock potential, 50–250 Mg ha^{-1}		
	Low	Low carbon stock potential, <50 Mg ha^{-1}		
Provision of water	High	Low level of water use and high recharge potential, >30 % of annual precipitation	Benyon et al.(2007), Zhang (1999, 2001)	Moderate
	Medium	Moderate water use and moderate recharge potential, 10-30% of annual precipitation		
	Low	High level of water use and low recharge potential, <10% of annual precipitation		
Water regulation	High	Potential high water regulation potential due to established vegetation	Land use and land cover maps; Zhang et al. (1999, 2001); Keenan et al. (2006)	Low
	Medium	Moderate level of vegetation cover and water regulation potential		
	Low	Low level of vegetation cover, e.g., agriculture/pasture		
Biodiversity*	High	Relatively intact areas of native vegetation with rare, threatened and endangered species and areas supporting vulnerable habitat type, score>10	Spatial analysis of GIS data mainly EVC layers from DSE (DSE, 2011) and plantation data, review of Threatened Fauna and Flora	Low
	Medium	Native vegetation with relatively smaller patch sizes, score 5-10		
	Low	Other areas with highly fragmented native vegetation, planted forest, and pastures, score <5		
Forage production	High	Area allocated for forage production, i.e., managed pastures, >10 DSE ha^{-1}	Saul et al.(2009, 2011), Blackwood et al.(2006)	Moderate
	Medium	Potential sites with medium forage production potential, 2–10 DSE ha^{-1}		
	Low	Native vegetation with potential to be grazed, e.g., native scrubs, <2 DSE ha^{-1}		

*Biodiversity score was calculated using Tables S3-2 and S3-3, Appendix 3-1, ** Confidence levels follow Reyers et al. (2009)

3.3.3.4. WATER REGULATION

Water regulation is an important ecosystem service provided by natural vegetation in the study area which provides the potential benefits of regulating runoff and flood mitigation to downstream water users. The important role of upstream vegetation cover in ensuring the delivery of high-quality water in downstream has been well recognised (Calder et al., 2007). However, due to lack of quantitative data, this service was assessed qualitatively by reviewing relevant literature to the study region (Brown et al., 2007; Keenan et al., 2006; Whirehead and Beadle, 2004; Zhang, 1999, 2001) into three classes – high, moderate and low capacity of each land use and land cover types (Table 3-3).

3.3.3.5. BIODIVERSITY

Biodiversity can be valued by society for its intrinsic worth or for its contribution to the provision of various additional EGS in the study area. Both natural and manmade ecosystems support certain levels of biodiversity and recently a number of methods and tools have been made available for biodiversity habitat condition assessment (Eyre et al., 2011; Parkes et al., 2003). Managed plantations can support a greater abundance of native fauna and flora than agricultural land but are not comparable to native vegetation (Brockerhoff et al., 2008; Felton et al., 2010; Kasel et al., 2008; Kavanagh et al., 2005, 2007; Loyn et al., 2007; Munro et al., 2009). However, establishing plantations on agricultural land may negatively affect species that prefer grasslands or open habitats, and the edges of woodland (Davies et al., 2001, Grimbacher, 2011; Law and Chidel, 2006). These studies support the notion that the biodiversity value for managed plantations can be higher or lower than agriculture depending on local context and the particular taxonomic unit under consideration. Therefore, in this study the heavily modified landscape such as pastures that are intensively used for grazing purpose and managed plantations for timber production were regarded as lower value for native flora and fauna relative to native vegetation.

To assess the potential biodiversity value we used the relative capacity of each land use/cover type to support habitat of flora and fauna based on the presence of threatened species, patch size (Rempel et al., 1999) and connectivity. Categories and associated scoring systems for patch size (Table S3-2) and connectivity (Table S3-3) were based on the vegetation condition assessment tool ‘Habitat Hectares’ that is widely used throughout Victoria (DSE 2004; Parkes et al., 2003) with similar systems used in other states within Australia (see Eyre et al., 2011; Gibbons et al., 2008). Scores for these components were summed and biodiversity assigned to three categories based on these scores (Table 3-3).

3.3.3.6. FORAGE PRODUCTION

Forage production is the production of forage for grazing rangeland livestock animals from pasture land which is an important economic land use and employer in the south-eastern Australia. In Australia, the Dry Sheep Equivalent (DSE) is a standard unit frequently used to assess the carrying capacity and potential productivity of a given farm or area of grazing land. This is usually estimated as the hectares of land required to maintain the body weight of a two year old 45 kg Merino sheep (DSE ha^{-1}) for each habitat type which is equivalent to 0.125 Large Stock Units (LSU). For this study we used estimated DSE ha^{-1} available from literature (Table S3-4) from the studies in this region and south-eastern Australia (Blackwood et al., 2006; Saul et al., 2009, 2011).

3.3.4. DATA

Key data sources used in the study included: (i) current land use based on Australian Land Use and Management (ALUM) classification (BRS, 2006), (ii) native vegetation/Ecological vegetation classes (EVC) (DSE, 2011), (iii) threatened flora and fauna, (iv) plantation data, (v) recent aerial photography (scale 1:10,000), (vi) climate data, and (vii) various topographical data such as roads, contours and watercourses. Further details on associated spatial layers, including spatial resolution is provided in Table S3-5. Data were accessed from a variety of sources including government agencies such as DSE, Glenelg Hopkins Catchment Management Authority (GHCMA), Bureau of Meteorology (BoM) and Geosciences Australia (GA) and also a number of private forest companies. These data were collated and analysed using a GIS (ESRI ArcGIS 10.0) as outlined in Fig. 3-1.

3.3.5. ANALYSIS

Several authors have assessed the relative capacity of land use/parcel as a service providing unit and ranked their potential to provide EGS (e.g. ‘low’, ‘medium’, ‘high’; or ‘poor’, ‘moderate’, ‘better’) based on expert opinion or interviews (Burkhard et al., 2009, 2012; Cork et al., 2007; Lovell et al., 2010; Vihervaara et al., 2010). Such approaches provide an understanding of the relative supply of different EGS from different land cover types at a given point in time (Burkhard et al., 2012; Busch et al., 2012). These types of rankings can be subjective and depend on the knowledge, experience and objectivity of the experts involved (Burkhard et al., 2012) and are often difficult to generalise for other landscapes. On the other hand, field assessment and estimation of all EGS can be very costly and time consuming (Grantham et al., 2008) especially for the study of multiple EGS (Wallace, 2007) which may delay conservation action (Grantham et al., 2009). We developed an alternative approach that used readily available information providing a good level of confidence for users and that could be repeated for other landscapes.

First, we estimated the range of absolute values for these landscapes using those tools (Table 3-3) and then classified these into three clearly defined categories (‘low’, ‘medium’, ‘high’; Table 3-4). The estimated quantity and associated value class information was transferred into GIS for spatial representation and mapping. The software tools and underpinning information were robust, widely used, supported by scientific knowledge and had been applied and tested in to the study region (Battaglia et al., 2004; Benyon et al., 2007, 2009; DCCEE 2011a, 2011b). For example we used the Carbon Farming Initiative (CFI) reforestation tool (DCCEE, 2011b) to estimate carbon stock. This tool allows users to define project areas and estimate emissions and removals from the proposed reforestation project using the FullCAM model (DCCEE, 2011b). Assessment criteria for selected EGS, ranking and associated confidence level are summarised in Table 3-3.

3.3.6. EGS HOTSPOTS

The areas in the landscape which provides a large component of particular service are classified as EGS hotspots (Egoh et al., 2008; Gimona and van der Horst, 2007). Here the areas with high relative capacity are delineated as EGS hotspots. The hotspots are further analysed by evaluating proportional overlap with one EGS to another (Reyers et al., 2009). Overlap analysis between multiple EGS was done in GIS environment by using the map calculator function (Table 3-5).

3.3.7. LAND USE AND LAND COVER CHANGE AND EFFECT ON EGS

To assess the impacts of land use and land cover changes we used three temporal reference points – (i) pre-European condition from modelled vegetation data: it was assumed that the study area remained with intact native vegetation until European settlement and vegetation modification in early 1850s, (ii) pre-1970s or conversion to pasture: the large proportion of native vegetation converted to pasture by this time and very limited or no plantation establishment or other afforestation activity, (iii) recent condition or post-1970s: in recent years large proportion of pasture and some native vegetation converted to managed forestry plantations. The effects of these land use and land cover changes on potential supply of EGS were assessed based on their relative capacity and represented using spider diagrams for the different time period. The changes in the demand and associated value of EGS over time was analysed qualitatively using historical population trend and changes in native vegetation in the study region, state and the country scale.

Table 3-4. Relative capacity of classified land cover/use types to produce selected ecosystem goods and services in the Sub-catchment G8, Lower Glenelg Basin. Assessment scale, N = no capacity L = low relative capacity, M = medium relative capacity, H = high relative capacity. See Table 3-3 for assessment ratings criteria which are based on analysis of available data using various tools, and published literature and are indicative.

Land cover types	Timber production	Carbon stock	Provision of Water	Water regulation	Biodiversity	Forage production
Native vegetation						
Native woodlands or forests	L	H	L	H	H	N
Native scrubs and heathlands	N	M	M	H	H	L
Wetlands	N	L	H	H	L	N
Softwood plantation (*Pinus radiata*)						
Matured/semi-matured (age >20 yrs)	H	H	N	M	L	N
Mid-rotation (age 5-20 yrs)	M	M	N	M	L	N
Young (age <5 yrs)	L	L	M	L	L	N
Hardwood plantation (*Eucalyptus globlus*)						
Matured/semi-matured (age >8 yrs)	H	M	N	M	L	N
Mid-rotation (age 4-8 yrs)	M	L	L	L	L	N
Young (age <4 yrs)	L	L	M	L	L	N
Pasture	N	L	H	L	L	H

3.4 RESULTS

3.4.1. SPATIAL DISTRIBUTION OF EGS

The spatial distribution of current EGS is heterogeneous across the landscape with little spatial overlap between different types of EGS (Fig. 3-3, Table 3-4). Mature plantations have the greatest carbon stocks, standing timber volume and potential for timber production. Relatively intact and healthy natural forest vegetation has both high carbon stocks and biodiversity.

EGS 'hotspots' are limited to a small proportion of the landscape (Table 3-5). Timber production has the lowest proportion of hotspots (6%) followed by forage production (18%). Water regulation and carbon stock have higher hotspots (Table 3-5). Moreover, there is a limited congruence between service hotspots – the lowest hotspots overlap was between timber production and carbon stock (6%). Carbon stock and water regulation share 35% of their service hotspots.

Table 3-5. Extent and proportional overlap of various ecosystems goods and services (EGS) hotspots

	Proportional overlap between EGS hotspots (% of study area)					
EGS	Carbon stock	Provision of water	Water regulation	Biodiversity	Forage production	Hot spot (% of study area)
Timber production	6					6
Carbon stock			35	34		41
Provision of water			34		18	21
Water regulation						48
Biodiversity			34			34
Forage production		18				18

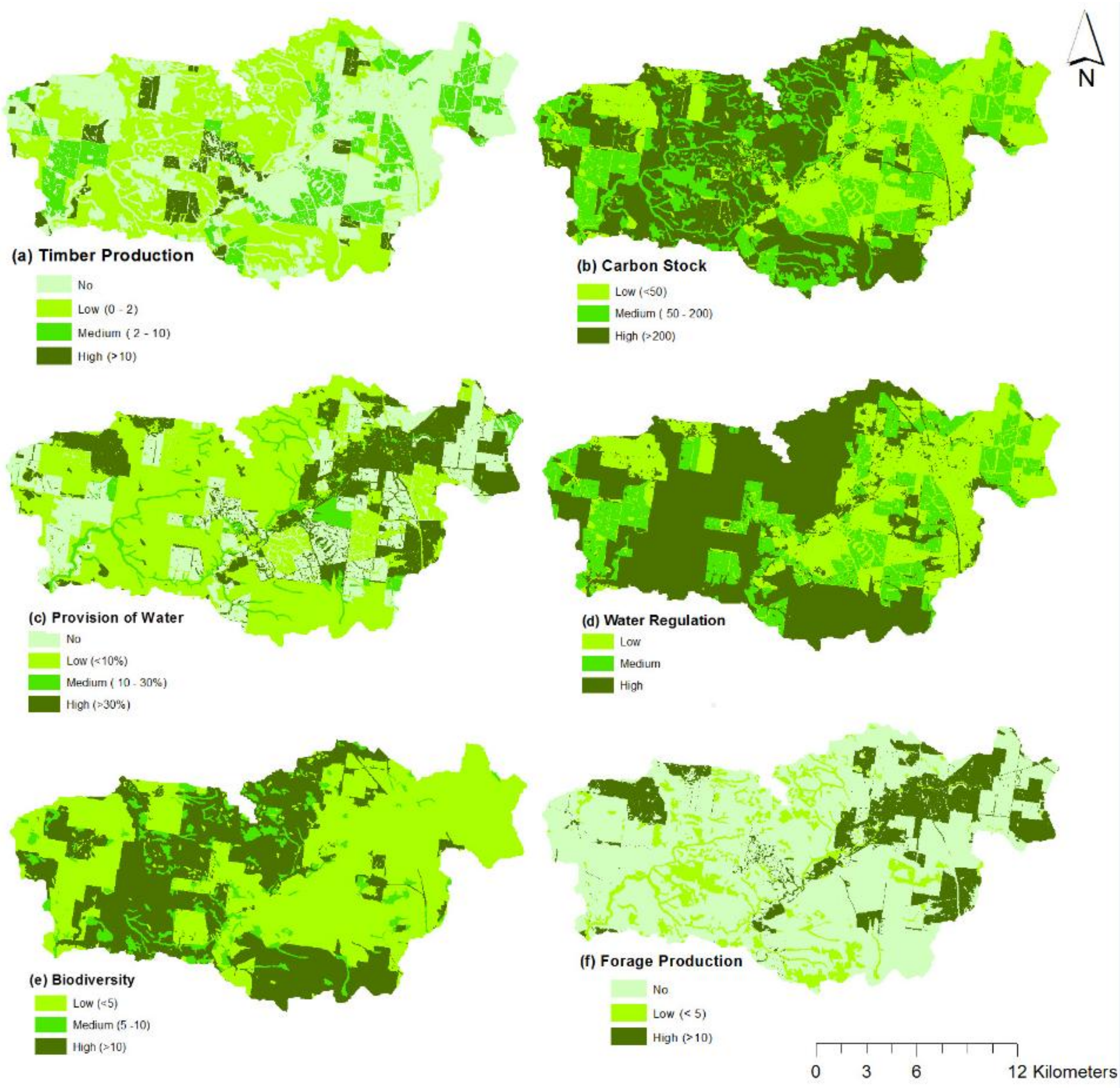

Figure 3-3. Spatial distribution of ecosystem goods and services in sub-catchment G8 of the lower Glenelg Basin: (a) timber production (MAI ha^{-1}), (b) carbon stock (Mg ha^{-1}), (c) provision of water , (d) water regulation (e) biodiversity, and (f) forage production (DSE ha^{-1}).

3.4.2. ASSESSMENT OF LAND USE AND LAND COVER CHANGES AND EGS FLOW

The major changes in land use and land cover between 1970s and 2006 were conversion of agriculture/pasture land to managed forest plantations and a small reduction of native vegetation. Over 6,800 ha (28% of sub-catchment) was converted to managed plantations. The majority (68%) of new plantations were established on pastures, 8% on sites with native vegetation (mainly grassland) and 1% were second rotation plantings. Previous land uses of some early established plantation (26%) were not recorded.

Spider diagrams (Fig. 3-4) show the change in the relative provision of EGS due to changes in land use and management practices. Total EGS from land with intact native vegetation was significantly reduced after conversion to pasture. In contrast, recent changes of pasture to managed plantation increased the provision of most of EGS. However, if we compare this with the pre-European condition there has been a significant loss in total provision of EGS. In contrast, the demand for most of the EGS has increased due to the number of user or beneficiaries of EGS since European settlement in Australia (Table 3-6).

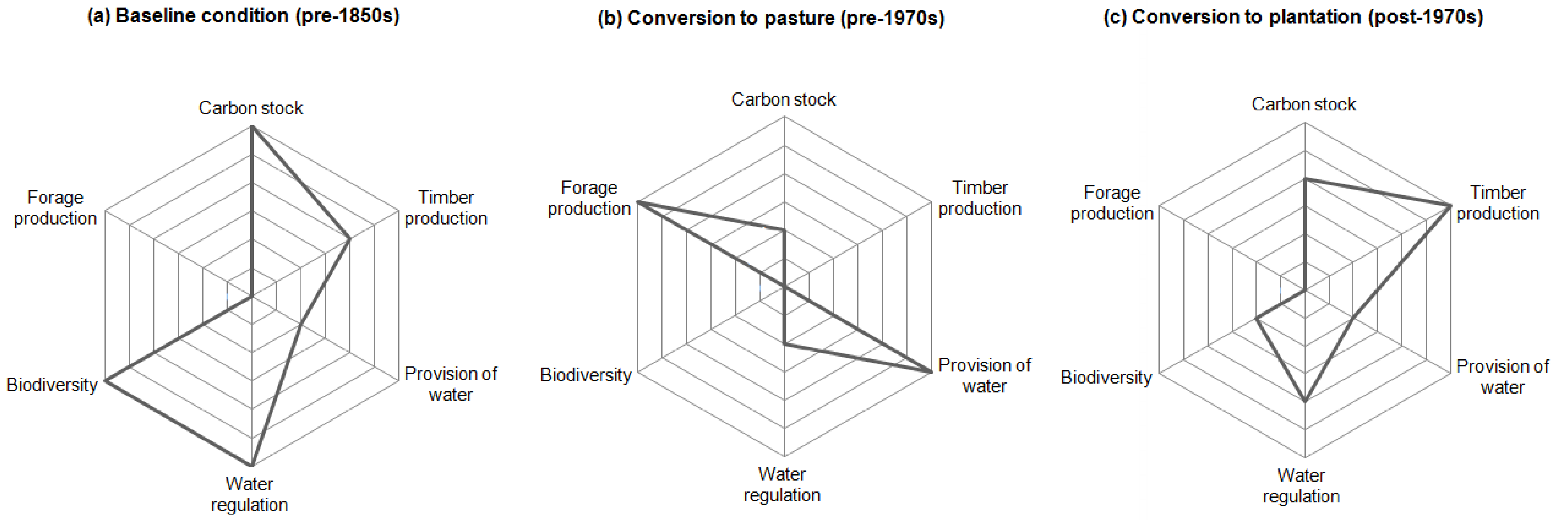

Figure 3-4. Changes in land use and impact on ecosystems goods and services in the study area: (a) baseline condition (pre-1850), (b) conversion of native vegetation to pasture (pre-1950s) and (c) conversion to managed plantations (post-1970s).

Table 3-6. Temporal change in the supply and demand in ecosystem goods and services (EGS) in the Lower Glenelg Basin. Time periods represents key shifts in management state within the study region. Management state: NV, Intact Native Vegetation; PA, Area under managed pasture for livestock production; PL, Forest plantation for timber or pulp. EGS supply provision refers to the capacity of the overall landscape to support specific bundle of EGS within a given time period and potential demand refers the number of EGS users and perceived value within a given time period: H, High; M, Moderate; L, Low and are indicative only. Table inspired by Burkhard et al. (2012) and Cohen-Shacham et al. (2011).

Time Period/Management State	Pre 1850s, NV		Pre 1970s, PA		Post 1970s, PL	
Demographics						
Proportion (NV:PA:PL)	100:0:0		50:46:2		44:17:37	
Population (Australia)	<400,000		~12,500,000		~22,000,000	
Population (Victoria)	~75,000		~3,500,000		5,500,000	
Population (Lower Glenelg Basin)	~1,000		~20,000		21,000	
Ecosystem Goods and Services	Supply	Demand	Supply	Demand	Supply	Demand
Carbon Stock	H	L	L	M	H	H
Timber Production	H	L	L	M	H	H
Provision of Water	M	L	H	M	L	H
Water Regulation	H	L	L	M	L	H
Biodiversity	H	L	L	M	L	H
Forage Production	L	L	H	H	L	H

3.5 DISCUSSION

Assessments of the contributions of different land uses in supplying EGS to human welfare have varying degrees of rigour and with varying assumptions and approaches (Cork and Shelton, 2000; Reyers et al., 2009). In most cases, EGS assessments have focussed on the magnitude and value of EGS delivered from natural ecosystems under current or past land management regimes (Lovell et al., 2010; Power, 2010).

Our study offered a relatively simple methodology for assessment and mapping of EGS in production landscape where GIS and other attribute data are readily available. In the Australian context for example, the Australian Government's Bureau of Agriculture and Resource Economics and Sciences regularly compile spatial data for the whole country (e.g. ALUM classification; BRS, 2006). If used as in this study, it can be provide a basis for assessing current supply and patterns of change in EGS for different spatial and temporal patterns of land use and land cover across the country.

Our appraisal and associated value maps are comparable to studies elsewhere (Burkhard et al., 2009, 2012; Cork et al., 2007; Lovell et al., 2010; Reyers et al., 2009; Vihervaara et al., 2010). They demonstrate that less modified landscapes and intact native vegetation have the capacity to supply a higher variety and overall greater level of the assessed EGS than highly modified ecosystems and landscapes. This is not surprising, since the goal in converting to modified systems is to focus energy and resources on the production of specific goods (MEA, 2005). This is true for conversion of native vegetation to pasture in this study. However, conversion of pasture to plantation enhanced most EGS while producing new ecosystem goods (such as timber). This can provide a greater diversity of industry and income sources at farm and regional scales. This changing pattern also indicates of how the beneficiaries value EGS and their change in demand over time from pasture to timber, carbon, and water more recently. The values of EGS are recognised by the beneficiaries and differ over time, space (Hein et al., 2006), and management state (Cohen-Shacham et al., 2011). A temporal change of

EGS due to different management regime in this study are comparable to work by Cohen-Shacham et al. (2011). In their study landscape in Israel, many EGS declined following drainage of wetlands while agricultural production was enhanced but the services further declined over time scales similar to this study.

Size, spatial configuration, rotations and management of plantation are also important in determining the provision of EGS such as biodiversity habitat. Larger plantations adjoining remnant native vegetation, or those managed on longer rotations, can enhance landscape connectivity for wildlife habitat or pollination (Archibald et al., 2011) while isolated patches of plantations generally are of limited biodiversity value (Brockerhoff et al., 2008; Cawsey and Freudenberger, 2008). Intensively managed, short rotation plantations also have limited biodiversity value, unless habitat features or native vegetation are specifically integrated into the layout and management of the plantation (Hartley, 2002; Loyn et al., 2007). In our study area, hardwood plantations are managed on short rotation for pulp production and the flow of EGS may vary according to rotation regimes and level of intensity. The carbon stock in the study area is comparable to previous studies (Grierson et al., 1992; Walsh et al., 2008) and the sites with the high carbon stock potential (>250 Mg ha^{-1}) are higher than the Victorian State-wide average (157 Mg ha^{-1}; Norris et al., 2010).

