The contribution of limited-focus land-use programmes in the provision of ecosystem services in New Zealand

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Abstract of a thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Economics.

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A common approach in the provision of Ecosystem Services (ES) is to develop comprehensive ES markets or establish payments for ES, both of which are complex and costly. As an alternative, this research has focused on (i) ES provided by different types of single or limited-focus, land-use programmes, (ii) people's preferences for different ES and effect on relative ES from single or limited-focus land-use programmes, and (iii) relative cost of delivering ES from single or limited-focus land-use programmes. To achieve these objectives, this research studied the ES from an afforestation (plantation) project and a reforestation project, either or both of which could arise from three forest-related programmes in New Zealand, the New Zealand Emissions Trading Scheme or ETS (a market approach), the East Coast Forestry Project (ECFP) (a subsidy/regulation approach), and the QEII National Trust (a partial subsidy through an NGO approach). Each programme provides incentives to landowners to plant and/or conserve trees on their lands to meet particular ES objective(s), but which also produce other ES. The impacts of the plantation forestry and natural reversion scenarios on flows of six ES – timber production, carbon sequestration, maintenance of water quality, regulation of water flow, soil erosion control, and natural habitat provision – were studied. For this purpose, biophysical models and a habitat function developed in New Zealand were used for estimating flows of ES (bio-physical assessment). Analytical Hierarchy Process and Max100 methods were used to derive preference weights for the flows of ES from members of the public (social assessment).

The Kaituna catchment in the Banks Peninsula was selected for the study site as it is on the Environment Canterbury list of potential flow-sensitive catchments. The results of converting steep, Class 4 and above land (about half of the catchment area) from existing sheep and beef grazing to

plantation forestry or to scrubland enhances a number of ES, namely climate regulation, water quality, erosion control, and natural habitat provision. However, water yield decreases by about 21 and 10 percent respectively in the plantation forestry and scrubland scenarios (an indicator that may be relevant in other low rainfall areas). Using a cumulative indicator score of all ES flows measured, calculated by normalising ES outputs for each land-use scenario, the plantation forestry scenario showed a higher combined ES flow score (1.88) than the scrubland scenario (1.39). The main reason for this is that timber revenue is foregone in the scrubland scenario and scrub stores less carbon than does plantation forests. The research also assessed three extreme (and less likely to occur) land use scenarios, in which all the land available in the catchment except Department of Conservation land, were converted to either plantation forestry, scrubland, or exotic pastures (dairy). In the extreme scenarios, an 'all plantation forestry' scenario gives the highest cumulative ES indicator score (2.77) whereas an 'all pasture (dairy)' scenario gives the lowest cumulative indicator score (-1.84).

A survey of members of the public in Canterbury found their preferences for ES in this order: water quality (regulating ES), followed by production (provisioning ES), other regulating ES (erosion control, and water yield, except carbon sequestration which was least preferred), and cultural ES. When ES indicator scores for each land-use scenario were weighted by preference weights, the rankings of which scenario provided the highest combined ES flows changed.

Different land-use programmes can be used for the provision of ES, but the relative costs of achieving the scenarios are different. The ETS had the lowest cost per hectare to deliver the programme. The treatment of extra land by natural reversion via QEII can be achieved at approximately half of the cost required for ECFP grants.

The research approach used demonstrates how readily available climate, landform, and soil data can be integrated with preferences of members of the public to analyse the impacts of land-use change on flows of ES without the need to monetise them. This research method is useful in situations where it is a struggle to find a balance between the interests of different stakeholders, while striving to maximise flows of ES at local, regional, and national levels.

Keywords: Ecosystem services, land use simulation, preference weights, cost analysis, New Zealand.

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List of Abbreviations

AAUs	Assigned Amount Units
AHP	Analytical Hierarchy Process
Alt	Altitude
ANP	Analytical Network Process
AVG	Average
CAA	Carbon Accounting Area
CBA	Cost Benefit Analysis
CI	Confidence Interval
CLUES	Catchment Land Use for Environmental Sustainability
CO_2	Carbon Dioxide
CO_{2e}	Carbon Dioxide Equivalent
CP	Commitment Period
CP2	Commitment Period 2
CR	Consistency Ratio
DOC	Department of Conservation
ECan	Environment Canterbury
ES	Ecosystem Services
ESApp	Ecosystem Services Approach
FAO	Food and Agriculture Organisation
GIS	Geographic Information System
GM	Geometric Mean
Km	Kilometre
LCDB2	Land Cover Database 2
LENZ	Land Environments of New Zealand
LUC	Land Use Capability
LUCAS	Land Use and Carbon Analysis System
m	metre
MAF	Ministry of Agriculture and Forestry
MAUT	Multi Attribute Utility Theory
MAV	Multi Attribute Value Theory
MAX	Maximum
MPI	Ministry for Primary Industry
MCDA	Multi Criteria Decision Analysis
MEA	Millennium Ecosystem Assessment
MfE	Ministry for the Environment
MIN	Minimum
mm	millimetre
NGO	Non-Governmental Organisation
NMV	Non Market Valuation
NZEEM®	New Zealand Empirical Erosion Model
NZIF	New Zealand Institute of Forestry
NZLRI	New Zealand Land Resources Inventory
NZUs	New Zealand Units
PES	Payments for Ecosystem Services
PFSI	Permanent Forest Sink Initiative
QEII	Queen Elizabeth II National Trust
RI	Random Index
RMA	Resource Management Act 1991

RP	Revealed Preference
SD/STDV	Standard Deviation
SMART	Simple Multi Attribute Rating Technique
SO_2	Sulphur Dioxide
SP	Stated Preference
SWING weighting	A method of eliciting relative weights on different criteria
WATYIELD	Water Balance Model

Chapter 1
Introduction

Human societies are heavily dependent upon nature for their survival and growth (Daily, 1997). The history of human civilisation reveals our dependence on nature; people very often lived close to areas that were abundant in natural resources and they could readily utilise nature's services which we now call ecosystem services (hereafter ES). History also reminds us how some societies have collapsed after the degradation of natural resources upon which they were dependent for their survival (Diamond, 2005). There has been a transition in human practices from mostly hunting in the Stone Age to the adoption of husbandry and agriculture which brought increased productivity when people started farming some 10,000 years ago (Fisher *et al.*, 2009). However, with the development of technologies and markets people began to domesticate nature more intensively by practicing mechanisation and using more synthetic fertilizers and pesticides, water, and improved crop varieties (Tilman *et al.*, 2002). Although this has helped to increase the average yield per hectare of cereals by 2.6 fold over the last 50 years (FAO, 2012) and produced cereals sufficient to feed the population globally, it has come at the cost of degradation of many ES which was highlighted by the first comprehensive ES assessment carried out at the global level (MEA, 2005). This report, called the Millennium Ecosystem Assessment (MEA) Report, links ecosystems and human welfare through use of an Ecosystem Services Approach (ESApp) and suggests governments and development practitioners could adopt this approach as a way to safeguard ES not only for the present generation but also for future generations. Following publication of the MEA Report many people have been looking for various ways by which ES could be restored or enhanced on both public and private lands. This research is a case study conducted in the Kaituna catchment, which evaluates the contributions of three forestry-related policies/programmes to ES provision.

1.1 An overview of ES

ES are the various goods and services produced as a result of complex interactions between ecosystem structures and processes (de Groot *et al.*, 2002), and which provide benefits to humans, directly or indirectly (Turner *et al.*, 2008). Thus, ES include directly consumable products such as food and fish that we eat and timber that we use for making houses and furniture. There are other categories of services called regulating ES which are not directly consumable but which provide benefits to humans in an indirect way such as flood regulation service which prevents property damages and loss of lives, pest and disease regulation services which help to control pathogens and insects respectively. MEA (2003) categorised ES into four distinct classes - provisioning, regulating, supporting, and cultural ES (Figure 1.1). However, there is a growing consensus among researchers to exclude supporting ES in ES valuations as they are used in the provision of other ES, meaning their values are already captured by other classes of ES (Daily *et al.*, 2009; de Groot *et al.*, 2010; Fisher *et al.*, 2009). This helps to avoid a double counting problem in ES valuation which was common in many early ES studies (Fisher *et al.*, 2009).

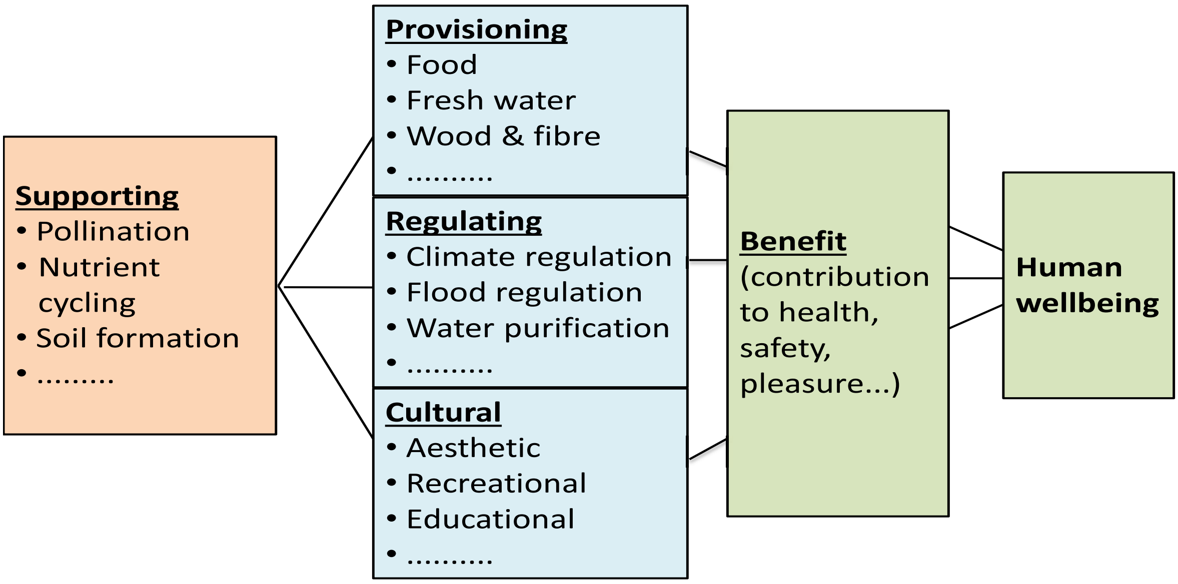

Figure 1.1 Linkage between ES and human wellbeing (from MEA, 2003, p. 13)

The ES approach or framework involves a series of steps that help to assess the impact of policies, programmes or projects on human welfare. It involves identifying changes in flows of ecosystem services, where these changes occur and by how much, valuing them in monetary and/or non-monetary terms, involving relevant stakeholders in various stages of ES assessment and decision making (de Groot *et al.*, 2010; Hein *et al.*, 2006). Therefore, it is useful for undertaking assessment as it includes not just a few ES that are traded in markets (tangibles) but also it incorporates all other ES (intangibles) that are at risk of being ignored in many policy frameworks. Use of an integrated ES framework in decision helps us to recognise that ES are not free gifts of nature, but are valuable flows which need to be integrated in natural resource use decisions. However, ES assessment carried out at the global level showed that human actions have severely degraded many valuable ES, as explained in the next section.

1.2 Status of ES

Humans have altered ecosystems more profoundly than they would have changed naturally (MEA, 2003). These changes have altered many of the ecosystems and their functioning, at scales ranging from local to global. For example, human activities are responsible for the collapse of fish stocks in the North Atlantic Ocean and for the reduction of ultraviolet radiation protection of the atmosphere due to higher concentrations of chlorofluorocarbons (Turner *et al.*, 2008). The disservices in these two examples are the loss of fish provisioning from the ocean and increased skin cancer cases in the Southern Hemisphere respectively (Turner *et al.*, 2008). A more alarming picture of ES degradation became clear when the MEA (2005) pointed out that human activities have degraded nearly two thirds of the world's ES. Among the direct and indirect drivers of changes in ecosystems and their services, excessive nutrient loading and climate change have been identified as the most important (MEA, 2005). For terrestrial ecosystems, major drivers of change have been land cover change and the application of new technologies for increasing food, timber and fibre production. Although increased food production has contributed to the wellbeing of the world population, it has come at the cost of degradation of aspects of the environment such as soil, water, and biodiversity and reduced the flows of some ES (Gordon *et al.*, 2010; MEA, 2005). We should be worried about the degradation of ES as not only will it make the present generation worse off by impairing the flow of ES but it will also affect future generations if they have to bear the costs of degraded ecosystems. Further, there are concerns that degradation of ES disproportionately affects poor households who are marginalised from the market economy (Dasgupta, 2002). Hence, there is an urgent need to find ways by which ES could be sustained or enhanced for supporting human welfare on earth. Before we look at those mechanisms, it is important to understand why there is such a widespread degradation of ES despite their vital role in human welfare.

1.3 Reasons for widespread degradation of ES

Various explanations have been advanced to explain the widespread degradation of ES. First, some ES are what economists refer to as public goods. This means use of these services by one person does not reduce their quantity available for consumption by others (non-rivalry) and no one can easily be excluded from consuming benefits from these services once they are provided (non-excludability) (Daly & Farley, 2004). Some examples of pure public goods are public defence systems, sunshine, and protection from UV rays, but other goods such as open access resources or common pool resources are quasi-public goods which are rival but non-exclusive (Tietenberg, 2006). It is the lack of excludability that prevents resource owners from getting full benefits from them due to free riding behaviour by those who cannot be excluded from consuming ES once they are provided. This results in incomplete or missing markets where people do not have incentives to engage in the provision of ES (Kroeger & Casey, 2007). Second, perverse subsidies and current market structures favour conversion over conservation of some resources by encouraging farmers to abstract more water, apply more chemical fertilisers and pesticides for producing marketable goods (Kemkes *et al.*, 2010). Although this has often led to enhancement of crops, livestock, and aquaculture, some services such as water for drinking and recreation have been severely degraded. Third, lack of incorporation of ES values into resource allocation decisions is cited as the major cause of ES degradation (Kroeger & Casey, 2007; MEA, 2003). There are two reasons for this, one is considering ES as free gifts of nature, and the second is unavailability of methods and tools to measure and value non-marketed ES until the development of non-market valuation (NMV) techniques. Not all ES can be valued with the most advanced NMV techniques available. However the bottom line is that, unless stewards of natural resources are paid or incentivised for the provision of ES, they are unlikely to engage in activities which promote maintenance or provision of public or quasi-public goods (Jack *et al.*, 2008).

1.4 Approaches to the provision of ES

In order to internalise the costs and benefits of ES that are left out of consideration by general markets, various mechanisms have been implemented worldwide which can be grouped into the following categories (Kroeger & Casey, 2007; Perrings, 2009).

- Regulation: Emission standards, harvest restrictions, quotas
- Moral and ethical tools: Education and training, information flows, duty of care
- Economic incentives: Taxes, subsidies, grants, payments for ES, eco-labelling, user fees, access fees and charges
- Market instruments: Mitigation markets, emission trading of carbon dioxide and sulphur dioxide, nutrient trading

Regulatory instruments can be difficult to enforce, they impose transaction and implementation costs, and do not encourage people to change their behaviour for the benefit of society (Kemkes *et al.*, 2010). Ethical tools work through community awareness, education and training, but tend to be less certain in their impact due to a lack of incentives. Providing tax incentives or subsidies for desired outcomes or imposing fees and taxes on undesirable outcomes such as pollution can be effective in achieving environmental improvement, but does involve administration costs. Further, taxes and charges can be implemented within existing institutions, but equity is of concern if a landowner has to pay for the provision of ES while others can enjoy ES benefits at no costs.

Subsidies are often criticised for the distortions they create - their impact on trade and food security, in countries like Japan, and European countries which heavily subsidise their farmers. Another subsidy type approach (whether financed from tax payers money or fees from voluntary users) in the provision of ES is payments for ecosystem services (PES) which is based on the principle that those benefiting from ES should pay for their provision (Gómez-Baggethun *et al.*, 2010). The form of PES range from government financed country-wide program called *Pago por Servicios* Ambientales (PSA) for reducing deforestation in Costa Rica (Pagiola, 2008) and the Programme for Hydrological Environmental Services in Mexico (Muñoz-Piña *et al.*, 2008), to user financed programmes such as in-kind payments for bird habitat and watershed protection in Los Negros, Bolivia (Asquith *et al.*, 2008) and Forests Absorbing Carbon-dioxide Emissions Forestation Program (PROFAFOR) in Ecuador (Wunder & Albán, 2008). However, initial assessments have shown that PES programmes need a great effort in implementation, are expensive to operate, difficult to withdraw once in place, and even counterproductive in some cases (Stone & Wu, 2010). Further, long-term finance is an issue in PES programmes, and with government payment programmes there is danger of people striving for money and undermining a duty of land care (Salzman, 2005).