Elsewhere in the world natural systems are also being heavily modified because of the increased human demands for goods and yet modern societies now demand a wider diversity and productivity of EGS from these landscapes. This is an emerging challenge for natural resource managers (Raudsepp-Hearne et al., 2010). While there are some opportunities for synergies between EGS, trade-offs will be required as some EGS are enhanced at the expense of others (Bai et al., 2011; Gimona and van der Horst, 2007; MEA, 2005; Rodriguez et al., 2006). As we have shown, this is not only for production versus conservation services, but could also apply to trade-offs between carbon sequestration and water supply (Jackson et al., 2005).

The trade-offs between EGS provided by production landscapes, such as timber production and carbon sequestration (Seidl et al., 2007), timber and biodiversity (Holland et al., 1994; Kant, 2002) and biodiversity and carbon (Caparros and Jacquemont, 2003) are well documented. However, there are many objectives that need to be considered in forest management, with one possibly affecting some or all of the others. As a result, assessment of multiple EGS and trade-off analysis is important in resource planning and decision making processes (Bennett et al., 2009; Raudsepp-Hearne et al., 2010). For example, Seidl et al. (2007) assessed the trade-offs between timber production and carbon sequestration using three different management strategies and found that carbon sequestration is sensitive to forest management with the highest amount of carbon stored in unmanaged forests. Similarly, Holland et al. (1994) and Kant (2002) using either an optimization or goal programming model found that increased biological diversity can be attained only at significant costs in terms of forgone timber harvest and financial returns. Therefore, trade-offs are inevitable while managing multiple EGS (Bai et al., 2011; Chan et al., 2011; Polasky et al., 2011).

Trade-offs are managed either through regulation of different land uses or through the market place. This study did not deal with the economic valuation. However, identifying land use and EGS changes, representing them in graphical form and displaying in maps can help planners and managers understand the complexity and associated trade-offs and synergies among EGS and can provide a framework for applying economic analysis. The study had some limitations, for example the spatial and thematic resolutions of GIS data were relatively coarse and the uncertainty associated with estimates of EGS was not assessed. Many finer scale landscape features and qualities were not represented.

Understanding trade-offs, synergies and interaction among multiple EGS can help managers make better informed decisions (Bennett et al., 2009) and facilitate forest restoration goals in creating new landscape mosaics that balance conservation with production and promote ecological, social and economic resilience (Lamb, 2011; Maginnis and Jackson, 2007). We developed a simple methodology based on readily available data that can be used to assess the relative capacity of different parts of the landscape to supply EGS and to integrate this information at a landscape scale.

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Appendix 3-1

Description of ecosystem goods and services (EGS), and methodology used to assess and map selected EGS.

Timber production

Plantation GIS data made available from forestry companies were used to identify and map the areas for timber production. The Mean Annual Increment (MAI) was estimated using CABALA (Bhattallia et al., 2004) and Farm Forestry Toolbox (FFT) (Version 5.0, Private Forests Tasmania, 2009). The accuracy of growth and yield estimation from CABALA and FFT tools was not validated with actual growth and yield data due to the confidential nature of the inventory data. However the results were compared with recent publication such as Forest Resource Inventory and other regional proxy data (Bush et al., 1998; DSE, 2009). Declining access to native forests resulted continuous decline in timber production from native woodlands (URS, 2007). However, some of the native woodlands can also produce timber and in such cases the nationally available MAI information was used to assess relevant capacity for timber production. Mature plantations were assigned the highest value, while a low value was assigned to native woodlands. Mid-rotation plantations were assigned medium value and young plantations were assigned low value as the timber is only usable at the time of maturity.

Carbon stock

Carbon stock refers to the number of tons of carbon locked on a land parcel which largely depends on the sizes of four carbon 'pools': aboveground biomass, belowground biomass, soil, and dead organic matter (Tallis et al., 2010). Managing production landscapes for carbon stock requires information about how much and where carbon is stored, or lost over time, and how shifts in land use affect the amount of carbon stored over time.

In assessing and mapping this service we estimated the total carbon 'pool'. For managed plantations we used CABALA (Battaglia et al., 2004) using the plantation GIS data available from forestry companies and climatic data available from the Bureau of Meteorology. For native remnant vegetation we used carbon stock values from relevant studies in south-eastern Australia (Grierson et al., 1993; Norris et al., 2010). Results are also compared with the relevant studies from south-eastern Australia (Guo et al., 2008; Paul et al., 2008, 2013). For other land uses such as, agriculture and pasture we used readily available proxy values for such land use land cover type (IPCC, 2006).

Native woodlands and mature plantations were assigned higher carbon stock values based on higher predicted biomass per hectare. Similarly young plantation and native scrubs/grassland were assigned moderate values and agriculture and pastures are low relative carbon stock value. We are highly confident with regard to the carbon stock values of the managed hardwood and softwood plantations, with a lower certainty for the value assigned to native woodlands as they are sourced from other studies.

Forage production

In Australia, the Dry Sheep Equivalent (DSE) is a standard unit frequently used to compare the feed requirements of different classes of stock or to assess the carrying capacity and potential productivity of a given farm or area of grazing land. The rate of stocking in a pasture will depend partly on the quantity of forage produced and partly on the quality of forage available to the livestock to enable it to produce economically satisfactory results.

It was difficult to assess this service without the information regarding the actual area utilised for forage production, species, and quality and quantity of forage produced. However it was important to assess this service as a significant proportion of the landscape is under the category of pasture and this land use has mostly changed in the past four decades.

To assess and map this service we used average values of DSE per hectare (Table S3-4) used in Southern Australia (Saul et al., 2009, 2011; Blackwood et al., 2006). Relatively high value (> 10 DSE ha^{-1}) was assigned to managed pasture land and a low forage production value (<5 DSE ha^{-1}) to the native scrubs due the potential for grazing. All other land uses were assigned 0 values as they have no forage production potential.

Table S3-1. Average water use (mm $year^{-1}$) and potential ground water recharge (provided in brackets, mm $year^{-1}$) across the studied land-use/cover types in south-eastern Australia. Values are provided for three levels of rainfall and indicative only. Management options and site factors influences the magnitude (Source: Benyon et al., 2007).

	Mean annual rainfall (mm $year^{-1}$)		
Land use/cover-type	500	700	900
Forest generic average	480 (20)	640 (60)	780 (120)
Plantations (~30 year rotations) e.g. *Pinus radiata*	470 (30)	620 (80)	760 (140)
Plantations (~12 years rotations) e.g. *Eucalyptus globulus*	460 (40)	610 (90)	740 (160)
Grasslands, Crop/pasture	410 (90)	520 (180)	600 (300)

Table S3-2. Criteria and scores for the area of the native vegetation patch. Criteria follow 'Habitat Hectares', the vegetation condition index used widely within Victoria, Australia (see DSE, 2004; Parkes et al., 2003).

Category and description	value
< 2 ha	1
2-5 ha	2
5-10 ha	4
10-20 ha	6
>20 ha but 'significantly disturbed'*	8
>20 ha but 'not significantly disturbed'	10

* as defined in the Regional Forest Agreement Old Growth analyses (DSE, 2004)

Table S3-3. Criteria and scores relating to the distance to core area Criteria follow 'Habitat Hectares', the vegetation condition index used widely within Victoria, Australia (see DSE, 2004; Parkes et al., 2003). Core area is defined as an area >50 ha.

Distance	Core Area not significantly disturbed	Core Area significantly disturbed
>5 km	0	0
1-5 km	2	1
<1 km	4	3
contiguous	5	4

Table S3-4. Estimated carrying capacities for various pasture types in south-eastern Australia (source Blackwood et al., 2006; NSW-DPI, 2012; Saul et al., 2009, 2011)

Pasture types	Estimated range of DSE ha^{-1}
Low quality native pasture (without management)	0.5 – 2.0
Good quality native pasture (some management input)	1.5 – 3.0
Improved native pasture (seed and fertiliser applied)	2.0 – 5.0
Managed pasture (seed + fertiliser but not irrigated)	6.0 – 10.0
Managed irrigated pasture	10.0 – 16.0
Degraded pasture	0.25 – 0.5

DSE, Dry Sheep Equivalent

Table S3-5. Summary of the main GIS data layers used in the analysis.

Layer name	Description	Data type	Resolution	Data source
ALUM land use and land cover	The Australian Land Use and Management (ALUM) Classification system provides a nationally consistent method to collect and present land use information that provides valuable information about the reasons for change in the condition of natural resources and associated ecosystem goods and services.	Vector	N/A	Australian Bureau of Rural Sciences
Ecological vegetation classes (EVC)	EVCs are a type of native vegetation classification described through a combination of floristic, life forms and ecological characteristics, and through an inferred fidelity to particular environmental attributes.	Vector	N/A	Victorian Department of Sustainability and Environment
Plantation database	Plantation database provides various useful details regarding managed plantations, such as, year of planting, area, species types, previous land use which are utilised to classify age classes, patch size and landscape context.	Vector	N/A	Various forestry companies
Threatened Flora	Data layer contains only Threatened flora as defined in the DSE Threatened Flora Advisory List. This dataset is intended to be used for the determination of the distribution of threatened flora species.	Vector	N/A	Victorian Department of Sustainability and Environment
Threatened Fauna	Layer contains records of threatened species of wildlife from the Atlas of Victorian Wildlife.	Vector	N/A	Victorian Department of Sustainability and Environment
Aerial photographs	A high resolution and fully ortho-rectified aerial photographs of the study area used to differentiate/correct some land use and land cover types	Raster	1:10,000	Victorian Department of Sustainability and Environment
Climate data	Mean annual precipitation, temperature etc	Table	N/A	Australian Bureau of Meteorology

N/A – spatial resolution not applicable

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CHAPTER 4: GIS-BASED CLASSIFICATION, MAPPING AND VALUATION OF ECOSYSTEM SERVICES IN PRODUCTION LANDSCAPES

This chapter has been published in a peer-reviewed conference proceedings as follows:

Baral, H., Kasel, S., Keenan, R. J., Fox, J., Stork, N., 2009. GIS-based classification, mapping and valuation of ecosystem services in production landscapes: A case study of the Green Triangle region of south-eastern Australia. In: Thistlethwaite, R., Lamb, D., Haines, R. (Eds.), *Forestry: a Climate of Change*. Caloundra, pp. 64–71.

4.1. ABSTRACT

This paper presents a GIS-based approach for classification, mapping and valuation of selected ecosystem services using market and non-market valuation techniques. First, we identified and compiled a variety of spatial and non-spatial data and developed a land cover typology of the study area into a GIS environment. Second, we estimate the annual flow of economic value of each service using various economic valuation techniques. We found that the economic value of market ecosystem services such as timber and carbon was relatively straightforward. However the quantification and valuation of non-market services such as biodiversity was complicated. Finally, we produced an annual flow of total economic value of sub-catchment G8 of the Lower Glenelg Basin, south-eastern Australia using the spatial economic valuation technique. We expect that this work will highlight research avenues to advance the ecosystem services framework as an operational basis in plantation dominant production landscapes in Australia and elsewhere.

4.2. INTRODUCTION

Production landscapes provide a variety of benefits for human beings – such as food, fibre, flood protection, clean water, and clean air. The benefits human populations derive, directly or indirectly, from ecosystem functions are labelled as ecosystem services (Costanza et al. 1998). According to this definition the goods and services are derived from the ‘functions’ and are utilised by ‘people’. The goods and services produced by the ecosystem are not always complementary, because the production of certain goods and services often results in the depletion or degradation of other goods and services. For example, timber extraction can affect visual quality, water quality and recreation. However, with proper management, there is a potential to integrate a variety of goods and services in production landscapes. The nature and typology of ecosystem services has been extensively elaborated elsewhere (de Groot et al. 2002; Boyd & Banzhaf 2007; Fisher & Kerry 2008; Wallace 2008; Fisher et al. 2009).

The process of identifying, classifying, quantifying and mapping ecosystem services at the landscape level is increasingly recognised as an essential prerequisite for the efficient allocation of natural resources (Heal et al. 2005). Estimating the economic value of ecosystem services can play an important role in conservation planning and ecosystem-based management (Plummer 2009; Stenger et al. 2009). Conversely, a lack of economic valuation can potentially conceal the importance of such resources. However, economic valuation of ecosystem services requires up-to-date and reliable information and considerably better understanding of the landscapes that provide such services (Troy & Wilson 2006).

We present a framework for classifying and mapping ecosystem services for a production landscape and assess the value of both market and non-market goods and services in a Geographic Information System (GIS). This provides a baseline estimate of the ecosystem services value (ESV) of selected ecosystem services, such as timber, carbon, water regulation and biodiversity.

4.3. CLASSIFICATION MAPPING AND ECONOMIC VALUATION

4.3.1. GIS AS AN ECOSYSTEM SERVICES MAPPING TOOL

Ecosystem services are not homogenous across the landscape and their supply changes through time (Fisher et al. 2009). For this reason, ecosystem services are best expressed and most easily studied at particular spatial and temporal scales (MEA 2003). GIS provides land managers with a tool for quantifying and mapping the values of multiple ecosystem services across landscapes for improved resource planning and decision planning. Moreover, the valuation of ecosystem services, and understanding of how these resources interact, also provides an indication of trade offs and synergies. This paper will demonstrate how GIS can be used to analyse disparate data to generate spatially explicit results within a production landscape.

4.3.2. ECONOMIC VALUATION OF ECOSYSTEM SERVICES

The knowledge and recognition of the importance of ecosystem services in providing benefits to society, and as the basis for the sustainable functioning of natural systems, have grown in recent years. Despite their importance, ecosystem services are yet to be incorporated into decision making (Chan et al. 2006). Many of these goods and services are not valued on markets and there is a gap between market valuation and the economic value of many ecosystem services (Stenger et al. 2009).

Ecosystem goods and services can be divided into two broad categories: (i) the provision of direct market goods or services such as timber, pulp and carbon; and (ii) the provision of non-market goods or services, which include biodiversity and habitat for plant and animal life (Wilson & Hoehn 2006; Mertz et al. 2007). Economic valuation of the former is straightforward while the latter is more complicated and controversial (Wilson & Hoehn 2006; Stenger et al. 2009). However, resource managers and policy analysts involved in protecting and managing natural resources must make decisions which involve multiple trade-offs in allocating resources. These are mainly economic decisions and based either explicitly or implicitly on the value society places on services. To this end, economic valuation provides a useful tool for justifying set priorities and programs, policies, or actions that protect or restore ecosystem and associated services.

4.3.3. ECOSYSTEM VALUATION TECHNIQUES

Market price method: This method estimates the economic value of ecosystem goods or services that are bought and sold in commercial markets. This method can be used to value changes in either the quantity or quality of a good or service (Wilson & Hoehn 2006). In this study, this method was used to estimate the economic values of timber/pulp and carbon sequestration.

Non-market valuation methods: Values for many ecosystem goods and services are not readily captured in market transactions, and thus require non-market valuation methods, such as travel cost method, hedonic approach, and contingent valuation (Wilson & Hoehn 2006; Stenger et al. 2009).

4.3.4. ENVIRONMENTAL VALUE TRANSFER

Value transfer is an accepted economic methodology which obtains an estimate for the economic value of non-market goods or services through work conducted at another site or group of sites (Troy & Wilson 2006). The ‘transfer’ itself refers to the application of economic values and other information from the original ‘study site’ to a ‘policy site’. This technique was used in this study to estimate the economic value of biodiversity and associated services.

4.4. METHODOLOGY

4.4.1. STUDY AREA

The study location lies within the Green Triangle region of southern Australia, some 300 km west of Melbourne, Victoria, and covers approximately 305 km^2 (Fig. 4-1). The area is known as sub-catchment G8 of the Glenelg Hopkins Catchment. This area was selected because of its concentration of commercially valuable hardwood and softwood plantations where the focus is on production forestry with the provision of a variety of environmental services.

The area has a variable annual rainfall of approximately 800 mm and mean annual temperature of 8 ºC (min) to 19 ºC (max). The altitudinal gradient ranges from 8–198 m above sea level. The major land use in G8 is production forestry including both hardwood (*Eucalyptus globulus*) and softwood (*Pinus radiata*) plantations (Refer Fig. 4-3). There are also some large areas of uncleared crown land (reserved forest) and limited grazing of sheep and cattle. Few social networks and services are available in sub-catchment G8 with Digby the only township, with a population of about 50 people. Community based groups include Rifle Downs Landcare, Miakite-Grassdale Tree Group, and the Smokey River Land Management Group.

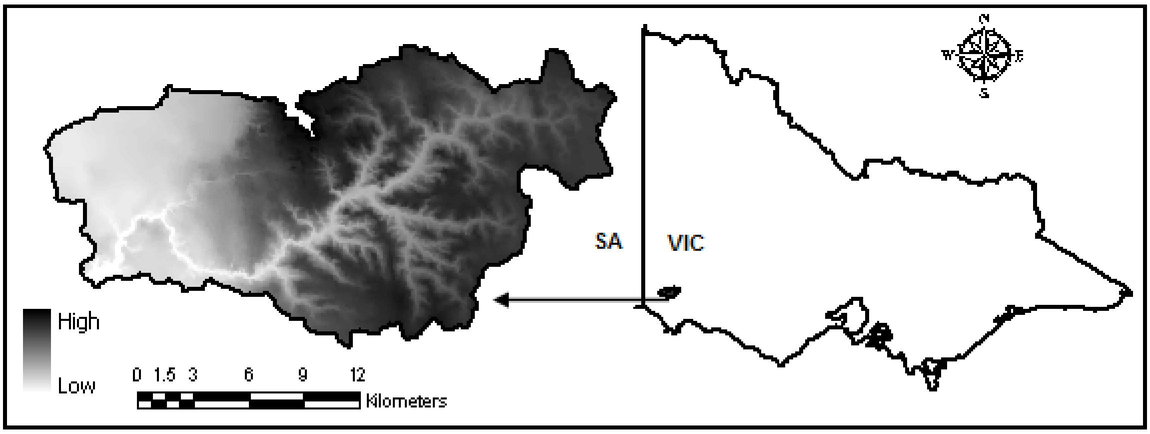

Figure 4-1. Location of the study area – sub-catchment G8, Lower Glenelg Basin within The Green Triangle region of south-eastern Australia. Shading represents areas of high to low relief according to a digital terrain model.

4.4.2. METHODS

The approach is based on a combination of market-based and non-market valuation techniques and has six key steps: (i) define the study area, identify the data requirement and compile data; (ii) develop land cover typology; (iii) select ecosystem services for economic valuation; (iv) map land cover and associated ecosystem services; (v) quantify goods and services and calculate economic value; and (vi) assign economic value in GIS and calculate total ecosystem service value (Fig. 4-2).

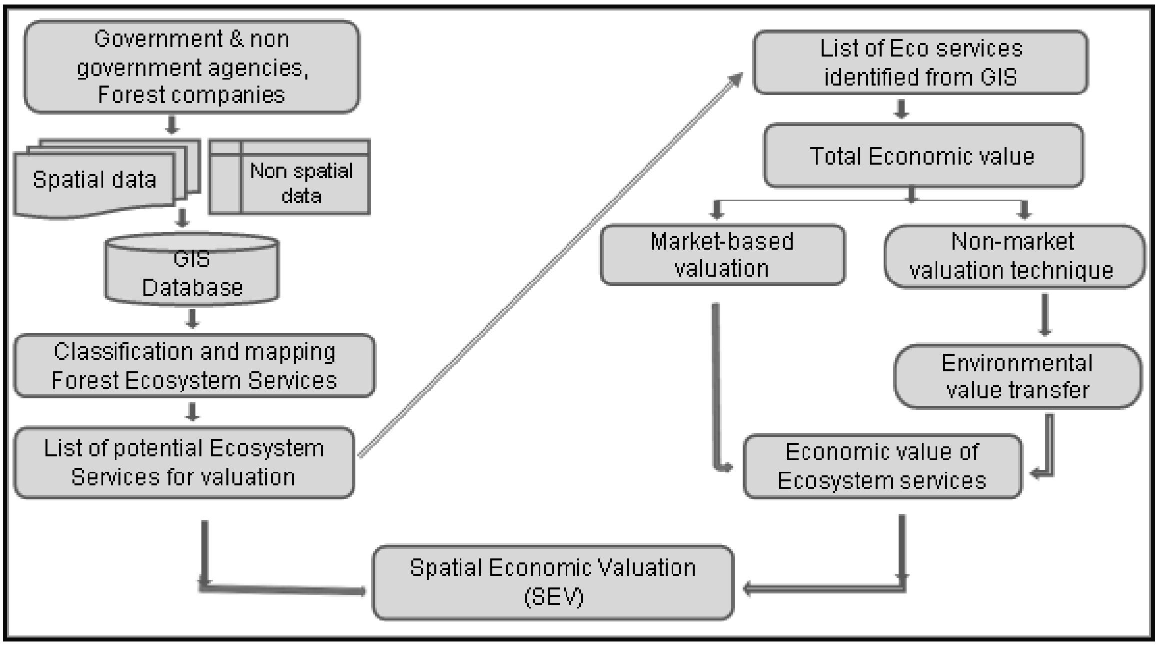

Figure 4-2. Conceptual framework for the method of classification, mapping and economic valuation of ecosystem services used in this study

The first step was to identify both spatial and attribute data requirements, and then compile the data from a variety of sources. Datasets included: (i) plantation GIS data, which includes location, plant year, species, previous land use; (ii) ecological vegetation class (EVC); (iii) location of threatened flora and fauna; (iv) a digital terrain model; and (v) topographic data such as contours, roads and watercourses. EVCs are systems of classifying native vegetation types based on differences in broad landscape features and environmental regimes (DNRE, 1997). EVC and plantation statistics provide an important overview of land cover types of the study area as vegetation is a highly visual component of the landscape and is an important part of timber resources as well as flora and fauna habitats. This study used the EVC dataset developed by the Victorian Department of Sustainability and Environment, and plantation GIS data available from the forestry companies represented in the study area (ITC, Timbercorp, Hancock Victorian Plantations, Wollybutt, Midway Afforestation, Great Southern Plantations, Green Triangle Plantation Forests, and Auspine).

The second step entails development of land cover typology for the study area and starts with a preliminary analysis of available GIS data and EVCs. Land cover types from EVC and plantation data present in the study area are listed, a range of ecosystem services produced from each land cover type are identified and possible means of quantification and economic valuation techniques are reviewed. Ecosystem services identified in step two are screened in the third step in order to determine which are most relevant to the planning and decision making, and to set priorities for further assessment and valuation. Given the limited time and resources, it was not possible to assess in detail all the ecosystem services and assign economic value.

In the fourth step, a land cover map is created using analysis tools in GIS which combine input layers from the diverse data sources to produce the final land cover map. Although significant variation within each land cover type may exist due to various factors, such as slope, aspect, and soil type, this level of detail was not measured in this preliminary study. Once each land cover type is finalised, then goods and services provided by each land cover type is quantified and economic value is assigned (Step 5). The economic value of ecosystem services was summed and cross-tabulated by each good and service and land cover type. Finally, a total spatial economic value map was produced (Step 6) by transferring ecosystem services value calculated in Step 5 using an ArcGIS 9.2 (from ESRI Inc.). The equation below illustrates the calculation of total ecosystem services value (ESV) in GIS environment (Troy and Wilson 2006).

$$V(ES_i) = \sum_{k=1}^{n} A(LU_i) \cdot V(ES_{ki}) \quad \ldots\ldots(i)$$

Where $A(LU_i)$ = area of land use/cover type (i), and $V(ES_{ki})$ = annual value per unit area of ecosystem service type (k) generated by each land cover type (i)

4.4.3. ECOSYSTEM SERVICES IDENTIFIED AND VALUATION FOR THIS STUDY

Although there are large numbers of ecosystem services produced by the sub-catchment G8 (timber or fibre, carbon sequestration and climate regulation, water regulation, biodiversity and associated services, erosion control, salinity mitigation, tourism, recreation and cultural value), this study only focused on four goods and services – timber, carbon, water, and biodiversity and associated services.

4.4.3.1 TIMBER

Plantation GIS data available from various forestry companies were used to identify and map the areas for timber production. Timber yield per hectare was calculated using a generic growth model (Fig. 4-4) available from Farm Forestry Toolbox (FFT) (Version 5.0, Private Forests Tasmania). Current timber value per unit area was estimated by multiplying the current stumpage price for hardwood and softwood logs and for pulpwood. Current market prices (2009 as a base year) were reviewed from Product Disclosure Statements (PDS) issued by various Managed Forestry Investment Scheme (MIS) forestry projects. The accuracy of growth and yield calculated from FFT was not validated with actual growth and yield data due to high level of confidentiality of inventory data.

4.4.3.2 CARBON

A generic Carbon Sequestration Predictor (Version 3.1, New South Wales Department of Primary Industries) was used to estimate average carbon sequestration per hectare per year. Plantation GIS data were used to classify sites and determine the area and age of plantation. The average market value of current CO_2 trading in Australian and international markets was used to calculate carbon value.

4.4.3.3. BIODIVERSITY

Classifying, measuring and valuing biodiversity was a challenging issue for a number of reasons – (i) it was complicated by the wide spectrum of biotic scales at which biodiversity operates, ranging from the molecular specific to the ecosystem level; (ii) even for a given level of diversity, e.g., presence of certain threatened flora or fauna, there is no well established and agreed means for defining, measuring and valuing biodiversity; and (iii) a number of different indicators have been proposed which neither provide consistent nor comparable results on which to base general interpretations (Bene & Doyen 2008).

As detailed mapping and valuation of biodiversity was not within the scope of this study, we were left with two alternatives – (i) transfer biodiversity values from other studies; or (ii) use an approximate dollar value employed by the Australian and various State government initiatives to conserve native vegetation on private land, such as ‘bush tender’ and ‘habitat hectare’ in Victoria, ‘biodiversity banking’ in New South Wales, ‘NatureAssist’ in Queensland, and ‘levy/biodiversity offset package’ in South Australia. The second option was used due to lack of comparable studies to transfer appropriate values for this site. The estimated value was transferred to each land cover type of native remnant vegetation.

4.4.3.4. WATER

Estimating accurate water use by plantations and various vegetation types is also a difficult issue. It is generally agreed that forest plantations use such a large quantity of water that downstream flow may be affected. Following harvest, water quantity increases but the quality may decrease where sediment discharge in the overland flow reaches stream channels. 3-PG, a simple, process-based forest growth model, developed by Landsberg and Waring (1997), was used estimate annual plantation water use per unit area. The average water harvesting charge per megalitre available from the Independent

Pricing and Regulatory Tribunal (IPART) NSW was used to estimate the cost of water utilised by forest plantations.

4.4.4. ESV TRANSFER

The ecosystem service value of selected ecosystem services, estimated by market and non-market valuation techniques, was transferred to the GIS and the total economic value of selected ecosystem services was calculated using equation (i) above.

4.5. RESULTS

The land-cover map of sub-catchment G8 is dominated by 'heathy woodlands' (27.4 percent) followed by 'plain woodlands' (19.3 percent). Hardwood and softwood plantations cover approximately 18 percent of the sub-catchment (Table 4-1 and Fig. 4-3).

Table 4-1. Land cover typologies (and proportion of area occupied) for sub-catchment G8, Lower Glenelg basin

• Heathy woodlands (27.4%)	• Lowland forests (3.9%)
• Plain woodlands (19.3%)	• Riparian or swampy scrubs (2.4%)
• Agriculture/pasture (18%)	• Heathlands (1.9%)
• *E. globulus* plantation (10.2%)	• Riverine grassy woodlands (0.5%)
• Herb-rich woodlands (8.8%)	• Wetlands (0.3%)

The values of the selected ecosystem services – timber, carbon, biodiversity and water – have distinctly different spatial distributions, although some areas are of high value for multiple services while others are low value (Fig. 4-5). For example, the preliminary assessment and economic valuation of these ecosystem services indicate plantations represent the highest economic value per unit area. This is mainly due to the relatively detailed valuation of consumptive services available from commercial plantation areas. The areas with higher timber yields also produce more carbon which further increases the economic value per unit area.

The value of native vegetation is relatively low due to our use of the conservation value based on various government initiatives to conserve native vegetation in private land. This does not reflect the true value of all native vegetation and the value of a number of other services such as erosion control and water regulation are not assessed in this study.

The land cover map (Fig. 4-3) was based on the most recent, updated plantation and native vegetation datasets. However, improved estimates for growth and yield, together with improved conservation values, will permit further refinement of our valuation of ecosystem services for sub-catchment G8.

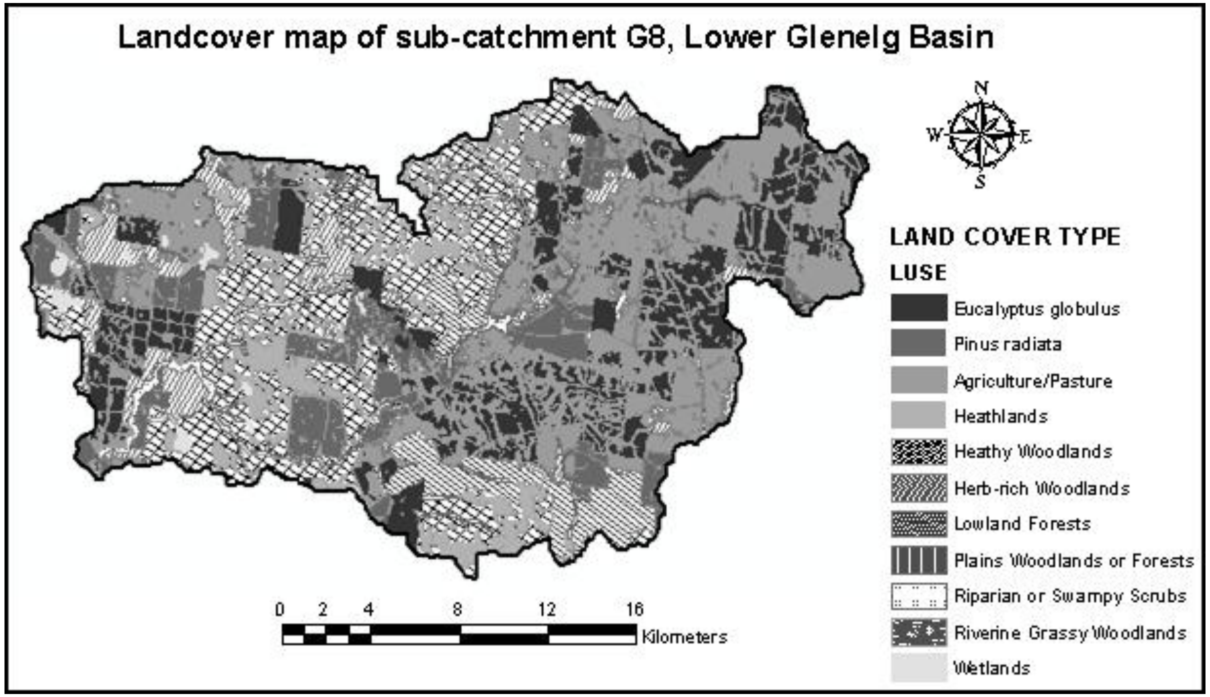

Figure 4-3. Land cover map of sub-catchment G8, Lower Glenelg Basin.

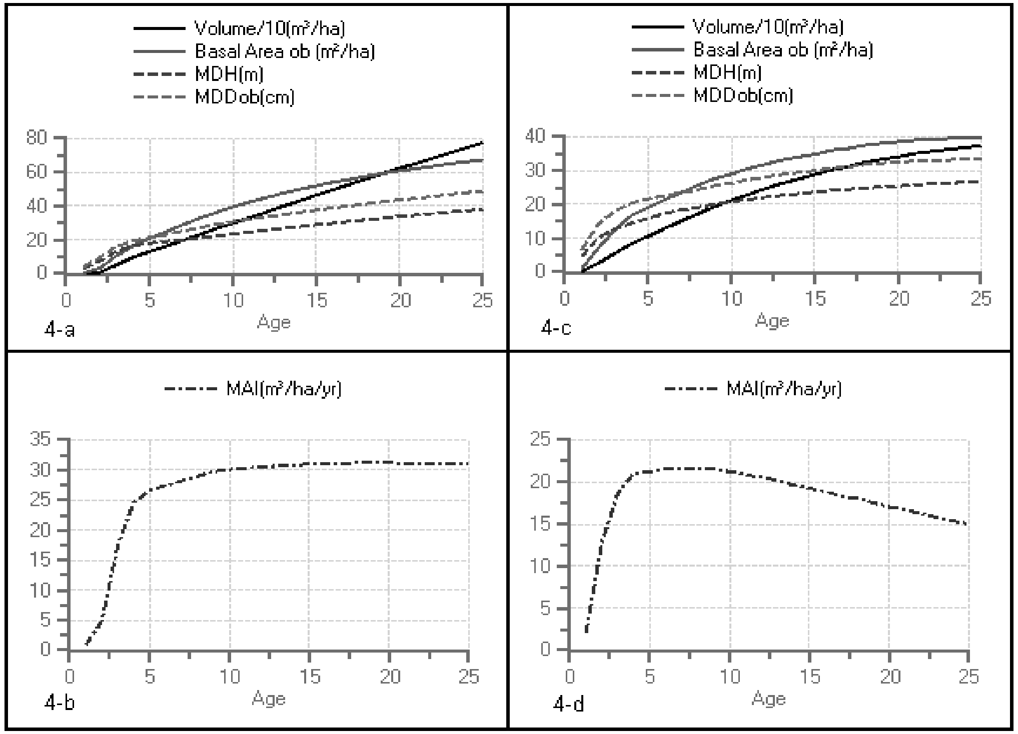

Figure 4-4. Site productivity (top) and mean annual increment (bottom) for *Pinus radiata* (4a, b) and *Eucalyptus globulus* (4c, d) used to estimate timber yield ha^{-1},(where, MDH = mean dominant height, MDDob = mean dominant diameter over bark and MAI = mean annual increment.)

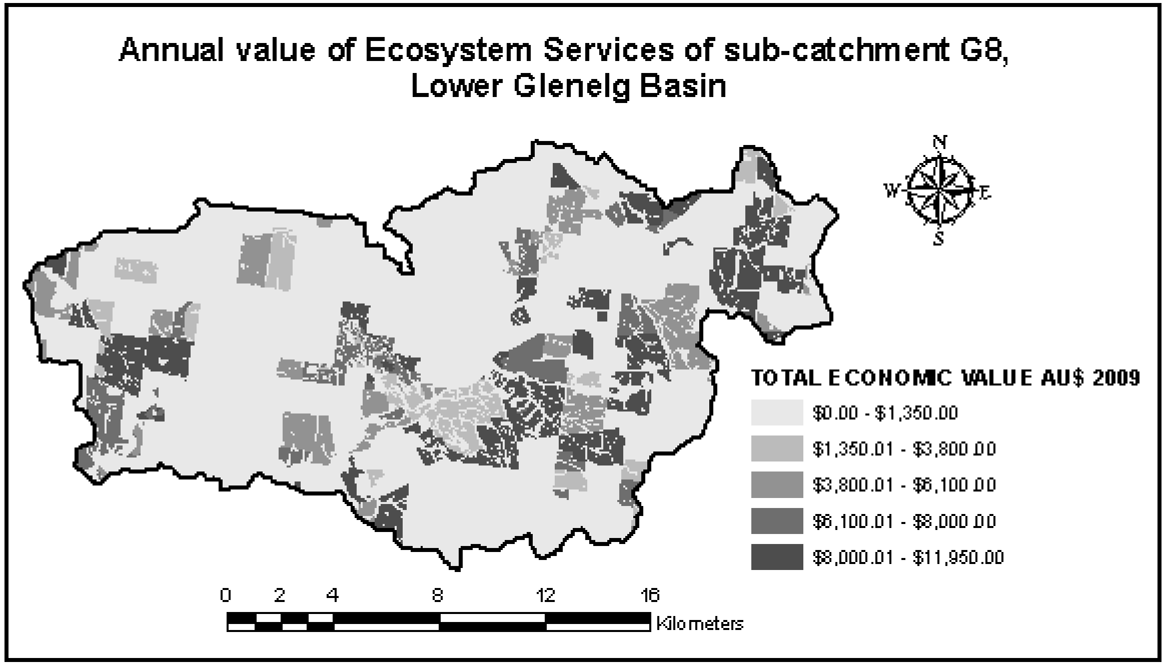

Figure 4-5. Sum of annual flow of selected Ecosystem services of sub-catchment G8, Lower Glenelg Basin. Total flow of ESV is generated using equation (i) the large light grey area indicates ESV less than \$1350 ha^{-1} yr^{-1} or no data available at this stage.

4.6. DISCUSSION

The quantification and valuation of timber and carbon were relatively straightforward due to readily available datasets. Similarly, the accuracy level is relatively high because prices are well-defined, and real data and accepted economic techniques were used. However, some issues, such as the true economic value of goods or services, may not be fully reflected in market transactions which are subject to market imperfections, seasonal variations and unforeseen impacts on markets.

Other services which are not readily bought and sold in the market place, such as biodiversity and water quantity and quality, are difficult to quantify and value. The complexity and uncertainty underlying the functioning of biodiversity contribute to the difficulty in assessing such services (Bene & Doyen 2008). Although it is difficult to put an accurate price tag on such services, it is important to estimate the value of these ecosystem services because of the growing environmental market.

While the current global financial downturn threatens markets for timber resources, eco-products are gaining in market popularity due to perceived environmental challenges, such as drought, declining supplies of drinking water, and loss of biodiversity (Metz et al. 2007). The economic valuation of ecosystem services provides better understanding of these forms of natural capital which is critical to our ability to plan and manage it over long term.

The critical underlying assumption of the value transfer approach is that the economic value of ecosystem goods or services at the study site can be inferred with sufficient accuracy from the analysis of existing valuation studies. Clearly, as the level of information increases within the source literature, the accuracy of the value transfer improves. For this reason we are currently compiling recent forest ecosystem valuation studies in Australia as most existing datasets are outdated.

We are also in the process of accessing CABALA (CArbon BALAnce), a more advanced model for predicting forest growth and carbon sequestration in plantations and managed forests developed by CSIRO, and anticipate that tree growth and carbon estimation will improve as a result.

4.7. CONCLUSIONS

This study presented a simple GIS-based process of classification, mapping and valuation of ecosystem goods and services at the landscape scale. Rather than a single methodological approach, this study used a number of tools to estimate ESV using market and non-market based valuation approaches in a spatially explicit manner. Although the study is still in its early stages and does not account for all non-market ecosystem services, it demonstrates an important contribution of such services at a landscape level. The approach and methodology can be used for more precise future mapping for all ecosystem goods and services, including agriculture, pasture and other forest goods and services.

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CHAPTER 5: SPATIAL ASSESSMENT AND MAPPING OF BIODIVERSITY AND CONSERVATION PRIORITIES IN A HEAVILY MODIFIED AND FRAGMENTED PRODUCTION LANDSCAPE IN NORTH-CENTRAL VICTORIA, AUSTRALIA

This chapter has been accepted for publication as follows:

Baral, H., Keenan, R.J., Sharma, S.K., Stork, N.E., Kasel, S., (accepted for publication 18 Sep. 2013). Spatial assessment and mapping of biodiversity and conservation priorities in a heavily modified and fragmented production landscape in north-central Victoria, Australia. *Ecological Indicators.*

5.1. ABSTRACT

Human impacts on the natural environment have resulted in a steady decline in biodiversity and associated ecosystem services. A major policy and management challenge is to efficiently allocate limited resources for nature conservation to maximize biodiversity benefits. Spatial assessment and mapping of biodiversity value plays a vital role in identifying key areas for conservation and establishing conservation priorities. This study measured biodiversity value using readily available data and tools in order to identify conservation priority sites in a heavily modified and fragmented production landscape. The study also assessed trade-offs among biodiversity and other ecosystem services. We used spatial tools for assessing and mapping biodiversity such as Patch Analyst in ArcGIS 10.2 to assess landscape alteration states, and the Integrated Valuation of Ecosystem Services and Trade-offs to identify habitat quality. Results indicated that areas of high biodiversity conservation value were concentrated in less modified land-cover types. Substantially modified land-cover types (generally associated with agriculture and irrigated pastures) had lower habitat quality and biodiversity value. The analysis revealed that assessments based solely on habitat condition may not be the most suitable basis for conservation planning because this does not include associated adjacent land uses, roads or other threats to biodiversity. Spatially targeted environmental plantings and less intensive agroforestry that reconnect native remnants in heavily fragmented landscapes can provide significant potential conservation outcomes. Planned landscape reconfiguration based on readily

available spatial data can yield net positive benefits to biodiversity by halting degradation of remnant native vegetation and increasing total habitat area.

5.2. INTRODUCTION

In recent years, the importance of biodiversity to global economies, human welfare and survival has been well documented and widely recognised (Butchart et al., 2010; Duffy, 2009; Rands et al., 2010; Steffen et al., 2009; TEEB, 2009). In Australia, biodiversity continues to decline in spite of Federal and state government efforts to manage threats (Bennett, 2003; DSE, 2010; NRMC, 2010; OECD, 2008; SoE, 2011; Steffen et al., 2009) with similar trends globally (Butchart et al., 2010; CBD, 2010; MEA, 2005; Steffen et al., 2009). Moreover, Australia has suffered the largest documented extinction of species of any continent over the last 200 years (DSEWPC, 2011). The main identified threats to biodiversity in Australia include loss, fragmentation and degradation of habitat or natural ecosystems, spread of invasive species, unsustainable use of natural resources, inappropriate fire regimes, and climate change (Bennett, 2003; NRMC, 2010; Steffen et al., 2009).

With significant expansion in production landscapes for agricultural activity around the world and a resultant ongoing decline of natural systems (FAO, 2005; World Bank, 2010), there is an increasing focus on the role of production landscapes in conserving biodiversity and providing a variety of ecosystem services (Bélair et al., 2010; Kandziora et al., 2013; Wilson et al., 2010). Securing biodiversity in the production landscape can enhance agricultural productivity through pollination and pest regulation, water quality and nutrient regulation, soil stabilisation, and carbon sequestration (Hopper et al., 2005; Kasel et al., 2011; Scherr and McNeely, 2008; Tscharntke et al., 2005). While there is ongoing debate about the relative merits of integrated versus partitioned conservation activity (Phalan et al., 2011; Tscharntke et al., 2012), conservation policy makers and land managers are giving strong support to conserving biodiversity in highly modified production landscapes (Wilson et al., 2010). Spatial assessment and mapping of conditions suitable for biodiversity conservation or restoration are also essential for the establishment of baseline biological data that will aid successful conservation planning and management in highly modified landscapes (Eigenbrod et al., 2009; Jones-Walters, 2008) and help identify priority sites for allocating limited resources (Brooks et al., 2006; Higgins, 2006).

Extent and quality of habitat conditions are often used as proxies of biodiversity (Nelson et al., 2011; Tallis et al., 2010) and remote sensing based techniques are being increasingly employed to generate biodiversity and ecosystem services indicators (García-Gómez and Maestre 2011; Lück-Vogel et al., 2013; Nagendra et al., 2013; Spanhove et al., 2012). Recent research has focused on linking current land use and vegetation types to biodiversity and associated ecosystem services (Burkhard et al., 2012; Falcucci et al., 2007; Foley et al., 2005; Hector and Bachi, 2007; Kandziora et al., 2013; Yapp et al., 2010). A variety of approaches have been used to identify conservation priority sites within production landscapes, each focused on a different aspect of biodiversity (e.g., Kandziora et al., 2013; Schneiders et al., 2012; Tallis et al., 2010) from global (Brooks et al., 2006; Jongman, 2013) to local scale (Higgins, 2006; Jongman, 2013). Given the imperative for expeditious implementation of conservation solutions (Watts and Handley, 2010), rapid assessment approaches that use readily available data and tools are highly desirable (Baral et al., 2013; Burkhard et al., 2012; Grantham et al., 2008, 2009).

The aim of this study is to spatially characterise a heavily modified and fragmented production landscape and assess biodiversity value using readily available data and tools in order to identify conservation priority sites. An additional aim is to assess the effect of land-use change on the provision of biodiversity and associated ecosystem services. To achieve these objectives we used spatial approaches and tools for biodiversity assessment and mapping such as Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) biodiversity models (Tallis et al., 2010) and patch analyst tool (Rempel et al., 1999, 2012). The resulting data and maps and subsequent analyses are used to consider the opportunities for re-configuring natural vegetation in cleared, modified and degraded landscapes to meet new sustainable landscape management objectives. Furthermore, we comment on the suitability of InVEST tools for habitat quality assessment and conservation planning.

5.3. METHODS

5.3.1. STUDY SITE

The study site is located in north-central Victoria, Australia between Kerang and Lake Boga, approximately 320 km north-west of Melbourne (35.972º S, 143.228º E, Fig. 5-1). The total area spans about 30,000 ha, essentially defined by the boundaries of the Little Murray and Lower Loddon Rivers in the North, West and South and the Murray Valley Highway in the West. Within the study area lies the Winlaton and Reedy Lakes Future Farming Landscapes (FFL) projects managed by Kilter Pty Ltd. The terrain is generally flat and low-lying (70-80 m above sea level) despite being a considerable distance from the coast. Mean annual rainfall of 50 years average is approximately 370 mm and mean annual temperature ranges from a minimum of 9 ºC to a maximum of 23 ºC.

Land and water use in the study area are dynamic. Irrigation water entitlements are being bought and sold, and there are ongoing changes in where and how farming takes place, and with people moving from rural properties to regional town centres (NCCMA, 2007). More recently, Kilter Pty Ltd (an asset management group servicing the superannuation sector), has been selecting land in north-central Victoria and managing it under Future Farming Landscapes (FFL), a long-term program that aims to restore landscapes to their most sustainable configurations. Through this program 25% or 7552 ha of the Reedy Lakes and Winlaton study area is currently being reconfigured and managed for both traditional and new income streams including agriculture, forestry, green energy, and water. This potential for future land-use change presented an ideal opportunity to assess the current status of biodiversity and associated ecosystem services provided by each land use-land cover type as a baseline for assessing the implications of future land management options.