In the US, markets have been developed for controlling Sulphur dioxide (SO_2) emissions by issuing permits to polluters which can be sold or bought in the domestic market (Stavins, 1995). Similarly, markets have been created for wetland protection through mitigation banking in the US and for carbon dioxide (CO_2) by issuing tradable permits in the US, Europe, New Zealand and Australia. Given the fact that these markets are government constructed and backed by monitoring and enforcement (e.g. wetland banking), there is no incentive for firms to provide ES outputs beyond what is required by government policy (Salzman & Ruhl, 2000). However, cap and trade mechanism provides an opportunity of generating new source of income to those who have excess allowances as these extra resources can be invested in low carbon technologies or practices.

In summary there are a variety of tools available to governments for motivating private landowners in activities that maintain or enhance ES on private lands. To this end, economic instruments have advantages over prescriptive policies due to greater flexibility, certainty, and lower compliance costs (Whitten *et al.*, 2004). Markets are superior to PES due to lower transaction costs, but creating ES markets require measuring flows of ES and their values, establishing institutions that enforce property rights and carrying out monitoring activities. The latest trend is the application of PES as a way to maintain or enhance quasi-public goods, but as explained earlier there are downsides of such payments too. This suggests that no policy or scheme is as yet a panacea for the provision of ES. As such different approaches need to be tested, evaluated, and adjusted to fit the existing socioeconomic, political and cultural contexts for better outcomes. Hence, as Carpenter *et al.* (2009, p. 1309) suggest, there is a need to identify 'what institutions, incentives, and regulations are effective in sustaining flows of ES?' In this context this research studied three limited-focus land-use programmes that provide different incentives to landowners to change their land-use for improving usually a single service, yet end up with multiple benefits.

1.5 New Zealand context

After the arrival of humans in New Zealand about 740 years ago, much of the country's landscape has been modified to fulfil human interests (Wilmshurst, n.d.). The most notable changes were massive clearance of indigenous forests, scrub, tussock and draining of wetlands to make land available for farming, human settlements and infrastructures. Compared to pre-human time, only 28 percent of indigenous forests and 10 percent of wetlands remain in the country (Ausseil & Dymond, 2010; Johnson & Gereaux, 2004). Although utilisation of ecosystem services for primary production (agriculture and forestry) and tourism has contributed to the economic growth of the country, it has come at the cost of degradation of water, soil and biodiversity due to clearing of native vegetation and intensifying land-uses (Baskaran *et al.*, 2009; Clark *et al.*, 2007; Cook, 2008; Hughey *et al.*, 2008; Ministry for the Environment, 2009; Moller *et al.*, 2008). This degradation has been reflected in a series of 'public perceptions of New Zealand's environment' reports where New Zealanders have repeatedly chosen deteriorating water quality as the most pressing environmental issue in consecutive years (Hughey *et al.*, 2008); 2013). Maintaining a resilient ecosystem is vital for the country's largest primary industries (agriculture, forestry, and fishing) and for tourism as they are directly dependent on the flows of ES. Therefore, safeguarding New Zealand's economy will require sustaining or enhancing not just provisioning and regulating ES but also cultural ES which are valued by both locals and international visitors.

The government of New Zealand has adopted various legislation for the protection and maintenance of natural resources, but the Resource Management Act (RMA) of 1991 is the overarching legislation which guides the management of land, forests, pollution, traffic, water and air (Parliamentary Counsel Office, 1991). Although the RMA does not explicitly mention ES, it has procedures that fit into the concepts of an ecosystem services delivery framework (Coleman, 2009). Under the RMA, regional, district, and city councils are responsible for managing natural resources within their jurisdiction. The efforts of regional councils in the past have mainly focused on the provision of food or fibre (provisioning ES), but this situation is changing as increasing numbers of people are raising their concerns for multiple ES and regional and district councils are seeking ways by which interests of different stakeholders are accommodated. Recently, the term ecosystem service has been explicitly mentioned in regional policy statements, for example Directive 7.1 of The Auckland Plan makes it clear that ES need to be acknowledged and accounted for in every decisions made for Auckland (Auckland Council, 2014). An ecosystem services objective (objective 3.7) has been included in the proposed Waikato Regional Policy Statement thereby giving it a high priority in the decision making of natural resources (Hart *et al.*, 2012).

The New Zealand government has implemented a variety of policy approaches for enhancing ES on private lands. This range of mechanisms includes Acts, By-laws, rules and regulations, grants, trading of ES in national and international markets and voluntary approaches. Table 1.1 lists important ones which controls and/or motivates individuals and businesses to induce land-use changes.

Table 1.1 Policy approaches that enhance ES on private land in New Zealand

Policy approach	Programme/scheme	Sector	ES targeted
Market	The Emissions Trading Scheme	Forestry, agriculture, energy, transport	Carbon sequestration
	Permanent Forest Sink Initiative (PFSI)	Forestry	Carbon sequestration
	Nutrient trading (nitrogen)	Agriculture	Water quality
Incentive	Afforestation Grant Scheme	Forestry	Carbon sequestration
	East Coast Forestry Project	Forestry	Soil erosion
	Hill Country Erosion Programme	Forestry	Soil erosion
	Nga Whenua Rahui Fund, Biodiversity Condition Fund, Natural Heritage Fund	Agriculture and forestry	Biodiversity conservation
Regulatory	Resource Management Act 1991	All sectors	Not specific to ES but has provision for the protection of soil, water and air
	Climate Change (Forestry Sector) Regulations 2008	Forestry sector	Climate regulation
	Water Conservation (Motueka River) Order 2004	All sectors	Water quantity and quality, cultural, aesthetic values
Voluntary	QE II National Trust, Forest and Bird, Landcare Trust	Agriculture and forestry	Biodiversity, soil, water

Market Approach

In recent years, the government has introduced market mechanisms to promote the climate regulation service of forests by putting a price on carbon (CO_2 sink), and a cap and trade mechanism to reward landowners who discharge lower than the permitted amounts of nutrients (nitrogen) into lakes as they can sell their unused quantities of nutrient discharges to those who cannot reduce their discharge to the capped limits (Waikato Regional Council, 2010). For example, ETS gives landowners an incentive to earn carbon credits at the rate of one New Zealand Unit (NZU) for one tonne of carbon dioxide (CO_2) gas removed from the atmosphere (removals) or liability to surrender one NZU for release of one tonne of CO_2 to the atmosphere (emissions) (Ministry for Primary Industries, 2011). The NZUs are mainly traded in the domestic market but some of these can be converted to Assigned Amount Units (AAUs) for selling overseas (Ministry for Primary Industries, 2011). Landowners participating in the Permanent Forest Sink Initiative (PFSI) earn carbon credits in the form of AAUs due to a covenant on the land for perpetuity. The covenant can be terminated only after 50 years and limited harvesting is allowed on a continuous cover basis.

The Emissions Trading Scheme (ETS) is the main New Zealand government response to its commitment to reduce greenhouse gases under the framework of United Nations Framework Convention on Climate Change and Kyoto Protocol (Ministry for Primary Industries, 2011). The main purpose of the ETS is to create a financial incentive for businesses and consumers by putting a price on carbon emissions. It covers almost all sectors of the economy, but the forestry sector was the first sector to participate in ETS from January 2008. In the forestry sector, landowners can earn carbon credits equivalent to the amount of atmospheric carbon dioxide gas sequestered in pre-1990 and post-1989 forests. Thus, for one tonne of carbon dioxide equivalent (tCO_2e) stored in trees, landowners earn one carbon credit which is measured in New Zealand Units (NZUs). Conversely, it also carries deforestation liabilities meaning that if a landowner releases 1 tCO_2e into the atmosphere, s/he has to surrender 1 NZU. In this way, ETS creates a market for carbon which previously had no price.

Incentive Approach

As can be seen from Table 1.1 incentive mechanisms include grants which aim to motivate landowners to undertake activities that promote quasi-public goods. These grants are mainly targeted at controlling soil erosion through sustainable land management practices. These include the East Coast Forestry Project, the Afforestration Grant Scheme (AGS) and the Hill Country Erosion Programme. The ECFP provides grants to landowners for planting trees or effectively managing natural reversion on severely eroding hills and adjacent lands in Gisborne region (Ministry of Agriculture and Forestry, 2007). These lands are identified as overlay 3A lands in the rule set by Gisborne District Council. The AGS is administered through tender mechanism which is open to all individuals and organisations. Hill Country Erosion Programme targets soil protection throughout New Zealand.