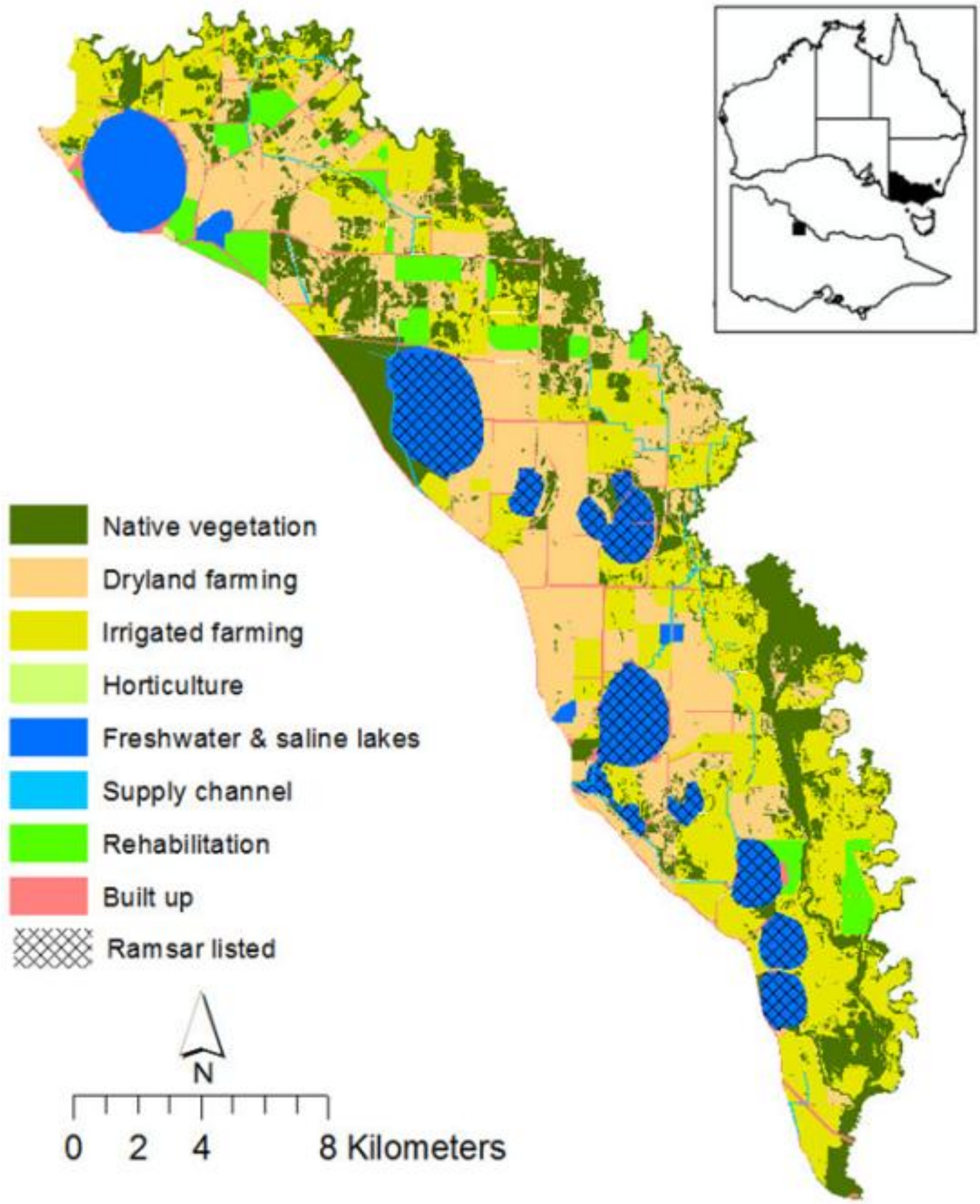

Figure 5-1. Location of the Reedy Lakes, Winlaton study area and major land use-land cover types in north central Victoria, Australia.

The area has been subject to extensive vegetation clearing for agriculture and pastoral production, with native vegetation now highly fragmented and often degraded (NCCMA, 2005). Since European settlement in the mid 1800s, an estimated 70% of native vegetation (18,300 ha) has been cleared. Associated effects of this clearing include widespread declines in biodiversity, increased soil and stream salinity and soil erosion (NCCMA, 2011). Each of these land management problems is of national importance (Steffen et al., 2009) and for this reason this study area is reflective of the challenges affecting many parts of the region. Major land use-land cover types and the proportion of the area occupied by each land use in Reedy Lakes and Winlaton include: (i) irrigated farming, 28%; (ii) dryland cropping, 26%; (iii) native vegetation, 23%; (iv) degraded land undergoing rehabilitation, 10%; (v) water, 10%; and (vi) other, 3%.

Reedy Lakes and Winlaton covers less than 0.2 % of Victoria's land mass; however, it supports a relatively large number of threatened flora (50 species, 2.5% of the total threatened flora for Victoria) and fauna (81 species, 45% of the total threatened species) (DSE, 2008a, b). The high levels of biodiversity, along with the pressures on it, have resulted in Reedy Lakes and Winlaton being identified as an important site for conservation by the Victorian Government (DSE, 2010). Wetlands within the study area support a high diversity and abundance of waterfowl species (Lugg et al., 1989) and some are of international significance, including the 'Kerang Wetlands Ramsar Site' (Fig. 5-1).

5.3.2. GIS DATA, SOFTWARE AND ANALYTICAL TOOLS

A number of datasets were compiled for the study site from a variety of sources and stored in Geographic Information System (GIS) database. Key datasets included: (i) a recent land use map based on the Australian Land Use and Management (ALUM) classification (BRS, 2006) (ii) native vegetation/Ecological Vegetation Classes (EVC) (DSE, 2011), (iii) threatened flora and fauna (DSE 2008a, b), (iv) Land Management Unit (LMU) data (Kilter Pty Ltd, 2011), (v) climate data, and (vi) topographical data such as roads, contours and watercourses. GIS raster datasets, with a land use-land cover code for each cell were produced by collating these datasets into ArcGIS 10.2 from ESRI Inc.

All datasets were projected into UTM54 South using a GDA1994 geographic coordinate system with the raster datasets additionally re-sampled to a common spatial resolution of a 50 m grid.

5.3.2.1. PATCH ANALYST TOOL

For this study, size and distribution of landscape patches were assessed for native vegetation including grasslands using the Patch Analyst extension for ArcGIS 10.2 (Rempel et al., 1999, 2012) and the output used to classify the landscape into alteration classes. The distribution of remnant native vegetation in Reedy Lakes and Winlaton was quantified using spatial metrics such as patch size and connectivity. Remnant native vegetation was categorised into three patch sizes based on area (Michaels et al. 2008): small patches (<10 ha), medium patches (10-50 ha) and large patches (>50 ha). We analysed core area (Rempel et al., 1999) with application of different buffers of 25 m, 50 m, and 100 m following Michaels et al. (2008) and evaluated the number of patches in each of three patch area categories relative to the initial patch analysis.

5.3.2.2. INVEST TOOL

The biodiversity model in InVEST tools generates two key sets of information useful in making an initial assessment of conservation needs: the relative extent and habitat quality in a region and its changes across time (Tallis et al., 2010). This tool assumes that large areas with a high habitat quality would support more flora and fauna species and individuals, and the areas that decrease in habitat extent and quality over time would contain reduced levels of biodiversity. More detailed description of input data for InVEST are outlined in Table 5-1 and a more detailed description of calculating a parcel’s habitat-quality and rarity score is outlined by Bai et al. (2011), Leh et al. (2013), Nelson et al. (2011), Polasky et al. (2011), and Tallis et al. (2010).

5.3.3. LAND COVER

For this study we used current land use-land cover types for the InVEST analysis (Tallis et al. 2010; Table 5-1) and a possible future land use based on proposed land use reconfiguration by the Future Farming Landscapes program to assess the impact of land-use change on biodiversity and various ecosystem services. The planned future land use reconfiguration covers 25% of the study area and includes: (i) irrigated cropping, 37%; (ii) biodiversity and environmental planting, 26%; (iii) grazing, 20%; (iv) perennial horticulture, 9%; and (v) agroforestry, 5%. A large number of native tree species are included under the environmental planting programme including Mallee Eucalypt (*Eucalyptus dumosa*), Black Box (*Eucalyptus largiflorens*), Red Gum (*Eucalyptus camaldulensis*) and a variety of *Acacia* species (Kilter Pty Ltd, 2011).

5.3.4. CONSERVATION PRIORITY SITES

Conservation priority sites were identified according to a number of criteria including: (i) extant vegetation types and their bioregional conservation status within the region, (ii) biodiversity goals and resource condition targets of the study region, and (iii) and relative abundance of threatened fauna and flora (Table S5-1).

Table 5-1. Input data for InVEST biodiversity model

Data	Description
Current LULC map	A GIS raster dataset with a numeric LULC code for each cell, 1 Native vegetation, 2 Agriculture, 3 Pasture, 4 Water bodies, 5 Built up areas.
Threat data and sources	A table of threats considered for this analysis e.g., agriculture, built up areas and sealed and unsealed roads and GIS raster file of the distribution and intensity of each threat. GIS shape files of polygons with data on the relative degree of proximity to potential threats (roads, built-up areas and agriculture) were used to assess the impact on biodiversity.
Accessibility to sources of degradation	A GIS polygon shape file containing data on the relative protection which provides barriers against threats. Formal conservation areas and protected lands were considered sites with minimum accessibility and were assigned a threat level of 0, while polygons with maximum accessibility (e.g. poorly enforced ownership, extractive reserves) were assigned 1. Polygons under intermediate levels of protection were assigned values between 0 and 1 (Polasky et al., 2011; Tallis et al., 2010;).
Sensitivity of habitat types to each threats	A table of LULC types whether or not they are considered habit and for LULC types that are habitat, their specific sensitivity to each threat. Sensitivity values range from 0 to 1 where 0 represents no sensitivity to a threat and 1 represents the greatest sensitivity (Polasky et al., 2011). Sensitivity scores are determined from the literature and expert knowledge (Bai et al., 2010; Polasky et al., 2011; Tallis et al., 2010).
Half-saturation constant	The numeric value indicating the half saturation constant. InVEST model uses a half-saturation curve is used to convert habitat degradation scores to habitat quality scores (Tallis et al., 2010). An inverse relationship between the degradation score and its habitat quality score is determined by this half-saturation constant. The half-saturation constant used was equal to the grid cell degradation score that returns a pixel habitat quality score of 0.5. That is, if the half-saturation constant is 10 then any pixel with a degradation score of 10 will have a habitat quality score of 0.5 (Tallis et al., 2010).

*LULC, Land use-land cover

5.3.5. LAND-USE CHANGES AND IMPACT ON BIODIVERSITY AND ASSOCIATED ECOSYSTEM SERVICES

Key ecosystem services associated with biodiversity in the study area are listed in Table 5-2 (DSE 2004, 2010; Parks Victoria, 2000; Steffen et al., 2009). A rapid qualitative assessment of ecosystem services provides an understanding of land use-land cover change and associated impacts on various ecosystem services. For this study we used peer reviewed papers, published reports and expert opinion for qualitative assessment and ranking (Baral et al., *in press,* Bullock et al., 2007, 2011; Cao et al., 2009; Dowson and Smith, 2007; de Groot and van der Meer, 2010; MEA, 2005; Ostle et al., 2009; Shelton et al., 2001;). In addition, feedback from other stakeholders and agencies has also been incorporated.

To assess the impacts of land use-land cover changes we used three temporal reference points – (i) pre-European condition from modelled historical vegetation data: it was assumed that the study area was intact native vegetation until European settlement and vegetation modification in the early 1850s, (ii) current or intensive agricultural focus: the large proportion of native vegetation converted to agriculture since the 1850s, and (iii) future farming landscape: proposed landscape reconfiguration through the FFL program.

Table 5-2. Key ecosystem services associated with biodiversity in the Reedy Lakes and Winlaton study area. Letters in brackets represent Millennium Ecosystem Assessment categories: provisioning (P), Regulating (R), Cultural (C) and Supporting (S) services.

Ecosystem services	Description
Forage production (P)	Production of forage for domestic livestock mainly from pasture and grazing land
Water supply (P)	Provision of water for consumptive use, includes both quality and quantity
Carbon stock (R)	Storage of carbon in wood, other biomass and soil
Carbon sequestration (R)	Capture atmospheric carbon dioxide in trees, shrubs and other vegetation
Water regulation (R)	Regulation of hydrological flows by vegetation and microorganisms
Salinity water disposal (R)	Storage of saline water
Flood control (R)	Control of floods
Nutrient regulation (R)	Internal cycling, processing and acquisition of nutrients by vegetation and microorganisms
Pollination (R)	Pollination of wild plant species and harvested crops
Aesthetic beauty (C)	Attractive landscape features helps enjoyments of scenery
Recreation (C)	Travel to natural ecosystems for eco-tourism, outdoor sport etc
Soil protection (S)	Promotes agricultural productivity and the integrity of natural ecosystems
Wildlife habitat (S)	Landscapes capacity to hold naturally functioning ecosystems support a diversity of plants and animal life

Table 5-3. Summary of native vegetation patch analysis in the Reedy Lakes and Winlaton study area.

Metric	Value
Patch Density and Size Metrics	
Number of Patches	4098
Mean Patch Size (ha)	1.8
Median Patch Size (ha)	0.06
Patch Size Coefficient of Variance	2036.4
Patch Size Standard deviation	35.6
Edge Metrics	
Total Edge (km)	1931
Edge Density	269.4
Mean Patch Edge (m)	471.2
Shape Metrics	
Mean Shape Index	1.4
Area Weighted Mean Shape Index	9.4
Mean Perimeter-Area Ratio	3008.2
Mean Patch Fractional Dimension	1.5
Area Weighted Mean Patch Fractal Dimension	1.4
Diversity and Interspersion Metrics	
Shannon’s Diversity Index	4.0
Shannon’s Evenness Index	0.5

5.4. RESULTS

5.4.1. SPATIAL CHARACTERISATION OF THE LANDSCAPE – PATCH ANALYST TOOL

Twenty two percent of the study area (6,800 ha) supported native vegetation. This vegetation was highly fragmented, in more than 4,000 irregularly shaped patches. Of these patches 98.5% were small sized patches (<10 ha), 1.2% were medium sized (10-50 ha) and only 0.3% were large sized (>50 ha). Although there was one large block of approximately 1,800 ha intact native vegetation (Fig. 5-2), the small sized patches of native vegetation dominated the landscape with mean patch size of 1.8 ha and median patch size of 0.06 ha. Small sized patches of native vegetation were distributed predominantly (82%) on privately owned land subject to agricultural and pastoral land uses. However, 40% of medium and larger patches were located on public land, often within conservation and habitat protection areas. Other metrics associated with native vegetation patch analysis such as, edge, shape and diversity and interspersion metrics are presented in Table 5-3.

The extent to which patches are at risk of depletion is dependent on the size of patches and the area of edge. This was assessed by measurement of various sized buffers (25 m, 50 m, and 100 m) around the patch. Increasing buffer size substantially decreased the number of patches of remnant vegetation. For example using a 25 m buffer reduced the number of vegetation patches by more than 50% (4,098 to 1,804) and a 100 m buffer, reduced the number of isolated patches by over 95%.

5.4.2. RELATIVE HABITAT QUALITY ACROSS THE LANDSCAPE – INVEST TOOL

The InVEST tool indicated that a very small proportion of the landscape currently provides high habitat quality and associated biodiversity values. Larger vegetation patches usually support greater habitat quality (Fig. 5-3), although this depended on surrounding land use-land cover and their associated threats. Two wildlife reserves and part of a large water body i.e., Lake Boga are classified as relatively high quality habitats. Interestingly the eastern study area boundary along the Little Murray River shows a higher habitat quality which is due to reduced intensity of threats and larger areas of extant native vegetation.

5.4.3. CONSERVATION PRIORITY SITES

Based on the North Central CMA's regional biodiversity goals and resource condition target and the bioregional conservation status of remnant native vegetation, the study area is classified into three categories of remnant native vegetation patches – high (44%), moderate (49%) and low (7%). The most cleared and underrepresented EVCs in the study bioregion, and therefore the high priority for conservation or restoration, are Plains Savannah, Plains Woodland, Chenopod Grassland and Semi-arid Chenopod Woodland. Moderate priority sites are represented by various EVCs such as, Lignum Swamp, Lignum Swampy Woodland, and Woorinen Mallee. Other EVCs such as Riverine Chenopod Woodland, Grassy Riverine Swamp and Lake Bed Herbland are reasonably well represented and classified under low priority sites. The sites with recorded threatened fauna and threatened flora are further classified as very high priority conservation sites (Fig. 5-4).

5.4.4. LAND-USE CHANGE AND IMPACT ON BIODIVERSITY AND OTHER ECOSYSTEM SERVICES

A qualitative assessment of past and future land-use changes and their impact on biodiversity and various ecosystem services (Fig. 5-5), indicates that prior to the 1850s the study area was covered with intact native vegetation that supported biodiversity and supplied a wide range of ecosystem services except agricultural commodities (Fig. 5-5a). After European settlement the majority of the landscape was cleared (over 70%), resulting in increased agriculture production at the expense of other ecosystem services (Fig. 5-5b). Under the FFL program the reconfigured landscape includes a combination of biodiversity, agriculture, and grazing (Fig. 5-5c). The main land-use changes from FFL's planned reconfiguration and associated impacts on a number of ecosystem services (Table 5-2) is summarised in Table 5-4 which indicates an overall positive impact on a number of ecosystem services for environmental planting, agroforestry and extensive grazing. However, there is strong trade-off between forage and food production in the case of conversion to agriculture.

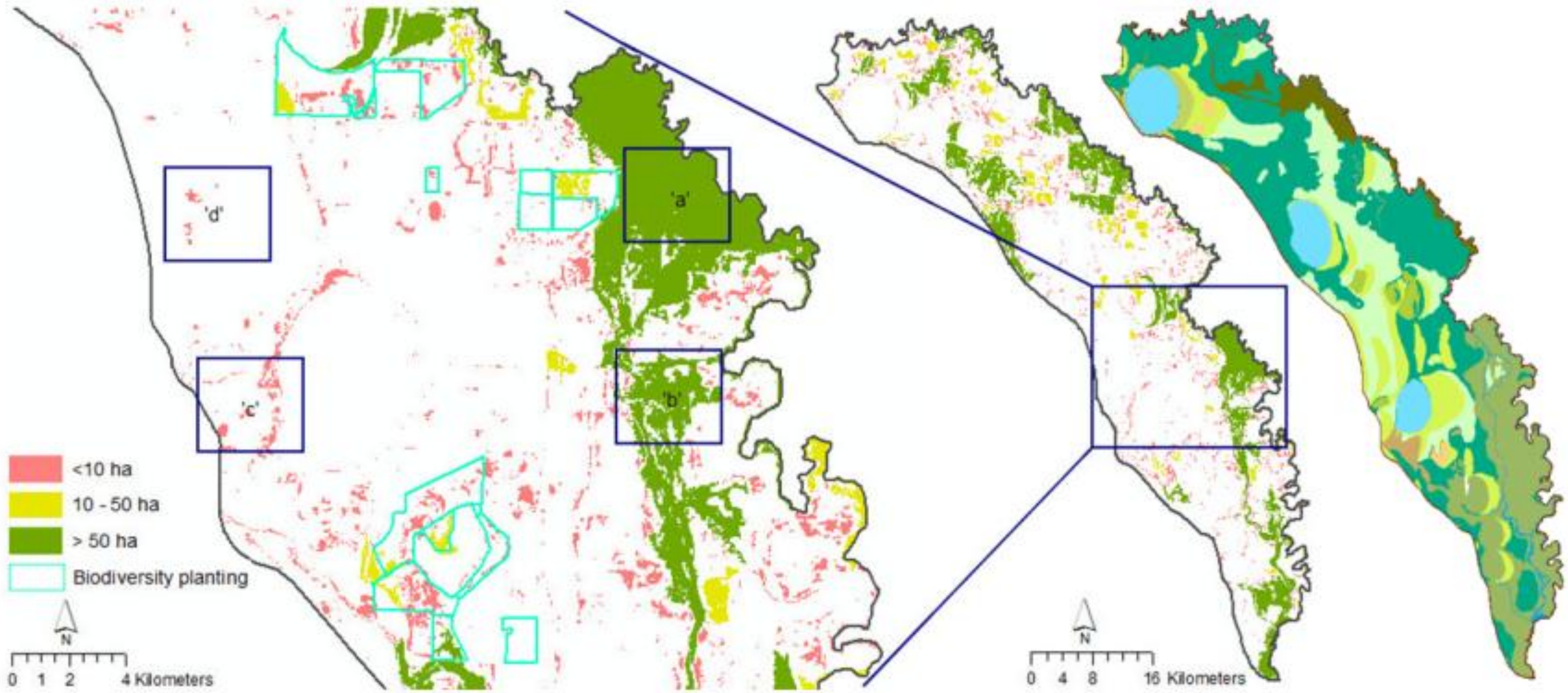

Figure 5-2**.** Distribution of native vegetation patches in Reedy Lakes and Winlaton according to patch size. Areas currently being converted to biodiversity planting as a part of Future Farming Landscapes are highlighted as are examples of landscape alteration states states (a1) intact, (a2) variegated, (a3) fragmented, and (a4) relictual (after McIntyre and Hobbs, 1999), (b) extant native vegetation, (c) pre-European (1750) vegetation distribution (colours represent simplified native vegetation groups, see Table S5-2).

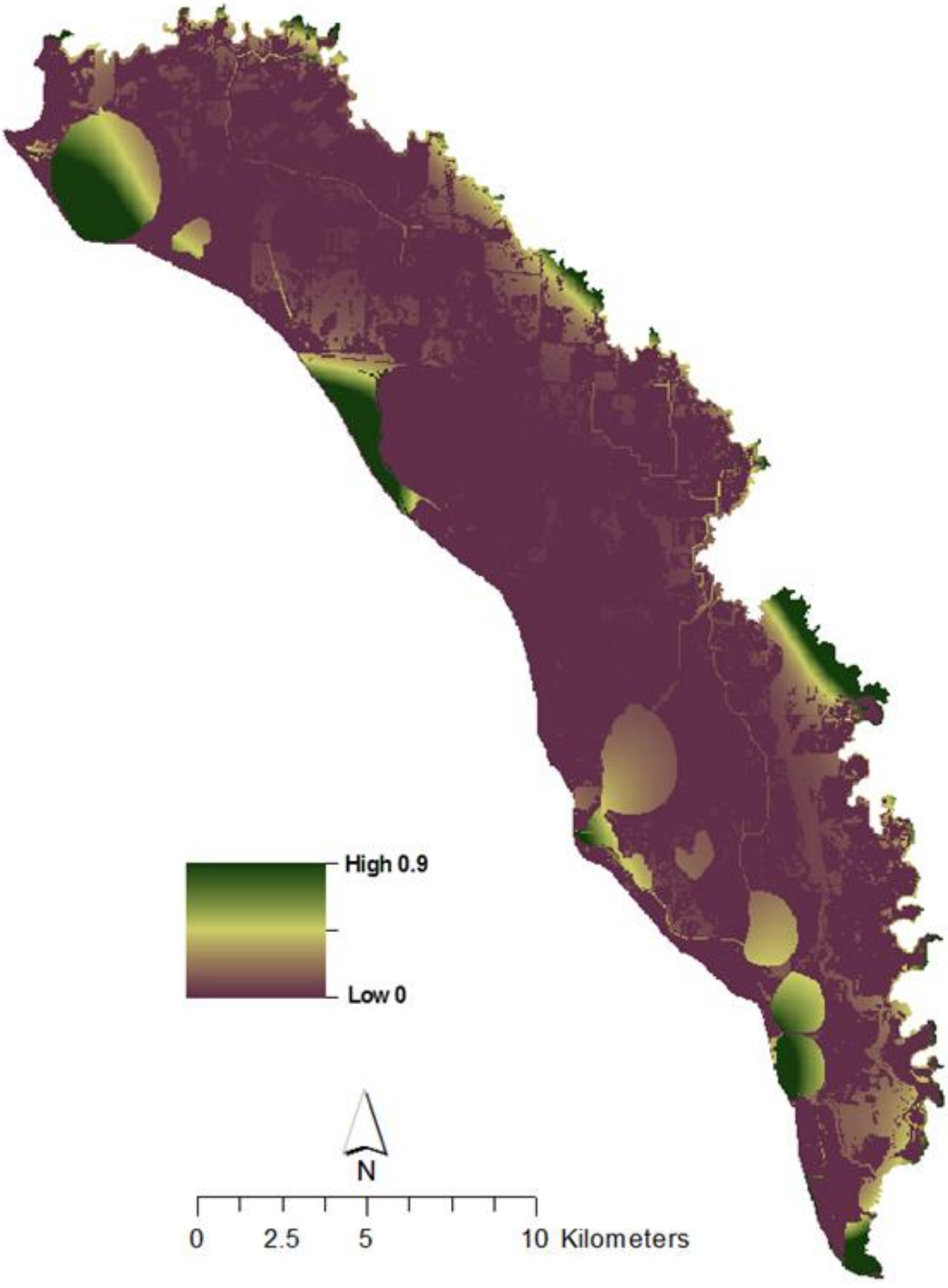

Figure 5-3. The InVEST model of relative habitat quality.

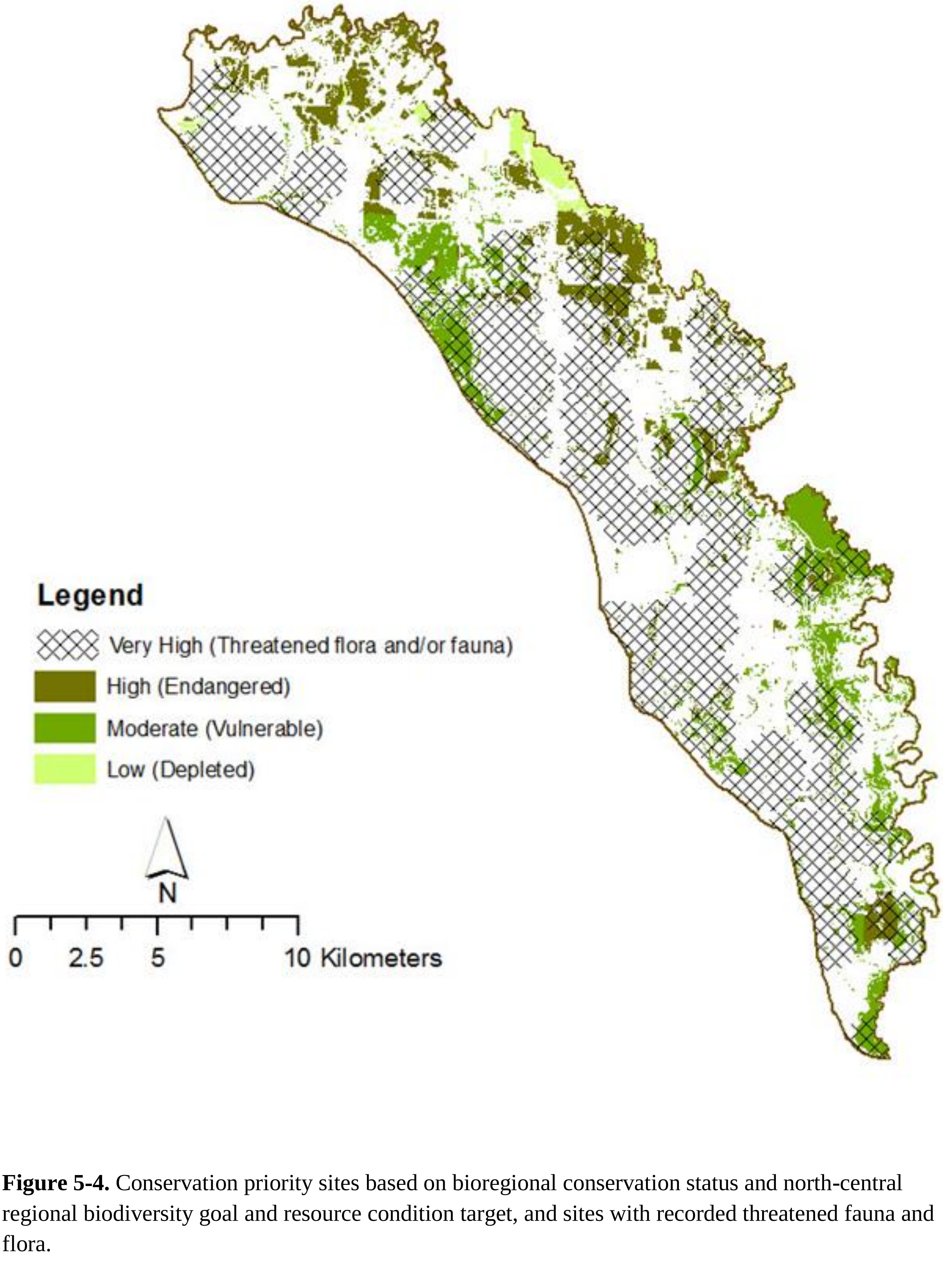

Figure 5-4. Conservation priority sites based on bioregional conservation status and north-central regional biodiversity goal and resource condition target, and sites with recorded threatened fauna and flora.

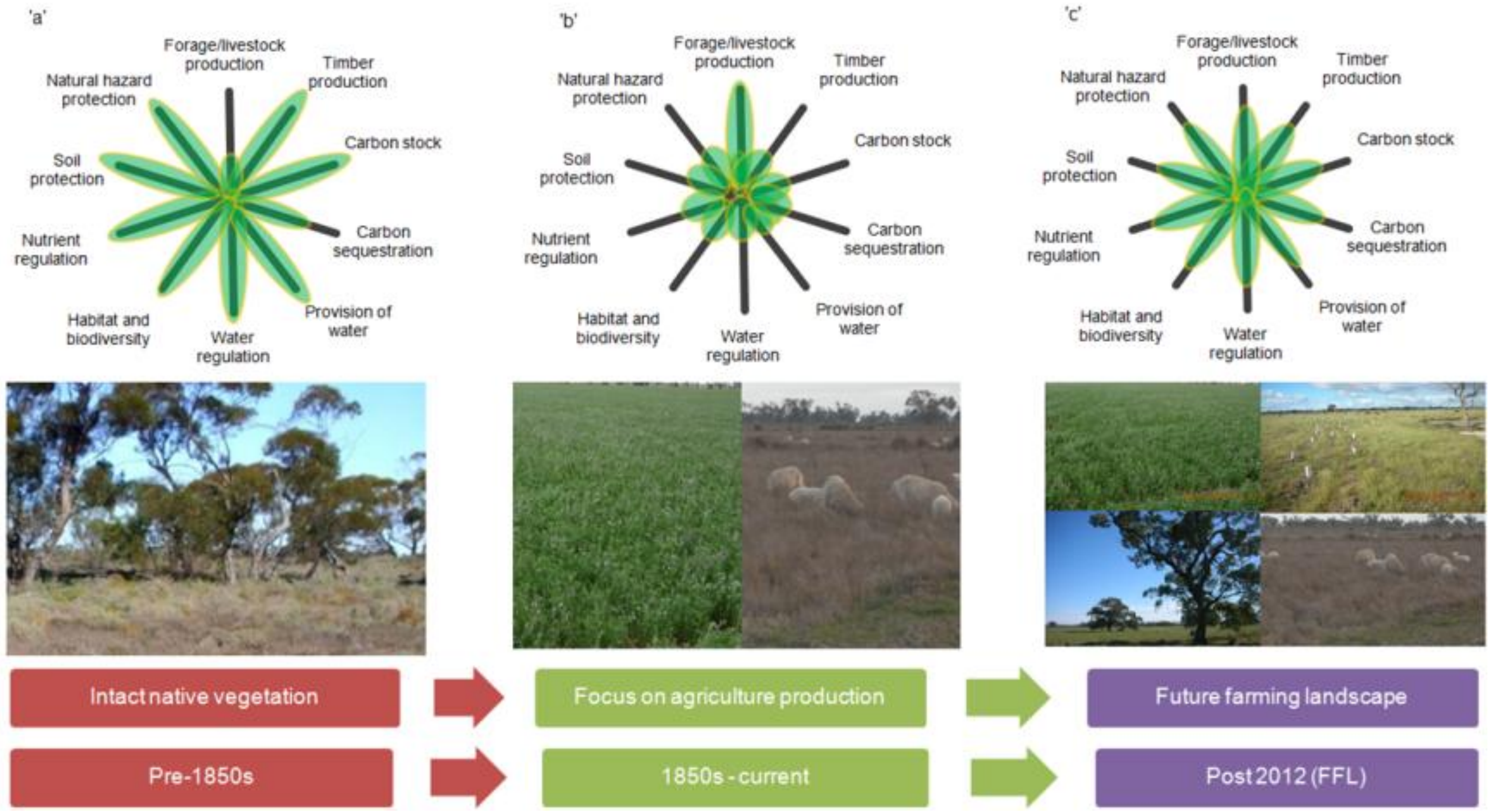

Figure 5-5. Typical land-use transition in the Reedy Lakes and Winlaton study area and potential trade-offs among multiple ecosystem services: (a) pre-1850s, (b) 1850s to current, and (c) future landscape under the Future Farming Landscapes (FFL) program. The provision of ecosystem services is applicable to particular transitions and indicative only (figure inspired by Foley et al., 2005).

Table 5-3. Potential effect of land-use change (conversion of irrigated and dryland farming to future land uses under the Future Farming Landscapes program) on various ecosystem services. Qualitative scale based on that used by others (Bullock et al., 2007, 2011; Cao et al., 2009; de Groot and van der Meer, 2010; Dowson and Smith, 2007; MEA, 2005; Ostle et al., 2009; Shelton et al., 2001): '+' positive, '++' strongly positive, '0' neutral or no change, '-' negative, '- -' strongly negative, '?' not known. Letters in brackets represent Millennium Ecosystem Assessment categories: provisioning (P), Regulating (R), Cultural (C) and Supporting (S) services.

	Future Land Use			
Ecosystem Services	Environmental planting (native species)	Agroforestry (exotic species)	Grazing (extensive)	Agriculture (intensive)
Forage production (P)	--	--	+	--
Water supply (P)	--	--	+	0
Food production (P)	0	0	0	++
Wood production (P)	0	++	0	0
Carbon stock (R)	++	++	+	0
Carbon sequestration (R)	++	++	+	0
Water regulation (R)	++	+	+	0
Salinity water disposal(R)	+	+	+	0
Flood control (R)	++	+	+	0
Nutrient regulation (R)	++	+	+	0
Pollination (R)	+	?	+	0
Aesthetic beauty (C)	?	?	?	0
Recreation (C)	+	+	?	0
Soil protection (S)	++	+	+	0
Wildlife habitat (S)	++	+	+	0

5.5. DISCUSSION

This study demonstrates that readily available spatial datasets and tools can be used to assess habitat quality and biodiversity values in human-dominated landscapes and can be useful for initial assessment and conservation planning. Our analysis also indicates that there is a high potential for protecting and enlarging small remnant patches for reducing fragmentation and increasing connectivity and associated biodiversity at the landscape scale.

5.5.1. SPATIAL CHARACTERISATION OF THE LANDSCAPE – PATCH ANALYST TOOL

Results from native vegetation patch analysis provided a wide range of indices relevant to landscape alteration state and opportunities for reconnecting landscapes for biodiversity enhancement in the study area. Michaels et al. (2008) assessed the level of landscape modification in north-west Tasmania based on the extent and distribution of remnant native vegetation. Similar to this study, their results suggest that conserving small remnants patches and revegetating around them can enhance landscape connectivity by reducing fragmentation at the landscape scale. However, parts of the study area were in a relictual state with limited capacity to be restored (McIntyre and Hobbs, 1999). In many cases, fragmented remnant vegetation may contribute some biodiversity value, including their role as stepping stones for biodiversity to move to larger patches and as dispersal sources (Lindenmayer and Fischer, 2006; Michaels et al., 2008; Rubio and Saura, 2012). Hilty et al. (2006) proposed planting corridors of native vegetation as a solution to habitat fragmentation allowing species to move between isolated fragments. Others have suggested that such appropriately located biodiversity corridors may be important in allowing plant and animal species to migrate due to climate change (Baranyi et al., 2011). Such corridor plantings need to start with the protection and connection of relatively high value biodiversity patches (CEF, 2012). If remnant native vegetation is to be managed sustainably on heavily modified agricultural land, its role in providing other ecosystem services, such as carbon storage or water quality, needs to be assessed, and in turn can support, and provide funding for conservation (CEF, 2012; Crossman et al., 2011; Foley et al., 2005).

5.5.2. RELATIVE HABITAT QUALITY ACROSS THE LANDSCAPE – INVEST TOOL

Vegetation condition assessment and mapping has become a major priority for Australian agencies and organizations responsible for natural resource management (Pert et al., 2012). However current approaches used in various Australian states , the ‘habitat hectares approach’ in Victoria (Parkes et al., 2003), ‘biometric approach’ in New South Wales (Gibbons et al., 2008), and ‘bio-condition mapping’ in Queensland (Eyre et al., 2011) focus mainly on vegetation condition with limited consideration of surrounding landscape and potential threats, and may not lead to the best biodiversity conservation decisions. The results of the InVEST tool differ to those of the Victorian government Department of Sustainability of Environment for the same area (Newell et al., 2006), and indicates that a focus solely on vegetation condition without considering surrounding landscape context and potential threats may not lead to the best biodiversity conservation decisions. Patterns in biodiversity habitat quality are inherently spatial and should be analysed in conjunction with the surrounding threats (Paukert et al., 2011) and their relative impact, the sensitivity of habitat to each threat, and distances between the habitats and sources of threats (Pert et al., 2012; Tallis et al., 2010).

Our results indicate that different assessment approaches might yield quite different results, impacting on conservation and restoration investment choices. However, there is a positive relationship between the size of native vegetation patch and habitat quality – that was consistent with many other studies (Fischer et al., 2006; Munro et al., 2007; Newell et al., 2006). This is especially true in fragmented production landscapes where a number of threatening processes surround remnant native vegetation and where smaller patches are more susceptible than larger patches (Munro et al., 2007). To this end, conservation measures should focus on consolidating smaller vegetation patches in to larger blocks. Landscape scale biodiversity assessments need to include the whole mosaic of land cover and land uses, including small fragments or individuals in areas used for pastoral production or agriculture outside patches of native vegetation.

5.5.3. CONSERVATION PRIORITY SITES

In recent years, there has been some progress towards biodiversity conservation, with an additional 2,000 ha of habitat improved for biodiversity conservation and the risk of extinction reduced for threatened flora and fauna at priority sites (NCCMA, 2011). However the study area still has a low cover of native vegetation (<30% of pre-European) and is therefore a high priority for protection of remaining EVCs based on the regional biodiversity goal and resource condition targets (NCCMA, 2003, Table S1). The location of biodiversity and associated threats are distributed unevenly therefore it is essential to prioritise the area for conservation to minimise the loss (Brooks et al., 2006; Higgins, 2006). Conservation priority maps generated in this study (Fig. 5-4) provide an indicative guide to natural resource managers and investors of where to allocate the limited resources available for nature conservation in order to maximize biodiversity benefits (Higgins, 2006). However, distribution of records of threatened fauna and flora are concentrated near water-bodies and accessible sites. This is mainly due to issues surrounding accessibility and the use of water bodies for recreational purposes by those people reporting species occurrences. Consequently, they may present a biased picture of habitat requirements, particularly for fauna.

In areas of high priority sites, conservation organisations can partner with other stakeholders interested in a variety of services to effect outcomes, effectively increasing the resources available for conservation (Goldman et al., 2008) and maximise the return on conservation investment (Underwood et al., 2008).

5.5.4. LAND-USE CHANGES AND PROVISION OF BIODIVERSITY AND ECOSYSTEM SERVICES

The relationship between biodiversity values and the provision of ecosystem services has been extensively discussed (Hectar and Bagchi, 2007; Kandziora et al., 2013; Kareiva et al., 2011; Leadely et al., 2010; Turner et al., 2007). Ecosystems functions affected by loss of biodiversity include pollination, seed dispersal, climate regulation, carbon sequestration, and agricultural pest and disease control (MEA, 2005). This is particularly important in this study area, where ecosystem services such as water quality, soil conservation and pollination are economically important. Provision of ecosystem services further justifies conservation and restoration of native vegetation (CEF, 2012; Nelson et al., 2008). Conservation purely for the sake of biodiversity is difficult to justify without first demonstrating direct benefits to human beings (Chen et al., 2010).

Land management has a major impact on biodiversity and the provision of ecosystem services. In many parts of the world, land-use change has altered most of the landscape and resulted in substantial ecological consequences such as decline in biodiversity and ecosystem services (Zhao et al., 2006). Our study landscape has undergone considerable habitat loss and fragmentation in a relatively short history of European occupation. We found that the proposed land-use changes in this study landscape could result in a net positive gain to biodiversity, mainly due to conversion of intensively-managed agriculture and pasture land to environmental plantings, low intensity grazing and agroforestry activities. The InVEST results inferred that smaller, fragmented patches that are exposed to threats are generally of low conservation value. Smaller patches may sustain smaller populations which increases the probability of extinction resulting from environmental and demographic pressures (Fischer and Lindenmayer, 2007). Therefore biodiversity plantings and other revegetation work will be more effective if they are consolidated to existing remnant vegetation patches in order to create larger habitat patches that have a higher probability of being randomly occupied by a given individual or species than smaller patches (Connor and McCoy, 1979). This confirms the view of McIntyre and Hobbs (1999) that relictual landscapes are of lower priority for conservation investments. The data from this study provides a basis for reconfiguring and consolidating the current biodiversity investment program for greater conservation benefits.

Limitations of applying geo-spatial and remote sensing techniques including InVEST tools for biodiversity assessments include the lack of assessment of small-scale characteristics and finer details (Spanhove et al., 2012) and field verification is required in many cases (Hernández-Stefanoni et al., 2011; Lück-Vogel et al. 2013). Furthermore, the value of a patch of habitat for species or ecosystem will depend on size, quality, functional condition, surrounding land uses and suitability for rare or threatened species. While the basic biodiversity model of the InVEST tool takes surrounding land uses into consideration, the habitat value of a patch is limited to its size.

5.6. CONCLUSIONS

Conservation of biodiversity and associated ecosystem services in highly modified and fragmented production landscapes is a crucial natural resource management issue in Australia and elsewhere. Availability of data and appropriate tools are often identified as issues in assessment of biodiversity and ecosystem services. Here we successfully demonstrate spatial approaches to classifying the landscape for habitat quality, based on the size, density, distribution and condition of native remnant vegetation in the landscape scale. Our findings indicate that simple and readily available spatial data, tools and models can be useful for conservation assessment, planning and management and, as observed by Polasky et al. (2008), higher levels of both biodiversity conservation and the provision of ecosystem services can be achieved by appropriate spatial patterns of restoration activities. Conservation organisations, or catchment management bodies, businesses and individual landowners can use these tools to align their strategies and locate their restoration activities on priority sites to maximize the outcomes of their conservation investment (Kareiva, 2010; Underwood et al., 2008).

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Table S5-1. Biodiversity goals and resource condition targets of the study region (NCCMA, 2003).

Goal	Resource condition targets
The ecological function of indigenous vegetation communities will be maintained and, where possible native plant and animal species will be restored to viable levels	*Target 1*: Improve the quality and coverage of all vulnerable or endangered Ecological Vegetation Classes and any others with less than 15% (as measured by habitat hectares, Parkes et al., 2003) by 2013
Threatened vegetation communities will increase in extent and improve in quality to achieve net gain by: • increasing the native vegetation cover of the region to 30% • increasing the cover of all Ecological Vegetation Classes to at least 15% of their pre-1750 distribution	*Target 2*: Increase native vegetation coverage to 20% of the region by 2030 *Target 3*: Maintain and improve existing viable population of significant threatened species from 2003 *Target 4:* No further bioregional extinctions from 2003

Table S5-2. Original and recent (2006) extent of Ecological Vegetation Classes in the Reedy Lakes and Winlaton study area and their bioregional conservation status (DSE, 2011).

Ecological Vegetation Class	Pre-1750 (ha)	Present 2006 (ha)	% Remaining	Bioregional Conservation Status
Riverine Grassy Woodland	41	32	77	Vulnerable
Lake Bed Herbland	185	121	65	Depleted
Lignum Swamp	340	202	60	Vulnerable
Grassy Riverine Forest	9	5	56	Depleted
Lignum Swampy Woodland	5457	2387	44	Vulnerable
Grassy Riverine/Swamp Complex	1111	460	41	Depleted
Riverine Chenopod Woodland	11323	3279	29	Depleted
Woorinen Mallee	34	9	26	Vulnerable
Chenopod Grassland	4567	787	17	Endangered
Plains Savannah	27	4	15	Endangered
Semi-arid Woodland	358	37	10	Endangered
Semi-arid Chenopod Woodland	3547	348	10	Endangered
Plains Woodland	1	0	14	Endangered
Ridged Plains Mallee	6	0	7	Endangered
Total	27005	7671	34	

CHAPTER 6: ECONOMIC EVALUATION OF LANDSCAPE MANAGEMENT SCENARIOS IN NORTH-CENTRAL VICTORIA,

This chapter is being submitted to *Land Use Policy*:

Baral, H., Keenan, R.J., Sharma, S.K., Stork, N.E., Kasel, S., (in revision). Economic evaluation of landscape management scenarios in north-central Victoria, Australia. *Land Use Policy*

6.1. ABSTRACT

Human-induced changes in the natural environment are affecting the provision of ecosystem goods and services (EGS). The overall impact on human welfare is difficult to assess because many EGS are not captured in economic analyses, and the distribution of economic impacts of the reduced supply of services is not well understood. Land use plans rarely include the value of public ecosystem goods such as climate regulation and biodiversity due to difficulties in valuing these services. In this study, we assessed total economic value (expressed as Net Present Value, NPV, over a 30 year period) for two types of products (agricultural commodities and timber) and three ecosystem services (carbon, water and biodiversity) under five future land-use scenarios using varying levels of costs, prices and discount rates. Results indicated that at higher discount rates normally applied to commercial activities, and assuming the current prices for goods and services, NPV was highest for landscape management scenarios aimed at maximising agricultural production. Potential income from services such as carbon and biodiversity does not offset projected income from agriculture. At higher discount rates, NPV was negative for the two scenarios aimed at enhancing the longer term ecological sustainability of the landscape. These results indicate that income from carbon sequestration and biodiversity conservation would need to be considerably higher than current levels in order to justify focusing management of this landscape on ecological outcomes. At lower discount rates (at levels normally associated with public investments), the more ecologically appropriate ‘mosaic farming system’ had the highest NPV, indicating that this type of system might be attractive for investors

interested in longer term return horizons or wider public benefits. Higher income from carbon or biodiversity, or increased return from timber by using higher value tree species, could potentially make more ecologically appropriate systems profitable at higher discount rates.