After Cyclone Bola caused extensive damage in the Gisborne region, the East Coast Forestry Project was continued because planting trees on slopes was a cost effective ways to reduce soil erosion (Ministry of Agriculture and Forestry, 2008). As controlling soil erosion provides several social benefits, the New Zealand government has committed to provide funds for the project until 2020. The project provides grants to landowners to maintain effective tree cover on eroding hills and adjacent areas in the East Coast region. The key point is that the funding is about getting some trees established either by planting or by encouraging natural regeneration. Harvesting is permitted but it has to be immediately followed by new planting to maintain an effective ground cover for the duration required by the ECFP covenant (at least 50 years).

Regulatory Approach

The main legislation for environmental planning and management in New Zealand is the RMA which controls all activity that are likely to damage the environment. Under the jurisdiction of the RMA, district and regional councils are responsible for managing natural resources in a way that people get benefit from them without compromising the environment. In this regard, district and regional councils have their regional plans which lists permitted activities and other activities that can affect the environment. The risky activities that can have a negative impact on the environment are controlled through the Resource Consent mechanism where people can oppose by submitting a written submission. Some examples, which require resource consent, include disposing waste into a stream, new forest plantings in flow sensitive catchments, building a dam on a river, or establishing a dairy farm.

Voluntary Approach

There are some voluntary organisations like QEII Trust, which are active in the protection and conservation of native flora and fauna, natural areas, wetlands and cultural heritage. One such organisation is the QEII National Trust, which provides partial support to those who are involved in the protection of natural and other areas of national significance on their private lands (QEII National Trust, 2010). With the QEII programmes, the main driving force is landowners' pride and satisfaction from protecting unique native species as well as some cash support for fencing and controlling pests. Forest and Bird is a not-for-profit organisation involved in protecting native species and natural areas through its 50 branches, but it does not receive funding from the government as the QEII Trust does. Likewise Landcare Trust is also a not-for-profit organisation which promotes sustainable land management with active support from local communities. Although these programmes are voluntary in nature, they do provide some incentives (partial) to landowners who are willing make desirable changes on their private land that helps to enhance public goods (e.g. biodiversity). These organisations get funding from government, some private organisations and voluntary members.

The Queen Elizabeth II National Trust, a statutory organisation established in 1977 under its own Act of Parliament, helps interested landowners and organisations to protect special features on private land. The mechanism providing long term protection is by registering an open space covenant on the title of the land so that it binds the current and all subsequent landowners in perpetuity (QEII National Trust, 2010). Using this approach, the QEII Trust has been successful in protecting a diverse range of special features on private lands such as native forest remnants, wetlands, cultural sites, and wildlife habitats which provide wider social benefits. The motivation for landowners to enter a QEII Trust covenant is some financial help that is available from the QEII Trust and other organisations such as the Department of Conservation and Regional Councils for fencing and pest control measures and the utility that comes from protecting unique heritage of New Zealand on their land. This research studied ETS, ECFP and QEII National Trust in the provision of ES. In this research, limited-focus land-use programmes mean those programmes that usually have a single focus. For example, ETS focuses on carbon sequestration, ECFP focuses on soil conservation and QEII focuses on conserving biodiversity by fencing off areas of national significance and areas that can revert to indigenous forests if animals are destocked. In order to demonstrate the impact of land-use change on flows of ES, Kaituna catchment was selected as it is near from the campus, yet offers a diversity of land-use within a varied topography. However, the method used in the research is applicable to any site in New Zealand.

1.6 Research problem

As explained above, there are market based initiatives such as the ETS and PFSI which give farmers the opportunity to earn carbon credits that are saleable in domestic and international markets respectively, and grant based schemes such as the Afforestation Grant Scheme and the ECFP which provide grants to individuals or groups for planting trees or managing natural regeneration on their lands (Ministry of Agriculture and Forestry, 2011a). These forestry programmes or PES programmes that have been implemented elsewhere (as for example Costa Rica, Ecuador, Mexico, etc.) usually focus on a single service. For example, ECFP focuses on soil conservation; ETS focuses on climate regulation through carbon sequestration; and PES usually focus on watershed protection (Wunder & Albán, 2008) and/or biodiversity conservation (Asquith *et al.*, 2008; Turpie *et al.*, 2008).

However, in the provision of a particular ES there are spill-over effects of providing other ecosystem services. As an example, planting exotic trees on hills not only prevents soil erosion and stabilises slopes, but it also enhances other ES such as water quality, air quality, biodiversity, climate regulation through carbon sequestration, and aesthetics (Cawsey & Freudenberger, 2008; Maunder *et al.*, 2005; Myers, 1997; O'Loughlin, 2005). In addition, it may also reduce water yields that reaches catchment streams (O'Loughlin, 2005). Hence, limited-focus programmes with spill-over effects (positive or negative) may provide simple and cost effective ways of ensuring a wide range of ES are provided. However, we do not know the actual or likely impacts of forestry programmes on the provision of a wide range of ES nor the costs of those programmes per unit of total ES generated. In this regard, this research studied the cost-effectiveness of provision of a wide range of ES by the New Zealand ETS, the ECFP, and the QEII National Trust.

1.7 Research questions

The main aim of the research was to find out if limited-focus land-use programmes provide an alternative to broad ES markets that are difficult to establish, complex, and costly. The specific research questions were:

- Do limited focus land-use programmes provide broad ES outcomes?
- Are there differences in ES outcomes between the ETS (market based), the ECFP (regulatory/grant based) and the QEII (voluntary local NGO) approaches?
- Which approach/programme is the most cost effective in the provision of ES?
- What are the public's preferences for different ES?

1.8 Justification of the research

New Zealand has been divided into sixteen regions of which Canterbury region is the largest in area and the second largest in population after Auckland region. Following the arrival of European settlers in 1850, much of the land in Canterbury was gradually developed for sheep farming. However, over time, Canterbury has witnessed a major land-use change particularly from traditional sheep farming to dairy farming. The area under dairy has increased from less than 16,000 hectares in 1982/83 (New Zealand Dairy Board, 1983) to nearly 220,000 hectares in 2011/12 (DairyNZ, 2012). Canterbury is also major producer of cereals, in 2011 supplying 88.5 and 67.2 percent of the country’s total wheat and barley production respectively (Statistics New Zealand, 2012a). These land-use changes have been supported by a 260 percent increase in irrigated area from 1985 to 2005. About 90 percent of the water abstracted is used for irrigated agriculture (Sage, 2008). At present Canterbury region not only allocates 58 percent of New Zealand's water for consumptive use, but also it has the highest dependency on water during dry periods (Canterbury Mayoral Forum, 2009). Further, the demand for water is expected to increase as there is an estimated future potential of 1,002,420 hectares irrigated area in Canterbury by 2021 (Morgan *et al.*, 2002). This calls for managing water in Canterbury sustainably, but equally important is to manage the whole range of ES for the long-term sustained production and growth of the region.

The Canterbury Regional Council (Environment Canterbury or ECan) is responsible for managing natural resources in the region. In the past, many of the council's efforts have focused on provisioning ES (cereals and dairy), but the situation is changing as people are concerned for regulating and cultural ecosystem services. People are showing their increasing concern for regulating services that determine water yield and water quality. In response, ECan has prepared a list of flow-sensitive catchments where forestry is restricted and potential flow-sensitive catchments where forestry is regulated. However, restrictions on forestry are based on heavy emphasis on water yield leaving aside other important ES such as carbon sequestration, water quality and soil erosion control. Second, peoples' preferences are rarely included in deciding which land-use to regulate and by how much. Third, it is important to encourage people in activities that promote the social good (ES) at minimum social cost.

What is required is an approach or a method that provides a framework for assessing impacts of land-use change on flows of ES, and integrates stakeholders' preferences in land-use decisions. The method used in the research, which is an ecosystem services approach, is simple to use, yet provides a holistic framework for integrating peoples' preferences in land-use decisions that affect flows of ES. This method is useful in situations where it is difficult to value certain ES in monetary terms, mainly those in the cultural ecosystem services group, as it uses weighted indicator scores for assessing impacts of land-use on flows of ecosystem services. Resource managers and policy makers can use this framework for assessing contributions of land-use programmes in the provision of ES.