This study showed that an EGS framework can be used to assess and value different land-use options and demonstrated the potential to manage landscapes to produce a mix of EGS. This can provide a useful input for land use policy and land management decisions.

6.2. INTRODUCTION

Human life depends on a wide variety of ecosystem goods and services (EGS) provided by healthy ecosystems. As described in the Millennium Ecosystem Assessment (MEA), these include the provisioning of resources such as food, fibre, and raw materials; regulating services such as water filtration, storm buffering, and climate stabilisation; supporting services such as soil formation, photosynthesis, and pollination; and cultural services that are spiritual, aesthetic, and recreational services (MEA, 2005). Many human activities impede ecosystem functions, thereby reducing or increasing flows of these EGS. While the supply of some goods is increasing, the MEA estimates 60% of the ecosystem services have declined globally in the past 50 years (MEA, 2005). However, the critical ways in which ecosystems support and enable human well-being are rarely captured in cost-benefit analysis for policy formulation and land use decision-making (Daily et al., 2009; Laurans et al., 2013; Nelson et al., 2008). Recent studies highlight the need to assess trade-offs among EGS under a variety of future land-use scenarios (Butler et al., in press; Carpenter et al., 2009; Sanon et al., 2012; Willeman et al., 2012).

Prioritising landscapes for the production or harvest of a single ecosystem commodity, such as food or fibre, can diminish other services such as water quality, erosion prevention or soil formation (Bennett et al., 2010; Bryan and Crossman, 2008; Raudsepp-Hearne et al., 2010; Stoate et al., 2009), as well as undermining overall ecosystem resilience (MEA, 2005). This is certainly the case for south-eastern Australia where such trade-offs have been observed over the past two hundred years (Bryan et al., 2010, 2011; Crossman et al., 2009, 2010; Sandhu et al., 2012). Several authors explore the spatial patterns of provision of multiple EGS in production landscapes, focusing on the win-win opportunities for conservation and production of multiple EGS (Bennett et al., 2009; Egoh et al., 2008; Naidoo et al., 2008; Nelson et al., 2009; Tallis and Polasky, 2009). However only a few deal with the economic valuation of future landscape management scenarios and associated impact on provision of EGS.

Changes in land use and land cover are ongoing due to changes in environmental conditions, patterns of human settlement, modes of production, and demands of society (Verburg et al., 2009). Large areas of native vegetation in Australia have been converted to agricultural production (SOE, 2011) resulting in unforeseen economic impacts such as the costs associated with reduced flood control, the provision of potable water, or increased salinity and soil erosion (i.e., ecosystem services) (SOE, 2011) that are not captured in standard analysis of farming systems. EGS research is relatively new and quantification and valuation of services remain highly uncertain (Hou et al., in press; Johnson et al., 2012). There are additional uncertainties with the future provision of services due to continuing land-use change and climate change. Therefore, a gross estimate of EGS at a point in time without considering future land-use scenarios will have limited value for decision makers (Fürst et al., in press; Swetnam et al., 2011).

Identifying such potential changes in land cover, and measuring and managing multiple EGS under future land-use scenarios is a key challenge for policy makers. In the state of Victoria, Australia, efforts are underway to address these challenges. One such initiative is the Future Farming Landscapes (FFL) program, a long-term (~ 30 years) program that aims to reconfigure landscapes to their most sustainable use. Here, we attempt to identify and assess provision of various EGS under a range of plausible landscape configurations, including one FFL-type scenario in this landscape.

Our specific aims were to (i) identify and define plausible land-use scenarios for the study area, (ii) estimate the value of key EGS: carbon sequestration, agricultural production, water, biodiversity and timber production under these land-use scenarios, and (iii) analyse the potential trade-offs and synergies among multiple EGS under these land-use scenarios.

6.3. METHODS

6.3.1 STUDY AREA AND POLICY CONTEXT

The study area is located in north-central Victoria (Fig. 6-1), a region spanning over three million hectares and encompassing three bioregions (Murray Fans, Victorian Riverina, Murray Mallee; DSE, 2004). These bioregions support over 2,000 native plant species, including 130 state-wide threatened species with 52 of these considered to be nationally threatened (NCCMA, 2011). They also support more than 400 native vertebrate fauna species including 101 threatened species of which 13 are nationally threatened (NCCMA, 2011). The region has been heavily modified since European settlement with native vegetation cleared originally for pastoral development (1860s to 1950s) and then for cropping from the 1950s onwards (Ransom, 2011). Conversion of deep rooted perennial vegetation to annual crops has resulted in a suite of environmental impacts including dryland salinity, habitat and biodiversity loss, and soil degradation (Jones et al., 2007; Pittock et al., 2012). Moreover, this region is situated within the Murray-Darling Basin – the largest river catchment area in Australia, and clearing for crops and over-use of irrigation in this catchment has resulted in extensive environmental impacts (CSIRO, 2012). In recent years, the Australian and state governments, business and landowners have employed a number of strategies, including market-based instruments for conservation, aimed at reversing this decline in environmental condition (Burgin, 2008; Eigenraam et al., 2006).

6.3.2. STUDY SITE - REEDY LAKES AND WINLATON

The study site lies between Kerang and Lake Boga in north-central Victoria, Australia, approximately 320 km north-west of Melbourne (35.972º S, 143.228º E, Fig. 6-1). The total area is approximately 30,000 ha, bounded by the Little Murray and Lower Loddon Rivers in the North, West and South and the Murray Valley Highway to the West. Within the study area lie the Reedy Lakes and Winlaton Future Farming Landscapes (FFL) projects managed by Kilter Pty Ltd (an asset management group servicing the superannuation sector). The terrain is generally flat and low-lying (70–80 m above sea level). Average annual rainfall is approximately 370 mm (mean, 1962–2012), and mean annual temperature ranges from a minimum of 9 ºC to a maximum of 23 ºC.

Reedy Lakes and Winlaton is a typical north-central Victorian landscape that has been subject to extensive vegetation clearing for agriculture and pastoral production and native vegetation is now highly fragmented and often degraded (NCCMA, 2005). Since European settlement in the mid-1800s, an estimated 70% of native vegetation (18,300 ha) has been cleared. This has resulted in widespread declines in biodiversity, increased soil and stream salinity and soil erosion (NCCMA, 2011). Nationally, natural resource management programs have focused on reduction in salinity, improving water quality and environmental flows, and protecting biodiversity (Hajkowicz, 2009). Major land use-land cover types include irrigated farming, dryland cropping, native vegetation, degraded land undergoing rehabilitation, and water bodies (Table 6-1).

The study area covers less than 0.2 % of Victoria's land mass. However, it supports a relatively large number of threatened flora species (50 species, 2.5% of threatened plants in Victoria) and fauna species (81 species, 45% of the threatened Victoria). The high levels of biodiversity, and the pressures on this biodiversity, have resulted in the area being identified as an important site for conservation by the Victorian Government (Wetlands Scientific Committee, 1993). Wetlands within the study area support high richness and abundance of waterfowl species (Lugg et al., 1989) and some sites are of international significance, including the 'Kerang Wetlands Ramsar Site' (DSE, 2004).

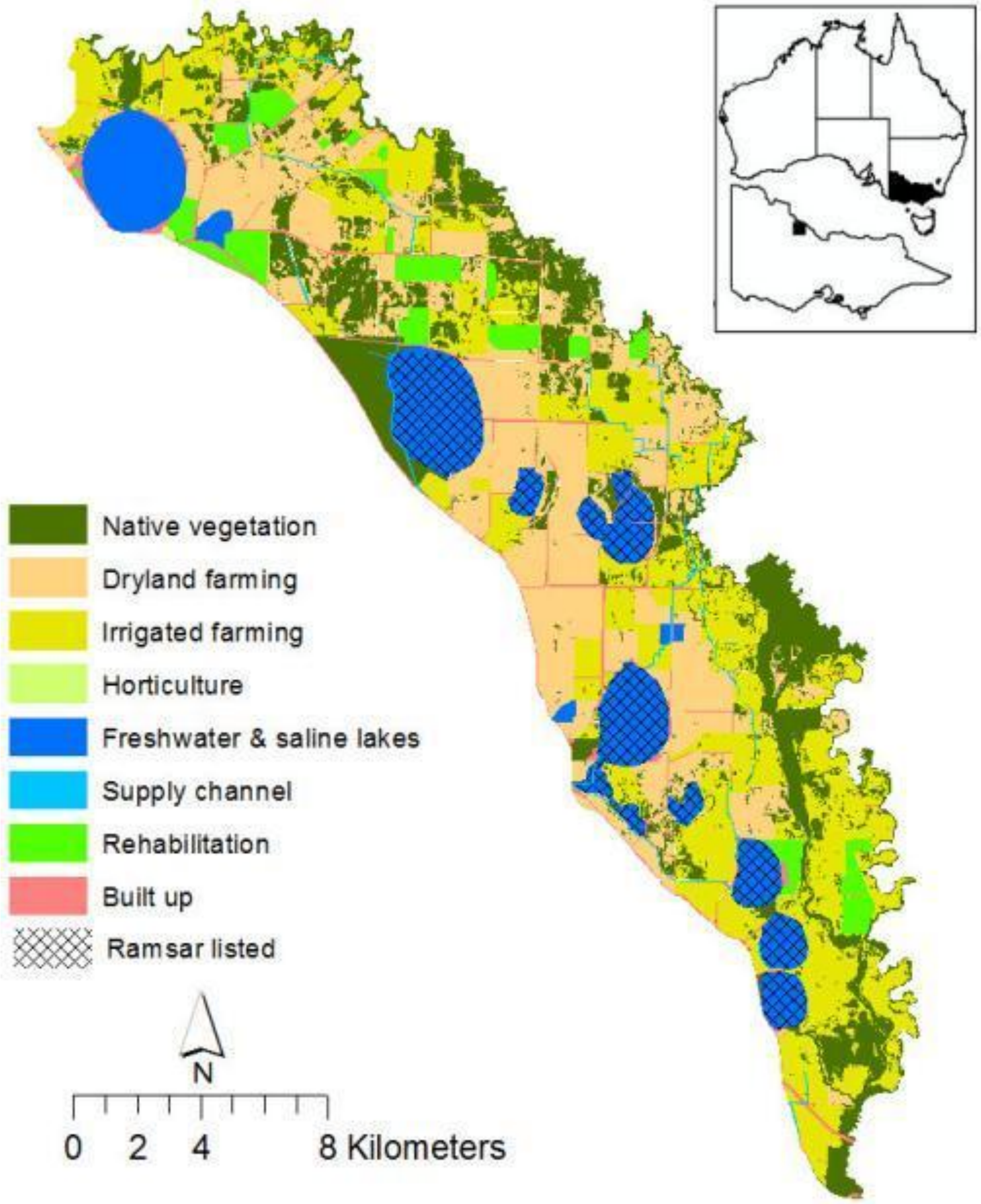


Figure 6-1. Location of the Reedy Lakes / Winlaton study area and major land use-land cover types in north-central Victoria, Australia.

Table 6-1. Distribution of current land use-land cover in the Reedy Lakes and Winlaton study area in north-central Victoria, Australia (see also Fig.6-1). Rehabilitated is degraded land undergoing rehabilitation and substantially modified (BRS, 2006).

Current Land Use	Area (ha)	% of study area
Native vegetation	6,799	22.6
Dryland cropping	7,800	25.9
Irrigated farming	8,516	28.3
Horticulture	157	0.5
Rehabilitated	3,068	10.2
Water	2,868	9.5
Built up	914	3.0
Total	30,122	100.0

6.3.3. PLAUSIBLE FUTURE SCENARIOS FOR LANDSCAPE CONFIGURATION AND ASSOCIATED LAND USE-LAND COVER

We developed five plausible future land-use scenarios for the study area (Table 6-2). This was based on a review of recent land use-land cover change patterns in south-eastern Australia and undertaken in consultation with stakeholders.

6.3.3.1. SCENARIO 1: BUSINESS-AS-USUAL (BAU)

This scenario assumed continuation of current farming and management systems with no further broad-scale clearing of remnant native vegetation. Gradual loss of remnant vegetation and opportunistic agricultural expansion will potentially occur at the farm scale but this was not included in the scenario. The BAU scenario was considered plausible as the current prices of agricultural commodities, while variable, are likely to be maintained or increased (Ransom, 2011). To this end, farms were likely to continue operating for the foreseeable future. Under this scenario we assumed approximately 0.14% loss of native vegetation per annum which is similar to current native vegetation clearance rate in Victoria (DSE, 2012).

Table 6-2. Estimated areas of different land use-land cover under future land-use scenarios. Descriptions of scenarios: 'BAU' business-as-usual, continuation of current farming and management system; 'MFS' mosaic farming systems, landscape reconfiguration to more ecologically sustainable uses that involve changes to farming practices and environmental plantings; 'ECO' eco-centric, substantial increase in environmental plantings due to increasing environmental market; 'AGRO' agro-centric, increase in agricultural land due to higher demand of food and livestock production in line with the population growth; 'ALU' abandoned land use, decline in agriculture and land abandonment due to reduced water availability and depopulation in rural areas. In many cases, ALU may ultimately become some form of native or exotic vegetation in the long run which may support biodiversity. This land type may also be subject to weed and pest infestations which negatively impact native biodiversity.

	Estimated area (ha) under each scenario					
	Current	BAU	MFS	ECO	AGRO	ALU
Native vegetation	6,799	6,519	6,799	6,799	2,297	6,799
Dryland cropping	7,800	8,079	3,900	0	10,951	0
rrigated farming	8,516	8,516	7,664	8,516	9,866	0
Horticulture	157	157	1,009	157	157	0
Freshwater lakes	2,573	2,573	2,573	2,573	2,573	2,573
Saline lakes and treatment	1,530	1,530	1,530	1,530	1,530	1,530
Channel/aqueduct	293	293	293	293	293	0
Rehabilitation	1,541	1,541	1,541	1,541	1,541	1,541
Built up	914	914	914	914	914	914
Environmental plantings	0	0	2,730	5,460	0	0
Forestry (production)	0	0	1,170	2,340	0	0
Abandoned land	0	0	0	0	0	16,765
Total	30,122	30,122	30,122	30,122	30,122	30,122

6.3.3.2. SCENARIO 2: MOSAIC FARMING SYSTEMS (MFS)

This scenario assumed that the landscape will be transformed to more ecologically sustainable uses involving changes to farming practices, low rainfall forestry and environmental plantings. This scenario is based on the FFL model and uses a similar land-use reconfiguration, with the goal of developing an estate that includes environmental plantings and extensive grazing (~51%), irrigated farming (horticulture, agriculture ~33%), perennial horticulture (~7%), commercial agroforestry (~4%) and other land uses (~5%) (Kilter Pty Ltd, 2011). The MFS scenario is considered plausible given that Kilter's initiatives were already underway on approximately 25% of the study area (Table 3). Under this scenario we assumed that approximately 50% of dryland farming was primarily converted to environmental planting (60% of converted land) due to the potential demand for carbon credits, and production forestry (30% of converted land). A small proportion (10%) of irrigated farming was assumed to be converted to perennial horticulture.

6.3.3.3. SCENARIO 3: ECO-CENTRIC OR ENVIRONMENTAL PLANTINGS (ECO)

This scenario assumed that there will be substantial increase in environmental plantings due to growing environmental concerns and growth of new commodities based on environmental values such as carbon and biodiversity credits (Bekessy and Wintle, 2008; Burgin, 2008). The Australian Government and Victorian State Governments have designed economic instruments that provide financial incentives to landowners for undertaking eligible carbon sequestration activity such as revegetation of fragmented landscape via various mechanisms such as Carbon Farming Initiative (DCCEE, 2011a) and the Land and Biodiversity Fund (Caripis et al., 2012; Keenan et al., 2012). Under this scenario it was assumed that all dryland faming would be converted to mixed species environmental planting (70%) due to potentially higher demands for carbon credits, and to a lesser extent commercial tree farming (30%) due to low profitability.

6.3.3.4. SCENARIO 4: AGRO-CENTRIC OR PRODUCTION ORIENTED (AGRO)

This scenario assumed that higher demand for food and livestock production due to continued population growth in Australia and globally (Godfray et al., 2010). Global food demand is expected to more than double by 2050 to meet this growing demand (Green et al., 2005). Relatively cheaper land prices, and improved farming and irrigation practices may reduce the production cost and make agricultural production a more profitable venture. The scenario assumed the current areas of agricultural production would increase through clearance of remnant native vegetation and conversion to agricultural production. Under this scenario it was assumed that all available native vegetation on private land (4,502 ha) would be cleared for dryland farming (70% of converted land) and irrigated cropping (30% of converted land).

6.3.3.5. SCENARIO 5: ABANDONED LAND USE (ALU)

This scenario assumed that higher labour prices and a strong currency may prevent Australian products competing effectively in international markets and reduced water availability due to water trading and climate change, resulting in a decline in agricultural terms of trade, and agricultural land abandonment (Garnaut, 2008; Race et al., 2010).. Under this scenario, all irrigated and dryland farming areas would be abandoned and either revert to native vegetation or become weed infested or a combination of both.

Table 6-3. Land currently undergoing change in management under the Future Farming Landscapes program being implemented by Kilter Pty Ltd (Kilter Pty Ltd, 2011). Data for re-configured land is current at December 2011, although this proportion will change over time.

Land Management Unit	Area (ha)	% of re-configured land	% of study area
Irrigated Cropping	2,789	37	9.3
Biodiversity	1,960	26	6.5
Grazing	1,489	20	4.9
Perennial Horticulture	658	9	2.2
Forestry (production)	342	5	1.1
Rural Living	292	4	1.0
Other	23	0	0.1
Re-configured land total	7,552	100	25.1
Study area total	30,123		

6.3.4. SCENARIOS AND ASSUMPTIONS FOR COSTS AND ASSOCIATED REVENUES

Cost of production and associated returns from each EGS were estimated under three commonly used scenarios: (i) base or central cost and revenue assumptions, (ii) optimistic or higher revenue but low production cost, and (iii) conservative or high production cost and lower revenue. Table 4 provides a summary of the various assumptions for each cost-based scenario.

6.3.4.1. BASE OR CENTRAL SCENARIO

This scenario used the actual establishment and management cost provided by Kilter Pty Ltd and a carbon price of \$20 Mg^{-1} CO_2^e. This price was based on the current price under the Australian Government's Carbon Pricing Mechanism (Clean Energy Future, 2012) less the estimated cost for assessment and verification, which was assumed to be approximately 15% of total value. Similarly it assumed moderate stumpage value of timber and average gross revenue from agricultural production.

6.3.4.2. OPTIMISTIC SCENARIO

This scenario used reduced establishment and annual management costs (to 50%) and a higher carbon price \$30 Mg^{-1} CO_2^e. Similarly it assumed higher stumpage value of timber and higher gross revenue from agricultural production.

6.3.4.3. CONSERVATIVE SCENARIO

This scenario used a higher planting and annual management cost but a lower carbon price of \$10 Mg^{-1} CO_2^e. This was an average price in the voluntary carbon market used in a number of analyses (Crossman et al., 2011; Polglase et al., 2011). The price of agricultural commodities and livestock would be reduced due to globalisation and increased production capacity through technological advancements. Similarly, this conservative scenario assumed there would be a lower stumpage price of timber and lower gross revenue from agricultural production.

Table 6-4. Scenarios and associated assumptions for cost and revenue estimation from environmental plantings, production forestry and agricultural production activities. Descriptions of scenarios: 'base' current actual establishment and management cost and value; 'optimistic' reduced management cost and increased value; 'conservative' higher management cost and lower value.

	Assumption for cost and revenue estimates		
Activities	Base	Optimistic	Conservative
Mixed species environmental planting			
Stocking (ha^{-1})	1,000	1,000	1,000
Establishment cost ($\$ha^{-1}$)	1,000	800	1,200
Annual management cost ($\$ha^{-1}$)	10	8	12
Carbon price ($\$Mg^{-1}$ CO_2^e)	20	30	10
Production forestry			
Stocking (ha^{-1})	1,000	1,000	1,000
Establishment cost ($\$ha^{-1}$)	2,000	1,6000	2,400
Annual management cost (($\$ha^{-1}$)	100	80	120
Stumpage value ($\$m^{-3}$)	50	60	40
Agricultural production (Irrigated farming)			
Total revenue ($\$ha^{-1}$ yr^{-1})	1500	1700	1300
Variable cost ($\$ha^{-1}$ yr^{-1})	1200	1300	1100
Gross margin ($\$ha^{-1}$ yr^{-1})	300	400	200
Agricultural production (Dryland farming)			
Total revenue ($\$ha^{-1}$ yr^{-1})	120	140	100
Variable cost ($\$ha^{-1}$ yr^{-1})	15	20	10
Gross margin ($\$ha^{-1}$ yr^{-1})	105	120	90
Other variables used for all analysis			
Price and cost inflation (% yr^{-1})	3	3	3
Project period (years)	30	30	30
Discount rate (%)	1, 5, 10	1, 5, 10	1, 5, 10

6.3.5. ECOSYSTEM GOODS AND SERVICES

We assessed and valued five important EGS provided by production landscapes using a mixed approach of quantitative assessment and economic valuation (Butler et al., in press; Crossman et al., 2009) for the various future land-use scenarios (Table 6-2). There are other valuable services generated in the Reedy Lakes and Winlaton region such as, salinity mitigation, water regulation, nutrient regulation, and recreation, but these were not considered in the analysis.

EGS values for carbon, timber, water, agricultural production and additional values from biodiversity were estimated as net present value (NPV) per hectare over a time horizon of 30 years (t = 30) at discount rates (r) of 1, 5, and 10%. These estimated values were compared with the estimated annual values of agricultural production per hectare available from Kilter Pty Ltd.

6.3.5.1. CARBON SEQUESTRATION

Carbon sequestration in environmental plantings was estimated as Mg ha^{-1} using the Carbon Farming Initiative (CFI) reforestation tool (DCCEE, 2011c). Monetary values were obtained firstly by transforming Mg of C (carbon) ha^{-1} into Mg of CO_2 ha^{-1} and secondly by multiplying the resulting Mg by the assumed carbon price. Similar to Crossman et al. (2010), NPV (ha^{-1}) from carbon is estimated by the following formula: $NPV = \sum_{t=0}^{T} \left(\frac{P * Q_t - (EC_c + MC)}{(1+r)^t} \right)$

Where P is the price of carbon, Q_t is the quantity of CO_2^e sequestrated in year t, EC_c is the establishment cost, MC is the annual management cost, and r is the discount rate.

Different carbon prices were used for base, optimistic and conservative scenarios (Table 4). For the base scenario we used the 2012 carbon price of \$23 Mg^{-1} of CO_2 which was introduced by the Australian Government on 1 July 2012.

6.3.5.2. PROVISION OF WATER

Woody vegetation usually uses a large proportion of rainfall compared to other land uses such as agriculture and pasture and can reduce the supply of this resource in streams and rivers (Zhang et al., 1999, 2001). Water yield from different forms of land cover was assessed based on the potential groundwater recharge (in mm yr^{-1}) under given rainfall conditions (Benyon et al., 2007, 2009). Run-off is typically estimated as the balance of water available after rain-based deep drainage and evapotranspiration are subtracted from precipitation (Barratt et al., 2007), that is: $R = P – E – D$. Here, R is run-off, P is precipitation, E is total evapotranspiration, and D is deep drainage/recharge. However, the net change in catchment water storage over a long period of time is zero (Bradford et al., 2001) and hence there is negligible change in deep drainage. To this end we used a simple water balance equation following Chan et al. (2006): $R = P – E$.

The amount of run-off reduction from revegetation was multiplied by the cost of water per ML ha^{-1} to identify the plantation water use cost for environmental planting and timber production. In the case of irrigation, the irrigation requirement for water ML ha^{-1} was multiplied by the prevailing water cost in \$ ML^{-1}. Further details regarding water use and costs are outlined in Appendix A.

6.3.5.3. BIODIVERSITY

Biodiversity can be valued by society for its intrinsic worth or for its contribution to the provision of various EGS in the study area. Both natural and modified ecosystems support certain levels of biodiversity and a number of recent studies have focused on measuring and valuing biodiversity (Atkinson et al., 2012; Butler et al., in press; Christie et al., 2006; Gracia et al., 2011; Salles, 2011). However, measuring and valuing biodiversity is a challenging issue for a number of reasons: (i) it is complicated by the wide spectrum of spatial scales at which biodiversity operates, ranging from the molecular, to gene, species, ecosystem and landscape levels; (ii) even for a given level of biodiversity, there is no well-established and agreed means for defining, measuring and valuing biodiversity; and (iii) a number of different indicators have been proposed which neither provide consistent nor comparable results on which to base general interpretations (Atkinson et al., 2012; Bene and Doyen, 2008; von Haaren et al., 2012).

Detailed assessment and valuation of biodiversity was not possible in this study. Rather we chose to use an approximate dollar value for biodiversity conservation resulting from market-based approaches used by the Australian and various State governments to conserve native vegetation on private land, such as 'bush tender' in Victoria (Stoneham et al., 2003), and 'biodiversity banking' in New South Wales (DECCW, 2009). This option was used because there were no comparable studies to transfer appropriate values for the study site. The assumption was that governments would be the primary purchasers of biodiversity conservation services from private landowners in the near future and the recent payments for establishment of mixed species environmental plantings that increase total habitat area and buffer existing remnant vegetation were used in the study (approximately \$450 ha^{-1} over the first 5 years).

6.3.5.4. TIMBER PRODUCTION

Commercial timber and wood fibre production is an ecosystem good provided by native vegetation and managed plantations. In contrast to the declining trends for most EGS, timber production capacity is enhanced in many parts of the world (MEA, 2005) due to increasing establishment of managed plantations (FAO, 2010). Although the actual value of timber is realised at the time of maturity, we converted future value in terms of net present value using various discount rates. In this study we used the tree-stand growth model 3-PG (physiological principles predicting growth; Landsberg and Waring, 1997) available from Farm Forestry Toolbox (Private Forest Tasmania, 2011) to estimate timber production. The 3-PG model uses climatic data, site factors, initial tree density, and management practices such as thinning and fertilizer application. We simulated the annual growth of Oil Mallee (*Eucalyptus kochii*, a low rainfall species native to Western Australia and suitable for our study site) as a monoculture plantation. Estimated mean annual increment is then multiplied with the rotation age and various stumpage prices (S. Dawkins, Oil Mallee Australia pers. comm.) and discount rate to calculate the net present value from timber production.

6.3.5.5. AGRICULTURAL PRODUCTION

Dryland cropping (barley, wheat, canola, oats), intensively irrigated cropping (legumes, corn, lucerne), annual horticulture (tomatoes, melons), and perennial horticulture (olives, almonds, stone fruits) are the dominant land use and primary economic activity in the study area (Kilter Pty Ltd, 2011). Agriculture is generally a profitable endeavour generating private returns to landowners. However, agricultural returns are highly variable, and subject to both unpredictable weather patterns and fluctuations in commodity markets (Ransom, 2011). The production value of agricultural land can be quantified by (i) spatially modelling agricultural profitability according to land and water use (Crossman et al., 2010), or (ii) obtaining estimated returns from secondary sources such as data from Australian Bureau of Statistics or landowners and stakeholders from the particular study area. Here we obtained present gross value of agricultural production $\$ha^{-1}\ yr^{-1}$ from Kilter Pty Ltd as this is more accurate rather than extracting other sources or profitability models.

Agricultural production also contributes substantially to Australia's total greenhouse gas emission profile (DCCEE, 2012) but these emissions were not considered in this analysis. However, the emissions from inputs into agricultural enterprises have to be deducted from agricultural profitability. Here we used total estimated greenhouse gas emission values available from Maraseni et al. (2007).

6.3.6. ANALYSIS

We compared the value of production of EGS under the different land-use scenarios in Australian dollars per hectare (Table 2).

6.4. RESULTS

6.4.1. EGS TRADE-OFFS UNDER DIFFERENT LAND-USE SCENARIOS

Two plausible land-use scenarios (mosaic farming systems and eco-centric) realised substantial gains in carbon sequestration, biodiversity conservation and timber production. Conversion of dryland and irrigated farming landscape to perennial vegetation types store more carbon in soils and biomass, which substantially increased carbon sequestration. However, the eco-centric scenario considerably reduced the value of agricultural production due to conversion of agricultural land to biodiversity plantings. Business-as-usual and abandoned land-use scenarios produced mainly negative or neutral outcomes for the assessed EGS (Table 6-5).

6.4.2. PROVISION OF EGS AND PROFITABILITY UNDER DIFFERENT LAND-USE SCENARIOS

Assuming base pricing and a ‘public’ discount rate (5%) and all values priced, mosaic farming systems produced the highest total NPV, followed by the business-as-usual, the agro-centric, the eco-centric and the abandoned land-use scenarios (Table 6-5). For the business-as-usual and agro-centric scenarios there were no additional gains resulting from timber production, carbon sequestration or reduced emissions due to clearing of native vegetation. The eco-centric scenario resulted in negative NPV due to the low productivity of the study area for timber production.

When using a commercial-level discount rate (10%), relative NPVs for the different scenarios changed considerably. The business-as-usual scenario produced the highest NPV followed by the agro-centric, mosaic farming systems and eco-centric and abandoned land-use scenarios. At the higher discount rate, returns from carbon and timber were negative, which affected the total NPV of the two more ‘environmentally sustainable’ scenarios: the eco-centric and mosaic farming system scenarios. This situation was reversed with a lower ‘social’ discount rate (1%). Overall, the NPVs from each scenario were in the same order, with mosaic farming producing the highest NPV and land abandonment the least. However, the NPV for the eco-centric scenario almost doubled due to increased benefits from timber and carbon. The land abandonment scenario produced the least benefits under all scenarios.

Returns from carbon sequestration produced positive NPV under the most optimistic and base level price assumptions. However, carbon farming resulted in negative benefits under the conservative scenario except at a very low discount rate of 1% (Fig. 6-2a). With additional payments similar to the BushTender payment mechanism (approximately \$450 ha^{-1} over the first 5 years), the NPV was positive, except when a high discount rate was used (Fig. 6-2b). However the economic benefits from this source are was considerably below those from agricultural production. Under the base pricing levels with a 5% discount rate and higher carbon price (\$32 Mg^{-1} CO_2^e), the NPV from dryland farming is positive for carbon farming. To compete with the NPV from irrigated farming, the carbon price would need to be considerably higher i.e., \$66 Mg^{-1} CO_2^e.

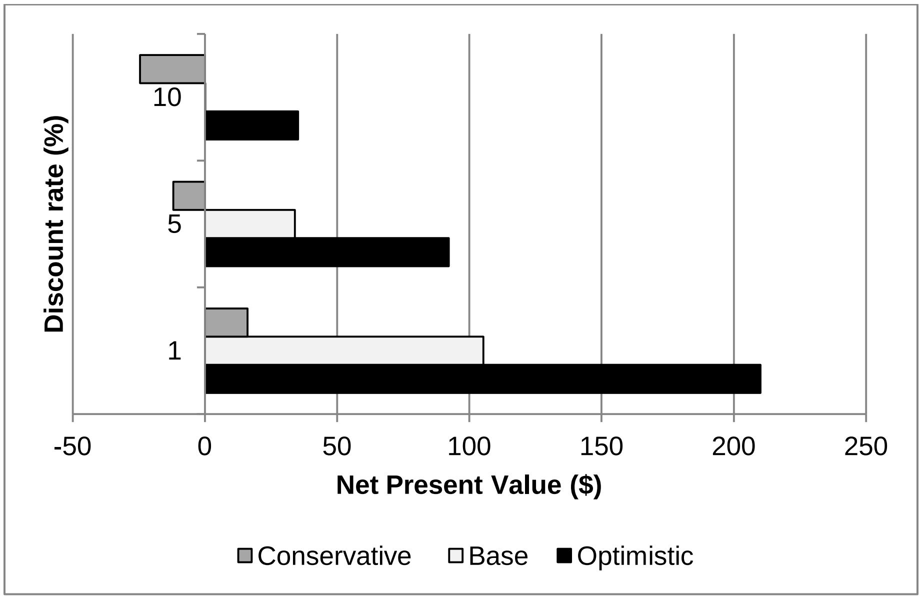
Returns from planting trees for timber production resulted mainly in negative NPV under conservative and base return scenarios (Fig. 6-3). Positive NPV could only be realised with lower discount rates of 1 and 5% and optimistic price and cost assumptions.

Table 6-5. Ecosystem goods and services trend under future land-use scenarios at base pricing and discount rate of 1, 5, and 10%. Descriptions of scenarios: 'BAU' business-as-usual, continuation of current farming and management system; 'MFS' mosaic farming systems, landscape reconfiguration to more ecologically sustainable uses; 'ECO' eco-centric, substantial increase in environmental plantings due to increasing environmental market; 'AGRO' agro-centric, increase in agriculture land; 'ALU' abandoned land use, decline in agriculture and land abandonment. Under MFS, agricultural production will increase by 20% with improved farming practices and efficient allocation of water.

Future land-use scenarios	Estimated total value of ecosystem goods and services under each scenario (in thousands)					
	Carbon	Agricultural production	Water[a]	Biodiversity	Timber	Total
Base pricing and 1% discount rate						
BAU	$0	$133,901	$0	$16,148	$0	$150,048
MFS	$6,541	$139,810	-$901	$16,841	$1,021	$163,312
ECO	$13,082	$100,269	-$1,802	$16,841	$2,043	$130,433
AGRO	$0	$142,324	$0	$5,690	$0	$148,013
ALU	$0	$0	$0	$16,841	$0	$16,841
Base pricing and 5% discount rate						
BAU	$0	$71,351	$0	$9,746	$0	$81,097
MFS	$2,782	$74,198	-$1,061	$10,165	-$560	$85,524
ECO	$5,564	$52,940	-$2,122	$10,165	-$1,121	$65,426
AGRO	$0	$75,866	$0	$3,434	$0	$79,300
ALU	$0	$0	$0	$10,165	$0	$10,165
Base pricing and 10% discount rate						
BAU	$0	$40,029	$0	$5,893	$0	$45,922
MFS	-$975	$41,632	-$2,059	$6,146	-$2,099	$42,645
ECO	-$1,949	$29,705	-$4,118	$6,146	-$4,198	$25,586
AGRO	$0	$42,566	$0	$2,076	$0	$44,642
ALU	$0	$0	$0	$6,146	$0	$6,146

[a] Negative value of water enhances the value of agriculture or timber production and therefore treated as ecosystem services

(a)



(b)

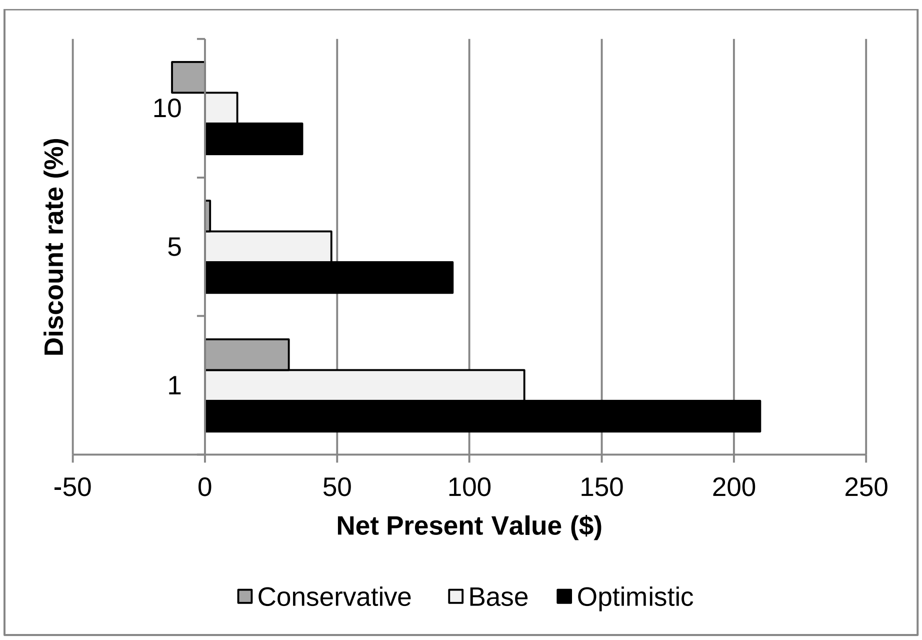


Figure 6-2. (a) Estimated returns from carbon payments ($\$ha^{-1}$ yr^{-1}), and (b) carbon payments with additional incentives from environmental payments (approximately \$96 ha^{-1} yr^{-1} for 5 years) under conservative, base and optimistic scenarios and discount rates of 1, 5, 10%. See Table 6-4 for assumptions of costs and associated revenues.

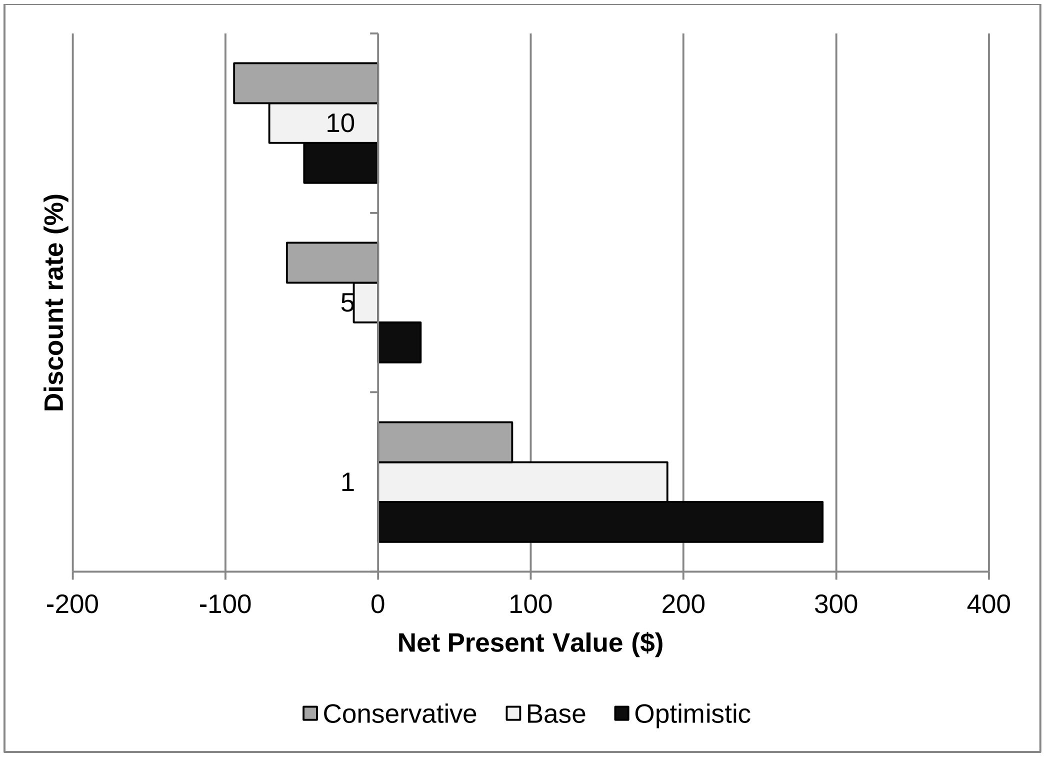


Figure 6-3. Estimated returns from timber plantations ($\$ha^{-1}\ yr^{-1}$) under conservative, base and optimistic scenarios and discount rates of 1, 5, and 10%. See Table 6-4 for assumptions of costs and associated revenues.

6.5. DISCUSSION

This study set out to identify and assess provision of EGS under a range of plausible future land-use scenarios to satisfy the changing demand of society for EGS. This study supports the concept of addressing conservation from the perspective of investment in EGS (Pagiola et al., 2010) such as payments for carbon sequestration (Crossman et al., 2011) or wetland and biodiversity banking (Carroll et al., 2008). However, those investing in these services will need to make considerable higher payments to produce a positive NPV at normal commercial discount rates, or accept lower returns.

Results from this study indicated that the economic value from the provision of various EGS varied considerably under each land-use scenario. While the provision of many desired EGS can increase or decrease according to land use and management practices under each land-use scenario, NPV depends on the productivity per unit area, the market value of the commodity or service and discount rate. Under the base scenario of cost and revenue with a 5% discount rate, both the mosaic farming system model, and business-as-usual practices had a positive NPV. However, with a commercial discount rate of 10%, landscape management regimes focused on agricultural production (the business-as-usual and agro-centric scenarios) had the highest NPV, despite management not producing other goods, such as timber, or services such as carbon.

Biodiversity value declined under both agriculturally-focused scenarios but levels of payment assumed in this study were not sufficient to offset the income benefits from farming. This supports the modelling from elsewhere that a focus on agricultural production can impact negatively on other services biodiversity, carbon and water (Crossman et al., 2009; Egoh et al., 2011; MEA, 2005). Although some studies suggest that the careful design of agricultural production can maintain or increase agricultural income, while also increasing value from other EGS (Batary et al., 2010; Pretty et al., 2006), in the case of biodiversity conservation there is ongoing debate about the relative merits of integrated versus partitioned conservation activity (Phalan et al., 2011; Tscharntke et al., 2012). Continuing profitability of agricultural production is also uncertain due to declining rural populations and labour availability, volatile commodity markets and climate variability (Steffen et al., 2009) and there are potential risk management benefits in maintaining options for multiple income sources.

At a 5% discount rate, the eco-centric scenario produced a lower NPV under the base assumptions for costs and revenues. This indicates that planting trees for carbon or timber alone is not commercially attractive in the study area due to relatively low productivity in these low rainfall conditions. This poses significant challenges to the Australian Government's Carbon Farming Initiative to increase carbon stocks in rural landscapes. Much of the land that might be used for this Initiative is in lower rainfall zones, with the land becoming available because water rights for irrigation associated with the land have been traded to other locations. Additional payments or incentives being implemented through the Biodiversity Fund or market-based instruments such as BushTender might makes some scenarios attractive but the combination of carbon and biodiversity payments did not come close to current expected returns from agricultural production at higher discount rates.

To compete with returns from dryland farming and irrigated farming, the eco-centric scenario requires either: (i) higher payments through well-designed economic instruments that provide incentives for landowners to sequester carbon and conserve biodiversity (our analysis indicated that the carbon price had to be substantially higher than current levels: \$32 Mg^{-1} CO_2^e and \$66 Mg^{-1} CO_2^erespectively) or (ii) investors need to base their returns on longer terms benefits through applying a low discount rate. The latter situation might apply to non-profit organisations or government funded programs that aim to produce public services.

Separate payment mechanisms for both carbon and biodiversity credits could provide increased incentives for the revegetation of degraded landscapes resulting in positive environmental outcomes (Bekessy and

Wintle, 2008; Crossman et al., 2011; Fox and Nino-Murcia, 2005). Because of the long time span between investment to establish plantations and income from timber, NPV from timber was also positive at the low discount rate. Similarly, at a carbon price of $25 Mg^{-1} CO_2^e$, returns from carbon can be as profitable as dryland farming. However, even at a 1% discount rate, the carbon price had to be much higher, i.e., $54 Mg^{-1} CO_2^e$ to produce similar returns to irrigated farming.

The abandoned land-use scenario was neither commercially attractive nor socially or environmentally desirable due to the decline of many EGS that are important for human survival and well-being. However, under certain conditions ‘abandoned’ land could produce better environmental outcomes, if it is managed in a light-handed way to support native vegetation and associated biodiversity (Lasanta-Marinez et al., 2005; Luck, 2010). In other cases, abandoned land could be purchased by environmental and conservation organisations such as Australian Wildlife Conservancy and Birds Australia and managed through conservation covenants (Luck, 2010). However, in many cases abandoned land becomes weed and pest infested resulting in ecosystem dis-services (Dunn, 2010; O’Farrell et al., 2007). In addition, such land may be prone to bushfires and may be difficult to monitor due to limited road access. Similarly, lack of pest management could increase invasive species such as the red fox and feral cat which would have devastating consequences for native fauna (Luck, 2010).

Although planting trees produces many public EGS such as enhanced biodiversity (Brockerhoff et al., 2008; Munro et al., 2009), carbon sequestration (Bottcher and Linder, 2010), reduced dryland salinity (Crossman et al., 2010), soil protection (de Groot and van der Meer, 2010), and water regulation (Keenan and van Dijk, 2010), planting trees for timber or wood fibre alone in many locations in Australia is not profitable due to low rainfall and low productivity. Two possible alternatives can overcome this situation.

1. Planting high value timber such as Australian sandalwood (*Santalum spicatum*). This species is climatically suited to the study site and can potentially generate significantly higher NPV per ha than other tree species (Brand et al. 2003; Jones, 2002).

2. Enhancing income from plantations through integrating multiple uses involving additional income such as grazing and carbon sequestration (Maraseni et al., 2012). A recent study by Maraseni et al. (2012) demonstrated an approximate 30% additional return potential from integrating grazing and carbon sequestration in timber production systems in medium rainfall study sites in south-east Queensland.

While this study demonstrated that higher economic values can be potentially be achieved through adopting management systems that integrate multiple goods and services, under the current policy there are very few payments or incentive mechanisms for producing a range of EGS (House et al., 2008). For example, timber plantations sequester significant amounts of carbon during their growth and carbon can be stored for long periods of time in a range of timber products but planting trees for timber production did not qualify for carbon credits under current Carbon Farming Initiative guidelines (DCCEE, 2011a). There has been some softening of this position recently and the Australian Government is considering a methodology that allows farmers to claim credits for farm forestry plantings (http://www.climatechange.gov.au/reducing-carbon/carbon-farming-initiative/methodologies/methodology-proposals).