1.9 Contribution of the study

This study is important in the New Zealand context where current land use practices have severely degraded some ES (Baskaran *et al.*, 2009; Clark *et al.*, 2007; Cook, 2008; Hughey *et al.*, 2008; Ministry for the Environment, 2009; Moller *et al.*, 2008). Degradation of ES will not only impair biophysical aspects of ecosystems, but it will also impair the ES base which is essential for sustaining major industries in New Zealand - hydropower, tourism, agriculture, and forestry. As there are uncertainties about the future of carbon markets in the post-Kyoto phase and requirements of effective and credible institutions for monitoring progress of PES programmes, it is important to look for possible ways of enhancing ES on private lands at minimum cost. For this purpose the research studied the application of limited-focus land-use programmes in order to find out if they provide an alternative to broad ES markets that require a great deal of effort and resources to make them function.

Ecosystem services indicators were used for measuring changes in ES flows, which were then normalised and integrated with preference weights to assess the contribution of limited-focus land-use programmes in the provision of ES. The method used in the research provides an alternative to economic valuation methods. By assessing the contribution of limited focus land-use programmes in the provision of multiple ES, the study has identified the most cost effective land-use programme amongst existing institutions for enhancing ES in New Zealand. Further, the research shows how normalised indicator scores and weighted indicator scores can be used in evaluating the contribution of land-use in the provision of ES. The method is simple, can be used with readily available biophysical data, and yet provides a holistic approach combining ES flows with societal preferences which are often poorly integrated in decision making on natural resources.

1.10 Outline of the thesis

The thesis is arranged as follows. Chapter 2 reviews the literature on forest ecosystem services in general, and methods of modelling flows of ES, their valuation, and the importance of integrating peoples' preferences into land-use decisions. Chapter 3 describes data collection methods and sources of data, the research site, biophysical models used for estimating flows of ES, and preference weight elicitation methods used in the study. Results of land simulations and weight elicitations are presented in Chapter 4 and 5 followed by normalisation of indicator scores and weighted indicator scores in Chapter 6. Chapter 7 is dedicated to appraisal of limited focus land-use programmes and presents data on the cost of those programmes. Chapter 8 discusses the findings of the research in light of previous studies and finally Chapter 9 presents a summary of the main findings, conclusions, and policy implications as well as limitations of the study and possible areas for future research.

Chapter 2

Measuring ecosystem services

2.1 Introduction

The MEA (2005) report highlighted the extent of ecosystem services degradation worldwide and their implications on human wellbeing. It places responsibility on governments for designing policies and institutions that encourage landowners in the provision of ES for the benefit of society. This requires identifying and measuring flows of ES, valuing them, and establishing institutions that provide incentives to those who are involved in the stewardship of natural resources (Daily *et al.*, 2009). However, this task is complex due to the fact that ES have some unique characteristics, both public and private good aspects; spatial and temporal dynamism; benefit dependence; joint production; and complexity (Fisher *et al.*, 2009). This calls for understanding ecosystem service characteristics and applying them to a decision making context. There is a need to look for practical ways of retaining and enhancing flows of ES, valuing them and using social weights in land-use decisions that affect flows of ES. For this purpose, limited-focus land-use programmes were studied to determine if they offer cost-effective ways of enhancing ES on private land. In order to answer the research questions raised in Chapter 1 information is needed on the levels of ES from forests. Research methods are needed to estimate flows of ES, to elicit public preferences for ES and to integrate that information into land-use decision making.

2.2 Framework for ES assessment

Although many issues and challenges still lie ahead to integrate the concept of ES in every natural resources use decision, integrated frameworks have started to emerge especially after the release of the MEA report (Daily *et al.*, 2009; de Groot *et al.*, 2010; Hein *et al.*, 2006; Liu *et al.*, 2010). The central theme of these frameworks is the adoption of ES approach put forward by MEA (2003). Among these, a simple framework is depicted in Figure 2.1. The ES framework involves a system approach that extends from identifying ecosystem functions, goods and services through to valuations and creating incentive mechanisms to motivate people involved in activities that promote ES maintenance and provision.

Defining and classifying ES is the first step in the framework depicted in Figure 2.1. Ecosystem services are "the benefits people obtain from ecosystems" MEA (2003, p. 3). This definition has been criticised for mixing ecosystem products and functions or processes and benefits together and making economic valuation difficult (Boyd & Banzhaf, 2007; de Groot *et al.*, 2002; Turner & Daily, 2008). According to Boyd & Banzhaf (2007, p. 619), ES refer to "components of nature, directly enjoyed, consumed, or used to yield human wellbeing". This definition argues that ES are ecological components of nature and makes a clear distinction between services and benefits to humans. However, one criticism of this definition is that ES do not necessarily have to be directly consumable end products (Fisher *et al.*, 2009). Hence, this research adopts the view that ES are ecological outputs that are consumed by humans, either directly or indirectly, to derive benefits (Turner & Daily, 2008). This definition is people-centred as it says that goods or services are ES only if they are valued by humans.

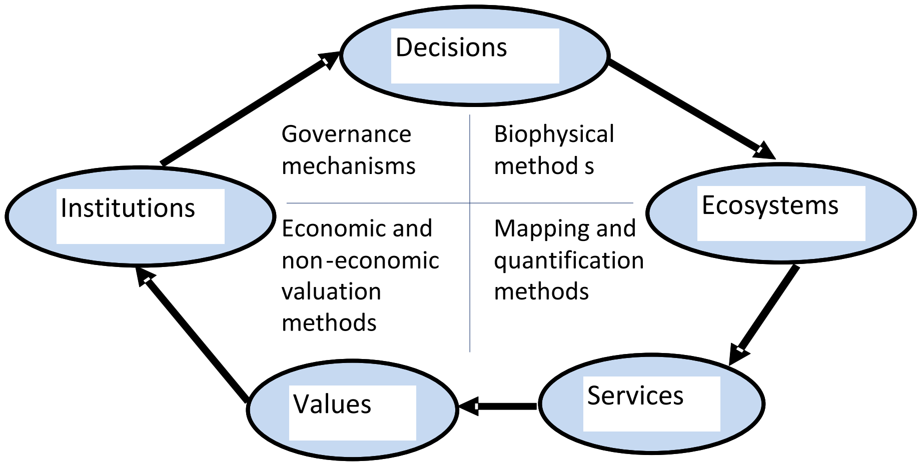

Figure 2.1 Integrated framework for implementing an ecosystem services approach (adapted from Daily *et al.*, 2009)

As the main aim of the research was to assess the contribution of limited focus land-use programmes in the provision of ES, which basically involves planting exotic trees or facilitating regeneration of native vegetation, the literature review was focused around ES flows from forests.

2.3 ES from forests

Forests provide a range of ES which can be grouped as provisioning, regulating and cultural (Table 2.1). Supporting ES (nutrient cycling, primary production) are intermediate to the production of these three groups of ES (Barkmann *et al.*, 2008; Layke, 2009). The range of ES listed in Table 2.1 can be obtained from a natural forest. However, commercial plantations have been established to fulfil timber demands and prevent natural forests from deforestation; globally plantation forests comprised 264 million hectares or 7 percent of the total forest area in 2010 (FAO, 2010). Of this, native and introduced species covered three-quarter and one-quarter of the plantation area respectively (FAO, 2010). So, plantations have a major role in the provision of timber.

Table 2.1 Various ES that a natural forest ecosystem provides

ES category	Examples of ES	Description of ES
Provisioning ES	Food	Forest ecosystem supplies food (e.g. wild fruits)
	Fibre	Forest ecosystem supplies extractable renewable raw materials (e.g. fuelwood, fodder, logs)
	Biological products	Forest ecosystem supplies biological resources that can be developed into biochemicals for medicinal or commercial use
	Ornamentals	Forest ecosystem supplies a variety of resources that can be used as ornamentals (e.g. furs, orchids, butterflies)
	Freshwater supply	Forest ecosystem supplies freshwater for use and storage
Regulating ES	Climate regulation	Forest ecosystem regulates albedo, air temperature, and precipitation and acts as both source of and sink for greenhouse gases
	Disease regulation	Forest ecosystem regulates abundance of pathogens
	Pest regulation	Forest ecosystem regulates abundance of pests
	Water regulation	Forest ecosystem regulates timing and volume of river and groundwater flows
	Water purification	Forest ecosystem purifies and breaks down excess nutrients and pollution
	Erosion control	Forest ecosystem helps in erosion control by stabilising soil
	Natural hazard regulation	Forest ecosystem regulates and protects against extreme natural events (e.g. floods, landslides, storms, droughts)
Cultural ES	Educational values	Forest ecosystem provides opportunities for scientific research and learning
	Conservation values	Forest ecosystem provides existence values for species including important values relating to biodiversity
	Aesthetic values	Forest ecosystem provides aesthetic (scenery) and amenity values
	Heritage values	Forest ecosystem provides cultural, historical, spiritual, religious qualities (sacred forest, Maori values)
	Recreational values	Forest ecosystem provides opportunities for recreational uses (e.g. hiking, biking, camping, ecotourism)

Source: (Adapted from Hanson *et al.*, 2010; Hernshaw *et al.*, 2010; Krieger, 2001; Nasi *et al.*, 2002)

In the New Zealand context, plantation forestry plays a major role in the landscape, covering about 1.8 million hectares (6.7% of total land area), of which the exotic species *Pinus radiata* alone covers 89 percent (Ministry of Agriculture and Forestry, 2009b). There are mixed views with regards to the contribution of plantations in the provision of ES. Some consider commercial plantation poor in biodiversity or even as “biological deserts” (Stephens & Wagner, 2007) while others see plantations as not just a provider of timber, but as providers of several ES such as carbon sequestration, erosion control, water and nutrient retention, creation of habitats, aesthetics, and recreation (Cawsey & Freudenberger, 2008; Maunder *et al.*, 2005; Myers, 1997; O'Loughlin, 2005). Recent studies in New Zealand have shown peoples' preferences for regulating and cultural ecosystem services provided by plantation forests as they were willing to pay for the improvement in water quality (lower sediments and algae) (RivasPalma, 2008) and enhancement of biodiversity in those forests (Yao, 2012).

Studies conducted in New Zealand have shown wider benefits of *Pinus radiata*, mainly stabilising slopes and preventing mass movements due to soil reinforcement by well-developed root systems about 10 years after planting (O'Loughlin, 2005); reducing small flood events (Davie & Fahey, 2005); providing many ES and contributing to indigenous biodiversity (Maunder *et al.*, 2005) or in some cases even providing better habitat for indigenous fauna than many pest infested indigenous forests (O'Loughlin, 2005). Similarly studies in New Zealand have shown that, land with forest (native or exotic) or scrub cover reduces landslide susceptibility by at least 80 percent compared to land without woody cover (Dymond *et al.*, 2006). Also plantations store a significant amount of carbon in their biomass, deadwood and forest litter (Ford-Robertson *et al.*, 1999; Manley & Maclaren, 2012). On the other hand, studies in New Zealand have shown that pastures planted with *Pinus radiata* have reduced annual water yield in catchments by at least 30 percent (O'Loughlin, 2005) and, in southern Chile, watersheds planted with *Pinus radiata* led to reduced water yields (Lara *et al.*, 2009). Hence, in catchments that have water shortages during summer, planting trees may reduce water yields below critical level required to maintain a flow for in-stream values, household consumption, and irrigation purposes.

It is well understood that the ES listed in Table 2.1 are the products of complex ecosystem functions and processes, but the complete understanding of quantitative relationship between ecosystem components and functions and services is one of greatest challenges in ecology (de Groot *et al.*, 2010; de Groot *et al.*, 2002). The non-availability of a complete set of indicators for ES, especially for regulating and cultural ES; their distinct characteristics such as joint-ness, (non) rivalry and non-excludability; and their variability over space and time make it difficult to accurately estimate flows of ES in any environment. Nevertheless, the quantitative relationship between land-use and the provision of ES can be studied with the help of biophysical models, though still limited to a few ecosystem services that fall in the provisioning and regulating ES class.

2.4 Modelling flows of ES

Modelling flows of ES is a difficult task as the interaction between living organisms and the environment that give rise to ES, is a complex process. Ecosystems are complex, dynamic, and evolving which means services they provide also change over time and space. One of the biggest challenges in ecological modelling is a lack of a clear understanding about the interdependencies between ecosystem structures and biodiversity and functioning of ecosystems (Braat & de Groot, 2012). Although it is still difficult to quantify the relationship between ecosystem components and processes and the services they provide, there have been achievements made on how a single service changes with respect to changes in ecological variables in a small area (Hougner *et al.*, 2006; Kaiser & Roumasset, 2002; Kremen *et al.*, 2002; Ricketts *et al.*, 2004). Even though these single service studies assess value of ES at much finer scale, they miss out many important ES and geographic and temporal scales at which most policy decisions have to be made (Nelson *et al.*, 2009). Studies that integrate multiple ecosystem services at the regional and global scales have also started to appear (Chan *et al.*, 2006; Naidoo & Ricketts, 2006; Nelson *et al.*, 2009). Global models such as IMAGE-GLOBIO and MIMES and regional models such as ARIES (http://ecoinformatics.uvm.edu/aries/) and InVEST (http://www.naturalcapitalproject.org/InVEST.html) are opening up new opportunities in ES modelling and decision making.

In the context of decision making, it is important to integrate all ES at relevant scales because failure to do so will give only partial estimate of ES, which may provide the wrong guidance to policy (Barbier & Heal, 2006). This was also the conclusion in the recent work by Bateman *et al.* (2013) where the authors have demonstrated how economic valuation methods can be combined with spatially explicit models for estimating values of both marketed and non-marketed ES in dollars. However, lack of data and resources, especially in developing countries, may limit usefulness of these national and global models. As the status of ES at the regional or national level is the cumulative impact of land-use decisions made at property, farm, or catchment levels, we need models that can assess impact of land-use change on ES at the levels where land-use decisions are actually implemented. This is where farm or catchment level models fit in.

A biophysical model is a simplified representation of reality which can be used to predict outcomes (e.g. crop yields, sediment load etc.) due to changes in land-use, environment or management factors (Rossiter, 2003). It tells us how biophysical processes and environmental factors affect production or flows of ES. Some ES models also have socio-economic elements to estimate flows of ES in economic terms. Bio-physical models can be used for *ex-ante* evaluations where alternative land-use scenarios can be compared with the existing or base scenario to find out likely changes in ES or in the *ex-post* evaluations of a project, policy, or a programme if baseline data and time series data after the intervention are available.

In New Zealand, biophysical models have been developed for analysing flows of selected ES. The WATYIELD model developed by Landcare Research is useful for analysing the effects of land use on annual water yields and low flows even when there is limited amount of data on climate, soils, and vegetation of a catchment (Fahey *et al.*, 2004). Water quality, which is external to general markets, can be estimated with the Catchment Land Use for Environmental Sustainability (CLUES) model (Semadeni-Davies *et al.*, 2011). The CLUES model estimates effects of land-use on total nitrogen, phosphorus, E. coli, and sediment loads at catchment, regional, and national levels. Erosion regulation (soil protection) can be estimated by the New Zealand Empirical Erosion Model (NZeem) (Dymond *et al.*, 2010). NZeem calculates the erosion rate for each land-use type based upon annual rainfall, a land cover factor, and an erosion coefficient that depends upon erosion terrain.

Cultural ES includes 'non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience' (Millennium Ecosystem Assessment, 2003, p. 58). Cultural ES are difficult to predict under different land-use scenarios as they are subjective and vary over space and time. There are methods available to value non-market ES, like the revealed preference method which observes individual's behaviour in actual or hypothetical markets and derives value of an ES (Gürlük & Rehber, 2008; Jim & Chen, 2009) and the stated preference method which directly elicits peoples' preferences for ES (Bateman *et al.*, 2002; Bennett *et al.*, 1996). These approaches require a great deal of resources and expertise. Further, measuring almost everything in dollars is questionable, especially those ES that people have a spiritual or emotional attachment to (Kumar & Kumar, 2008) or fall in the public domain (Howarth & Farber, 2002). Hence, a framework that integrates ecological, socioeconomic, and cultural dimensions of ES, uses economic and/or noneconomic methods for their valuation, and engages stakeholders at various stages of ES assessment or valuation, is needed.

2.5 Economic methods of valuing ES

The value of ES can be estimated by economic and/or non-economic methods (Table 2.2). This is important as ES values convey to decision makers the relative importance people place on ES, which is a fundamental component in designing rewards (payments) for ES (de Groot *et al.*, 2012). Economic valuation methods are employed to find out change in peoples' welfare in monetary terms due to change in supply of ES. In this regard, cost benefit analysis (CBA) has been developed and extensively used for valuing projects and management actions. However, conventional CBA is problematic for valuing environmental projects if it struggles to provide accurate value of ES for which markets do not exist or are poorly developed. The existence values of species (Pearce & Turner, 1990) or some cultural values of environmental resources (Kumar & Kumar, 2008) are not captured by market prices. Due to a lack of property rights and markets for these intangibles, CBA practitioners may undervalue or erroneously assign zero prices to these ES (Loomis *et al.*, 2000; National Research Council, 2005). As well, basing resource use decisions on economic efficiency criteria does not guarantee ecological sustainability and fairness in distribution (Bishop, 1993).