Analysis revealed trade-offs and synergies in the production of goods and services under different land-use scenarios. For example, the eco-centric and mosaic farming systems scenarios involved deriving income from carbon and timber production at the cost of agricultural production. While there was synergy between carbon sequestration and biodiversity, trade-offs were observed between timber production and biodiversity. Similarly, in the business-as-usual and agro-centric scenarios, the focus on production of agricultural goods has an impact on the supply of carbon, timber production and biodiversity benefits. There was potential to reduce these trade-offs at landscape scale without compromising overall profitability (Onaindia et al. 2013) but , in many cases, these trade-offs are inevitable at the site or property scale (MEA, 2005; Rodríguez et al., 2006).

6.6. CONCLUSION

Land-use decisions are typically determined by a combination of government policies and the choices of private landowners (Nelson et al., 2008). Information about the effects of different choices on the provision of different types of EGS can provide the basis for more informed policy decisions (House et al., 2008), particularly for regions undergoing considerable change in management due to changing water use demographics and commodity prices. In this study, we assessed total economic value (expressed as Net Present Value, NPV, over a 30 year period) for two types of products (agricultural commodities and timber) and three ecosystem services (carbon, water and biodiversity) under five future land-use scenarios using varying levels of costs, prices and discount rates. Results indicated that at higher discount rates normally applied to commercial activities, and assuming the current prices for goods and services, NPV was highest for landscape management scenarios aimed at maximising agricultural production. Potential income from services such as carbon and biodiversity does not offset projected income from agriculture. At higher discount rates, NPV was negative for the two scenarios aimed at enhancing the longer term ecological sustainability of the landscape. These results indicate that income from carbon sequestration and biodiversity conservation would need to be considerably higher than current levels in order to justify focusing management of this landscape ecological outcomes. At lower discount rates (at levels normally associated with public investments), the more ecologically appropriate ‘mosaic farming system’ had the highest NPV, indicating that this type of system might be attractive for investors interested in longer term return horizons or wider public benefits. Higher income from carbon or biodiversity, or increased return from timber by using higher value tree species, could potentially make more ecologically appropriate systems profitable at higher discount rates.

The abandoned land-use scenario produced negative NPV under all assumptions. Land abandonment potentially threatens native biodiversity and produces ecosystem dis-services due to potential growth of weeds and pest animals. This study showed that an EGS framework can be used to assess and value different land-use options and demonstrated the potential to manage landscapes to produce a mix of EGS. This can provide a useful input for land use policy and land management decisions.

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Appendix 6-1: Estimation of water use by various land-use types and associated costs

Tree plantings typically have positive environmental effects by lowering saline water tables and also supporting biodiversity, but some communities have become concerned that they can reduce available water for other uses, such as irrigated agriculture and the environment (DOE, 2009). A number of recent studies have investigated the effects of plantations, their location within the landscape, species and management practices on water quality and quantity (Zhang et al., 2003; Benyon et al., 2006, 2007, 2009). Key findings relevant to the study area are outlined below:

- Tree planting decreases available water from streams and groundwater;
- Forests use more water than pasture or agriculture;
- Each tree planting is unique and effects on available water levels vary. Generally, the higher the rainfall, the bigger the effect; and
- Many other factors influence how tree plantations reduce stream flow and groundwater level such as, tree density, management regimes, soil type, and availability of groundwater.

Zhang et al. (2001) examined the reasons for differences in water use between forests and herbaceous vegetation such as pasture or agriculture and concluded that: (i) forests generally absorb more of the incoming solar radiation, resulting in higher evapotranspiration; (ii) forests usually have higher canopy interception due to higher or more persistent leaf area and greater canopy roughness; and (iii) forests often have much deeper root systems than pastures and many agricultural crops, enabling trees to access water from deep in the soil profile, or from groundwater and thus maintain higher water use rates during drier periods of the year. The Reedy Lakes / Winlaton study area has a relatively low mean annual rainfall of approximately 370 mm and to this end, new tree plantings will not have a sizeable effect on available water and stream flow (Zhang et al., 2003; Benyon et al., 2007, 2009).

The potential runoff reduction in the study area after conversion from agriculture to environmental planting or production forestry was estimated to be approximately 25 mm yr^{-1} which is equivalent to 0.25

ML ha^{-1} (Fig. S1 and Table S1) which is negligible given tree planting is a small component in the landscape. Using a current water price of approximately \$20 ML^{-1} (David Heislers, Kilter Pty Ltd, pers. comm.), the net economic cost of available water due to conversion of herbaceous vegetation such as grassland or pasture to environmental planting is estimated to be approximately \$5 ha^{-1} yr^{-1}. In addition, new plantings will require irrigation for the first five years after planting at a rate of 2 ML ha^{-1} yr^{-1} which is equivalent to \$40 ha^{-1} yr^{-1} (Table S2). This does not include the cost of a water license which is approximately \$2,000 ML^{-1} for permanent high security entitlements (NWC, 2010).

Table S1 Average water use (mm $year^{-1}$) according to mean annual rainfall for various land uses in south-eastern Australia (Benyon et al., 2007, 2009).

	Mean annual rainfall (mm $year^{-1}$)		
Land use/ potential ground water recharge	500	700	900
Forest generic average	480	640	780
Potential ground water recharge	**20**	**60**	**120**
Plantations (long rotations ~30yrs) e.g., *Pinus radiata*	470	620	760
Potential ground water recharge	**30**	**80**	**140**
Plantations (short rotations ~12yrs) e.g., *Eucalyptus globulus*	460	610	740
Potential ground water recharge	**40**	**90**	**160**
Environmental planting	460	605	n/a
Potential ground water recharge	**40**	**95**	**n/a**
Crop/pasture	410	520	600
Potential ground water recharge	**90**	**180**	**300**

Table S2 Estimated irrigation water requirement for various farming practices in the Reedy Lakes and Winlaton study area (David Heislers, Kilter Pty Ltd, pers. comm.). Estimated cost is based on \$20 ML^{-1} which is subject to change depending on demand and supply. For environmental planting, irrigation is inconsequential and not included in the analysis.

Land use	Quantity ML ha^{-1} yr^{-1}	Estimated Cost \$ ha^{-1} yr^{-1}
Environmental planting and production forestry (~1000 stems ha^{-1}) (for the first 5 years after establishment)	2	40
Irrigated annual cropping, annual horticulture and pasture	10	200

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CHAPTER 7: SYNTHESIS AND CONCLUSIONS

7.1 INTRODUCTION

The impacts of human alteration on nature and its capacity to produce EGS that are required for human health and well-being is being questioned at the local to global scale. Many EGS are in decline due to lack of appropriate means to measure and ignorance of their value and inadequate social and economic mechanisms to manage them sustainably. This thesis aims to fill the gap in measuring and managing EGS by identifying 'easy to apply' approaches for EGS assessment, mapping and trade-offs analysis. It contributes to the emerging science of EGS by developing concepts and methods for measuring and managing multiple EGS in primary production landscapes using readily available spatial and non-spatial data and tools. This thesis also provides an understanding of future land-use scenarios and associated impacts on multiple EGS with special reference to south-east Australian production landscapes. The in-depth review and empirical studies of selected EGS within the study region contributes to an improved understanding of complex human-environment interactions and associated outcomes. *Chapter 2* sets the scene of the thesis and *Chapters 3 – 6* provide an understanding and interaction of multiple EGS across two contrasting landscapes. Methodological framework and tools and approaches used here can be replicated and employed in diverse production landscapes in other parts of Australia and elsewhere.

7.2 ACHIEVEMENTS

The overarching goal of the thesis was to characterise and map EGS in production landscapes, assign associated values to selected services, and analyse trade-offs and synergies among them. Additional aims included modeling future land-use scenarios and analysing the potential impacts on EGS and associated economic returns as an aid for the sustainable management of production landscapes for future generations. This was achieved in a step-by-step approach and key research findings during each step are discussed under the headings below and are related to the five research objectives (*Chapter 1*).

7.2.1 RESEARCH QUESTION 1

What are current approaches for measuring EGS at the landscape scale? How can EGS be rapidly assessed in production landscapes?

In *Chapter 2*, I reviewed the role of production landscapes in providing and maintaining multiple EGS with reference to south-east Australian production landscapes. In addition, I explored various approaches such as, qualitative, quantitative, monetary and social valuation to measuring and managing the multiple EGS provided by production landscapes. I found that the provision of EGS by production landscape can vary considerably depending on land use and land cover and management choices. Landscapes solely dedicated to agricultural production can be limited to single ecosystem goods while landscapes with a mosaic of various land use and land cover can produce a wide range of services. Measuring EGS in a spatially-explicit way is a vital step for valuation and for payment to landowners or managers for production of currently unpriced services. However, inconsistency in methods to assess and map EGS presents challenges for robust valuation of EGS for inclusion in national accounts and broader policy and natural resource management decision making. Furthermore, future changes in land use or land cover and climate change present additional challenges for measuring and managing multiple EGS. To this end, availability of up-to-date data and robust tools and approaches to measure and map the production of different EGS, and to analyse trade-offs can support land managers and policy decision makers in determining the appropriate mix of land uses at a landscape scale.

7.2.2 RESEARCH QUESTION 2

How can EGS be characterised, assessed and mapped using readily available datasets and tools? How does the demand and supply of EGS change over time and space?

In *Chapter 3*, I developed a framework for classifying, assessing and mapping EGS into a GIS environment. I carried out a quantitative and qualitative appraisal of selected EGS (timber production, carbon stock, provision of water, water regulation, biodiversity, and forage production) to understand how these have altered in a complex landscape mosaic that has undergone significant change over the past 200 years. I choose readily available datasets and tools to assess the EGS so that the method can be replicated elsewhere. Results indicate that there was a high level of variation in the production of different EGS across the landscape. Relatively intact native vegetation provides mainly regulating services whereas modified landscapes provide mostly provisioning services such as timber and forage production at the cost of regulating services.

Aside from providing the empirical demonstration of spatial assessment of six important EGS, *Chapter 3* also provided an understanding of EGS change over space and time as a result of changing patterns of land use and land-cover. To assess the impacts of changes in land use and land cover, I used three temporal reference points: (i) pre-European condition from modelled vegetation data (ii) pre-1970s or conversion to pasture and, (iii) recent condition or post-1970s. The changes in the relative provision of EGS are presented in tabular form and spider diagrams which for ease to understand by planner and decision makers. In contrast to work elsewhere, I found the recent changes in land use and land cover have an overall positive impact on EGS due mainly to the conversion of pasture to managed plantations which are connected to the larger areas of remnant vegetation.

This chapter contributes the emerging science of EGS by adding a novel approach to assessing and mapping of EGS using readily available data and can also be a useful tool for policymakers in identifying trade-offs and synergies associated with land-use change and management objectives. This manuscript has been published in *Ecological Complexity*.

7.2.3 RESEARCH QUESTION 3

How can EGS be quantified, valued and mapped in economic terms?

In *Chapter 4,* I presented a spatial economic valuation framework that integrated a wide variety of data and tools to quantify, assign economic value, and produce EGS flow maps into GIS environment. While the value of EGS has been widely recognised, some of them have price tags and are traded in markets (e.g., timber, agricultural commodities) although many others are not given a price in markets and are rarely incorporated into planning and decision making (e.g., biodiversity, water regulation services). To this end, I produced a spatially explicit economic valuation that can be used to analyse trade-offs in EGS for policy and decision making. For this analysis I used both market and non-market valuation techniques to estimate the value of selected EGS. Determining the economic value of EGS that are readily bought and sold in the market place (e.g. timber and carbon) was relatively straightforward. However the quantification and valuation of non-market services such as biodiversity was complicated. Although this study did not value all EGS produced by the study landscapes, it provided a methodological framework that can be applicable in other multifunctional production landscapes in Australia and elsewhere. This chapter contributed to the EGS valuation framework as one of the early attempts to assess and value multiple EGS in south-eastern Australia.

This manuscript has been peer reviewed and published in the Biennial Conference of the Institute of Foresters of Australia, Caloundra, Queensland, 2009.

7.2.4 RESEARCH QUESTION 4

How can biodiversity values be spatially assessed and represented?

In *Chapter* 5, I assessed biodiversity value in a heavily modified and fragmented production landscape, identified the conservation priority sites to efficiently allocate limited resources for nature conservation in order to maximise biodiversity benefits. For this analysis I used readily available spatial information and tools, such as native vegetation Patch Analyst and Integrated Valuation of Ecosystem Services and Trade-offs (InVEST), to assess landscape alteration states, habitat quality and associated biodiversity values and to investigate potential benefits of revegetation activities across the landscape. Through the empirical analysis, I demonstrated that spatial assessment and mapping of biodiversity value plays a vital role in determining key areas for conservation and establishing conservation priorities.

Most importantly this work was carried out interactively with the landowners who are currently reconfiguring land use for improved environmental outcomes. I found that the assessments based solely on habitat condition may not be the most suitable basis for conservation planning because this does not include the potential effects of adjacent land uses, roads or other threats to biodiversity. Spatially targeted environmental plantings and less intensive agroforestry that reconnect native remnants in heavily fragmented landscapes can provide significant potential conservation outcomes. Planned landscape reconfiguration based on readily available spatial data can yield net positive benefits to biodiversity by halting degradation of remnant native vegetation and increasing total habitat area.

This manuscript has been accepted for publication in *Ecological Indicators*.

7.2.5 RESEARCH QUESTION 5

What are the impacts of land use-land cover change over time on the provision of EGS? What are the effects of alternative future land-use scenarios?

In *Chapter 6*, I identified and defined five plausible future land-use scenarios (business-as-usual, mosaic farming systems, eco-centric, agro-centric and abandoned land-use) and assessed the economic value of five important EGS (carbon sequestration, timber production, provision of water, biodiversity and agricultural production) under each scenario. Land-use decisions are typically determined by a combination of government policies and the choices of private landowners. The changing land use–land cover and associated impact on human welfare is difficult to assess because the impacts on many EGS are not captured in economic analyses, and the distribution of economic impacts of the reduced supply of services is not well understood. Land use plans rarely include the value of public ecosystem goods such as climate regulation and biodiversity due to difficulties in valuing these services.

Assessment of five EGS indicate that the land-use reconfiguration for multiple outcomes such as mosaic farming systems can supply multiple EGS while business-as-usual and agro-centric are focused on the supply of single ecosystem goods. The assumed discount rate is an important factor. Using higher discount rate, the business-as-usual scenario produces higher overall economic benefit and the value of mosaic farming systems is lower. With a low discount rate the economic benefit is highest with mosaic farming systems. This study demonstrated that there is potential to balance multiple EGS at the landscape scale. The economic incentive to adopt more sustainable land use practices that produce a wider range of services is compromised due to the lack of economic valuation of services generated by activities such tree planting and the mechanisms for society to pay for these services.

This study shows that using an EGS framework to assess and value different land use options can provide a useful basis for land policy and land-use decisions. This manuscript is to be submitted to *Land Use Policy*.

7.3 MAIN SCIENTIFIC CONTRIBUTION OF THE THESIS

7.3.1 FRAMEWORK FOR SPATIAL ASSESSMENT AND MAPPING OF MULTIPLE EGS

In this thesis, I present a novel framework (Fig. 3-1) to integrate a wide range of spatial and non-spatial data into a GIS environment for qualitative and quantitative assessment of multiple EGS. A number of previous studies suggested that spatial assessment of EGS would be useful for improving the management of production landscape for multiple EGS (Costanza, 2008; Bennett et al., 2009). Some of these highlight the urgent need for conservation actions based on available information rather than waiting for improved data and tools (Grantham et al., 2008, 2009) and others highlight the need for easy to apply methods (Burkhard et al., 2012). I use both biophysical and socio-economic data and successfully demonstrated that multiple EGS can be assessed with a mixed approach (qualitative and quantitative) involving readily available data and tools. This approach can potentially be rapidly applied elsewhere using available data. Mapping EGS flow is meaningful to policy makers for several reasons; (i) it helps identify which part of a landscape should be given priority due to their high supply of EGS (Balvanera et al., 2001); (ii) it helps to distinguish between supply and demand of EGS as a good basis for maintaining the balance (Burkhard et al., 2012; Crossman et al., 2013); and (iii) it is a useful tool for assessing spatial trade-offs and synergies among multiple EGS (see Egoh et al., 2008; Naidoo et al., 2009; Nelson et al., 2009; Raudsepp-Hearne et al., 2010).

7.3.2 SPATIAL ECONOMIC VALUATION FRAMEWORK

Previous studies have demonstrated the importance of spatially explicit valuation of ecosystem services (Costanza et al., 1997; Troy and Wilson, 2006). However, associated values have been primarily derived from the ‘benefit transfer approach’. In this thesis, I extended the work of Troy and Wilson (2006) by integrating both market and non-market valuation approaches into a GIS environment. This combined approach adds a new dimension to spatial economic valuation and the methodological framework presented in this thesis (Fig 4-1) can be easily replicated into new areas where multiple EGS need to be evaluated at the landscape scale.

7.3.3 METHODS OF IDENTIFYING FUTURE LAND-USE SCENARIOS AND EGS ASSESSMENT

Modeling future land-use scenarios and associated impacts on multiple EGS has been highlighted as an important area of investigation (House et al., 2008; Nelson et al., 2009). However, the majority of earlier studies examining the spatial pattern of the provision of multiple EGS were based on current land use (e.g., Chan et al., 2006; Egoh et al., 2008; Naidoo et al., 2008). Some studies have examined future land-use scenarios (House et al., 2008; Lindborg et al., 2009; Butler et al., in press). In this thesis, I demonstrated a method to identify a number of plausible future land-use scenarios and assessed associated EGS under each scenario. Different land-use patterns generate different bundles of services and associated economic profitability. This can be really important where land use and land cover is continually changing in accord with the changing demands of society.

7.3.4 MULTIPLE WAYS TO ANALYSE TRADE-OFFS AMONG EGS

Identifying trade-offs among EGS is important area of investigation (MEA, 2005; Rodriguez et al., 2006). Many earlier studies examined trade-offs among two EGS such as, timber and carbon (Seidl et al., 2007), carbon and water (Jackson et al., 2005), timber and biodiversity (Kant, 2002), and biodiversity and carbon (Caparros and Jacquemont, 2003). However recent studies recent studies focused on trade-offs among multiple EGS (Tallis and Polasky, 2009; Bryan et al., 2010; Hall et al., 2012; Onaindia et al., 2013). In this thesis, I demonstrated various ways of analysing landscape scale trade-offs among multiple EGS, associated with changes in land use and land cover, management choices and future land-use scenarios. Understanding multiple trade-offs helps policy makers in making informed decisions on land use and land cover change for current and future generations.

Chapter 2 assessed EGS qualitatively and demonstrated trade-offs among multiple EGS based on observed land-use changes over the past 200 years and planned land-use changes for the near future. Trade-offs among various EGS was inevitable in both cases (Figs. 2-2, 2-3; Table 2-5). This approach demonstrated how sensible conclusions can be drawn using a relatively simple conceptual approach and readily available data.

Chapter 3 advanced the trade-offs analysis by using a spatial approach of assessment of multiple EGS in a complex landscape. I collated readily available data and tools in a GIS framework (Fig. 3-1) and assessed EGS quantitatively and qualitatively. Finally I assessed the land use and land cover changes and flow of EGS using spider diagrams for three points in time (Fig. 3-4). Interestingly, in contrast to many other studies, changes in land use and land cover enhanced many EGS in the study area (Fig. 3-4). Trade-offs demonstrated by this analysis included reduced provision of water while timber production was increased due to commercial plantations. This provides an improved understanding to policy makers for allocation of land for different goods and services at the landscape scale.

Chapter 6 assessed EGS under various future land-use scenarios and also in monetary terms. As observed in previous chapters, the changing land use has positive and negative impact on provision of various EGS. Furthermore, the future land use depends on the decision of land owner whose anticipated rate of return depends on the market value of various goods and services. For example, while planting trees produces various positive environmental outcomes and public benefits to the society, the land owner may not be interested unless planting trees is profitable (see Fig 6-2). This demonstrates that the production of EGS is dependent on market value and associated economic returns. Appropriate policy intervention, such as payment for ecosystem services can motivate landowners to produce public EGS. Therefore trade-offs among EGS depends on multiple factors and understanding this complex reality is vital for land-use planning and decision making.

7.4 FUTURE RESEARCH DIRECTIONS

7.4.1 PAYMENT FOR ECOSYSTEM SERVICES

Payments for ecosystem goods have commonly occurred in markets throughout human history. However, payments for ecosystem services (PES) are part of a new and more direct conservation paradigm and an important area of investigation (Kosoy et al., 2008; Kemkes et al., 2009; Farley and Costanza, 2010; Cranford and Mourato, 2011). In this thesis, I identified and pointed to the requirement of PES or similar mechanisms such as market-based instruments which has been practiced in south-eastern Australia for some time. The underlying idea of PES is that EGS beneficiaries (which may include individuals elsewhere, firms or broader community through the government) make direct, contractual and conditional payments to local landholders in return for adopting practices that provide increased services, for example through ecosystem conservation and restoration. Therefore, better understanding of payments for ecosystem services or other incentive mechanisms that motivate landowners to supply public EGS is an important area of investigation.

7.4.2 EGS IN A CHANGING CLIMATE

Global environmental change coupled with other stressors, is affecting the ability of ecosystems to continue providing the quality and quantity of EGS required for human welfare. Assessments of climate change and its consequences for the provision of EGS have been the focus of more recent research efforts (Pearing, 2010; Dossena et al., 2012; Garcia-Lopez and Allue, 2012; Jochum et al., 2012). However, there is still considerable debate and uncertainty on the nature and extent of impact, due to variable projections and different climate change scenarios. Such ambiguity has hindered prompt adaptive responses, and societies may run the risk of going beyond critical tipping points (Bellamy and Hulme, 2011; Lenton, 2011). Further research on evidence of climate changes and observed and potential impact on various EGS can be useful for landowners and policy makers to design appropriate adaptation strategies.

7.5 CONCLUDING STATEMENT

Production landscapes provide humans with a wide variety of ecosystem goods such as food, fibre, forage and freshwater, those are essential to human well-being. The productivity and sustainability of these goods rely on the biodiversity and ecosystem services provided by natural ecosystems including, nutrient regulation, pollination, biological pest control, and hydrological services. The concept of EGS which includes both goods and services, constitute a promising idea for promoting sustainability in production landscapes. Demands for all EGS are increasing in line with the population. However current management practices are focused on production of ecosystem goods at the cost of many other services. Measuring EGS is a vital step for managing multiple EGS in order to (i) analyse trade-offs and synergies, (ii) value EGS and provide associated payments or compensation, and (iii) enhance the net well-being of societies in a sustainable manner. This thesis contributes to the emerging science of EGS by developing framework to assess, map and value multiple EGS at landscape scale and understanding the inherent trade-offs and synergies among them.

High hopes have been placed on spatial assessment, mapping and economic valuations of ecosystem goods and services to influence policy makers for coping with the accelerating degradation natural capital. However, many previous studies pointed to the challenges of availability of appropriate data and tools for EGS assessment for landscape planning (Naidoo et al., 2008; Seppelt et al., 2011). This thesis addressed some of these challenges by developing an 'easy to apply' approach for EGS assessment using readily available data and tools which can be applicable into resource and data-poor environments. Further research on payment of EGS and climate change and associated impacts will contribute to the EGS science and the development of effective land-use policy and decision-making.

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