In the absence of markets for many ES, non-market valuation (NMV) methods have been developed to estimate surrogate prices to reflect values for ES (Table 2.2).

Table 2.2 Techniques available to value Ecosystem Services

Economic techniques	**Non-economic techniques**
Market price approaches: Market cost approaches: • Replacement costs approaches • Damage cost avoided approaches • Production function approaches Revealed preference methods: • Travel cost method • Hedonic pricing method Stated preference methods: • Choice modelling • Contingent valuation Participatory approaches to valuation: • Deliberative valuation • Mediated modelling • Benefits transfer	Consultative methods: • Questionnaires • In-depth interviews Deliberative and participatory approaches: • Focus groups, in-depth groups • Citizen juries • Health-based valuation approaches: • Q-methodology • Delphi surveys • Rapid rural appraisal • Participatory rural appraisal • Participatory action research Methods for reviewing information: • Systematic reviews

Source: (Christie *et al.*, 2008)

The non-market valuation (NMV) methods include revealed preference (RP) methods, stated preference (SP) methods, and various cost based methods (Murlis *et al.*, 2010). RP methods such as travel cost or hedonic price rely on the observations of people's behaviour in markets to estimate the value of environmental attributes under consideration (Bennett *et al.*, 1996). The value of scenic beauty can be estimated by observing house prices in the vicinity of the scenic area and comparing them to (similar) house prices in a region distant from the scenic area. Similarly, the value of recreation at natural sites can be approximated by studying the relationship between costs people incur in travelling to those sites and their visitation rates (Bennett *et al.*, 1996). SP techniques, on the other hand, creates hypothetical market scenario then asks people to express their willingness to pay for improvement in one environmental attribute(s), or willingness to accept compensation for loss in an environmental attribute(s) (contingent valuation). Choice modelling asks survey respondents to select their most preferred resource use option from a number of alternatives and reveal their willingness to trade-off environmental attributes against a financial cost (Bennett *et al.*, 1996). Primary NMV studies are difficult and costly (Liu *et al.*, 2010) and some practitioners have sought to sidestep the problem by transferring values from an existing 'study site' to a 'target site' a technique named benefit transfer (Bateman *et al.*, 2002; Nijkamp *et al.*, 2008; Rolfe, 2006). There are a range of cost based methods available to use as proxies for value including those based on costs of replacement or damage avoided (Murlis *et al.*, 2010).

Although NMV methods have greatly contributed in monetising values of many regulating and cultural services which were previously neglected in conventional CBA, they too have their own limitations. Besides being time and resource consuming, NMV methods need well trained experts which may limit their applicability in countries with resource and technical constraints. Even the low cost NMV method, benefit transfer, has its own limitation as it is difficult to find a target site that resembles a study site having the same bio-geophysical and socioeconomic characteristics as well as scarcity of the ES (Rolfe, 2006). Further, it is difficult, if not impossible, to value all ES from an ecosystem even using more advanced NMV technique such as choice modelling due to difficulty in designing choice experiments with all environmental attributes included. Further, ES values derived from damage cost methods should be used with great caution as these are not based on preferences (Liu *et al.*, 2010).

Economic valuation methods fail to accommodate psycho-cultural values of ES held by people and society which could provide valuable insight into the valuation and management of ES (Kumar & Kumar, 2008). This means relying only on economic valuation methods will lead to partial estimates of ES values. However, decision making on natural resources require knowledge of all factors that affect flows of ES (Pagiola *et al.*, 2004). Thus, for clear, well-founded policy advice, what is required is a framework that can incorporate not only an economic efficiency goal, but also sustainability and fairness goals, and which can simultaneously consider values of all ES acceptable to the society (Liu *et al.*, 2010). Multi Criteria Decision Analysis (MCDA) is such a tool that can incorporate multiple goals and calculate social values of ES (Fernandes *et al.*, 1999). However, MCDA is not a supplement to monetary valuation methods, rather these methods can complement each other in ecosystem management and environmental policy making (Henkens *et al.*, 2007).

2.6 Noneconomic methods of valuing ES

Noneconomic valuation methods involve collecting individual or group preferences for deriving values for ES. In this regard, MCDA has been a widely used method (Spash *et al.*, 2005). It allows integration of economic, ecological and social objectives of management options in the decision making of natural resources (Fernandes *et al.*, 1999). People express their preferences over various alternatives or objectives in cardinal or ordinal values which are then used to rank or score the performance of decision alternatives against multiple objectives measured in different units (Ananda & Herath, 2003; Herath, 2004; Munda *et al.*, 1994). Another feature of MCDA is that it can deal with long time horizons, complex values, uncertainties, and risks (Ananda & Herath, 2009), which NMV methods fail to accommodate. Hence, MCDA has some advantages over NMV methods (Chee, 2004; Herath, 2004) as it incorporates multiple criteria in assessments rather than a single criterion of dollar value, and is simpler in process than NMV methods.

Among the various methods available in MCDA, the most frequently used in forestry planning and management are Multi-attribute utility theory, Multi-attribute value theory, and Analytical Hierarchy Process (Ananda & Herath, 2009).

2.6.1 Multi-attribute utility theory (MAUT)

MAUT involves deriving preference scores for each alternative from a utility function and aggregating the utility function of each criterion to derive an overall utility function for an alternative (Russell *et al.*, 2001). Thus MAUT also relies on a social welfare theory like CBA which is based on utility maximisation.

A general MAUT model is given by

$$U(A) = \sum_{i=1}^{n} w_i(u_i x_i) \qquad (2.1)$$

Where $U(A)$ represents the overall utility for option A, and is the weighted sum of the utility derived from each of the attributes x_i, w_i is the weight of the i^{th} attribute and $u_i(x_i)$ is the utility function of the i^{th} attribute (Ananda & Herath, 2005).

The main advantage of MAUT is that it can deal with multiple objectives and incorporate the value of risks and uncertainties (decision makers' preferences) in the selection of alternatives (Montis *et al.*, 2005; Russell *et al.*, 2001). However, MAUT suffers from its main assumptions of deriving total global utility from the sum of individual utilities as does CBA. Further, the strict assumption of independence among criteria is not always true and may lead to false rankings (Rehman & Romero, 1993). MAUT's application is difficult due to the lengthy process in establishing utility functions (Løken, 2007; Montis *et al.*, 2005). Due to this reason, the use of MAUT in solving decision problems is less as compared to other methods such as AHP which is simpler and relatively easier than MAUT (Ananda & Herath, 2009).

Despite its disadvantages, MAUT has been used in a number of cases. Kangas (1993) used MAUT for choosing reforestation alternatives of a forest stand in western Finland. Ananda & Herath (2005) used MAUT for analysing societal risk preferences on public forest land-use attributes in Australia. Further uses of MAUT in the forestry area include harvest solving problems (Howard & Nelson, 1993), forest biodiversity conservation (Kangas & Pukkala, 1996; McDaniels & Roessler, 1998), and risk and uncertainty in forest management (Ananda & Herath, 2005; Pukkala & Miina, 1997).

2.6.2 Multi-attribute value theory (MAVT)

In MAVT, the alternatives are first evaluated with respect to each attribute and the attributes are weighted according to their relative importance. The attribute weight reflects the relative importance of the change in the attribute from the worst attribute level to the best attribute level (Belton & Stewart, 2002). Hence, it may be possible that an alternative which performs poorly in one attribute can still overall be the most desirable if it performs well on the rest of the attributes. The overall value for each alternative can be derived by an additive or a multiplicative value function, but additive value functions are more common due to ease of use for both researchers and stakeholders.

A simple additive value function for MAVT is given by (Belton & Stewart, 2002):

$$V(a) = \sum_{i=1}^{m} w_i \, v_i(a_i) \qquad (2.2)$$

Where:

$V(a)$ is the overall value of alternative a, $v_i(a_i)$ is the single attribute value function reflecting alternative a's performance on attribute i and w_i is the weight assigned to reflect the importance of attribute i.

The attribute weight reflects the relative importance of the change in the attribute from the worst attribute level to the best attribute level. Hence, for the worst and best vi scenario

$$v_i(\text{worst } ai) = 0, \qquad v_i(\text{best } ai) = 1, \qquad i = 1,2,\ldots,n$$

$0 < w_i < 1 \qquad\qquad i = 1,2,....,n$

$\sum W_i = 1$

The main weakness of MAVT is its assumption that a bad performance on one criterion (for example a high impact on native species) can be compensated by a good performance on another (for example a high income). This feature makes MAVT an inadequate tool in decision making where strong sustainability is conceptualised. Use of MAVT in decision making of natural resources is limited. Some examples include analysis of forest policy in Australia (Ananda & Herath, 2006), and conflict resolution in a river rehabilitation project in Switzerland (Hostmann *et al.*, 2005).

Weight calculation for MAUT and MAVT

The weights in MAUT or MAVT can be calculated by well known ratio estimation methods such as Simple Multiattribute Rating Technique (SMART) and SWING. In SMART, the decision maker or the respondent is asked to identify the least important attribute and assign it a score of 10, and then scores greater than 10 to other attributes based on their importance relative to the least important attribute. In the SWING method, respondents are told that all attributes are at their lowest level. They are asked to choose one attribute which they want to improve to its highest level and assign that attribute a score of 100. Then they are asked to give lower scores to other attribute ranges to denote their relative importance compared to the first chosen attribute. The weights are calculated by normalising scores.

The SWING technique has been used for eliciting people's preferences for evaluating environmental impacts of electric utilities (McDaniels, 1996), valuation of wilderness preservation benefits (McDaniels & Roessler, 1998), valuation of non-market losses (McDaniels & Trousdale, 2005). Although some modifications of this method are found in the literature, for example use of intervals for modelling imprecision in decision making (Mustajoki *et al.*, 2005), the SWING technique still has greater applicability due to the ease of use of the method.

A slight variation of the SWING method is called Max100. In Max100 method attributes are not assumed to be improved from their current levels to higher levels. Rather, respondents are asked simply to choose one attribute from a set of attributes that they consider is the most important and assign that attribute the highest scale value of 100 (Bottomley & Doyle, 2001). Then they are asked to assign a score of less than 100 to another attribute which they think is second most important. This procedure is continued till all the attributes are assigned a relative score on the scale. The actual weights are calculated by normalising the sum of the given scores to 1.

For all the above mentioned methods, the weight of the attribute i is calculated as

$$w_i = \frac{x_i}{\sum_{j=1}^{n} x_j} \qquad (2.3)$$

Where, w_i is the normalised indicator score (i.e weight) of attribute i, x_i corresponds to indicator score of attribute i, $\sum x_j$ is the sum of all indicator scores, and n is the total number of attributes.

The other method of weight elicitation, which is commonly used in studies, is Analytical Hierarchy Process (AHP). This method can also be used in selecting the best alternative among available alternatives to achieve a certain goal.

2.6.3 Analytical hierarchy process (AHP)

AHP is another MCDA technique. It uses the theory of ratio scale measurement based on mathematical and psychological foundations (Kangas, 1993). It decomposes the decision problem into decision schema and elements which are judged qualitatively (Ananda & Herath, 2003). Respondents express the relative importance of criteria in the first round and then alternatives in the second round of questions. Thus AHP can be used for weight elicitation of criteria and indicators and/or solving multi-objective problems. The AHP process involves a series of steps as depicted in Figure 2.2. These steps are explained in the following sections.

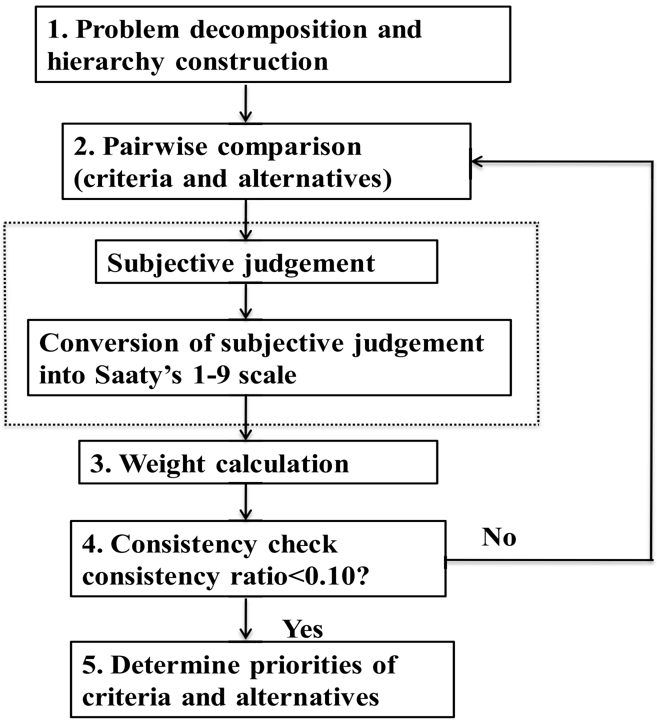

Figure 2.2 Steps in the AHP method (Chand, 2011)

Pair-wise comparison

Respondents are asked to prioritise between two elements at a time and then asked to quantify the relative degree of importance using a nine point scale developed by Saaty (1994). The value '1' indicates the two elements are of equal value and the value '9' indicates absolute importance of one element over the other (Table 2.3).

Table 2.3 Measurement scale of AHP

Degree of relative importance	Definition
1	Equal importance
3	Weak importance of one over the other
5	Essential or strong importance
7	Demonstrated importance
9	Absolute importance
2,4,6 and 8	Intermediate values between two adjacent judgements
Reciprocals of above nonzero	If attribute i has one of the above nonzero numbers assigned to it when compared to attribute j, then j has the reciprocal value when compared with i

Source (Wind & Saaty, 1980)

Pair-wise comparison data can be analysed using an Eigen value technique that constructs a matrix using reciprocals of pair-wise comparison (Saaty, 1990b). Thus, for each criterion C, an n-by-n matrix **A** of pair-wise comparisons is constructed (Equation 2.4).

$$\mathbf{A} = a_{ij} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \quad (2.4)$$

Where, a_{ij} represents the pair-wise comparison between attributes i and j. The theoretical validity of the comparison matrix is based upon four axioms (Duke *et al.*, 2002).

- Reciprocal comparison: If $a_{ij} = x$, then $a_{ji} = 1/x$ where, $x \neq 0$
- Homogeneity: It states that there should not be a big difference between elements under comparison at each level. Otherwise, there will be error in judgements.
- Independence: According to this axiom, the priorities of the elements in a hierarchy do not depend on lower level elements. This means, the weight of a higher element is not influenced by elements in the lower level.

- Expectations: The proposed hierarchical structure for a decision problem is assumed to be complete.

Weight calculation

After the equation 2.4 is filled with responses (1 to 9 scale values) the next step is weight calculation. This is achieved by summing up each column and dividing each row element by this sum and then taking the arithmetic mean of normalised elements in each row shown in Equation 2.5 (Mau-Crimmins *et al.*, 2005). But for better estimates of weights, Saaty (1990b) proposed raising the power of the matrix until the weighted values converge. This is done by summing up each row and normalising values to add to 1. These are called priority vector weights which express the priorities among the elements belonging to the same level in the hierarchy.

$$\mathbf{A} = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \cdots & \cdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{bmatrix} \qquad (2.5)$$

When there is a perfect consistency among subjective pair-wise comparisons, then

$$AW = nW \qquad (2.6)$$

Where, W is the principal right eigenvector, but in reality some degree of inconsistency exists in subjective pair-wise comparisons, for which Saaty (1994) proposed the following formula

$$AW = \lambda_{max}W \qquad (2.7)$$

Saaty (1994) showed that the largest eigenvalue (λ_{max}) of a reciprocal matrix $\mathbf{A}$ is greater than or equal to n depending upon consistency in the pairwise comparisons. The consistency index (CI) for an n x n matrix $\mathbf{A}$ is given by

$$CI = (\lambda_{max}-n)/(n-1) \qquad (2.8)$$

The value can be compared with the consistency index for a randomly generated n x n matrix denoted by random index (RI). Saaty and his colleagues performed experiments by generating 500 random reciprocal n x n matrices using 1 to 9 scale. The process of raising power for each random matrix was carried out until the result finally converged very close to Υmax. They found consistency index for n=1 through n=15, which are presented in Table 2.4.

Table 2.4 The random index table

n	1	2	3	4	5	6	7	8	9	10	11	...	15
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.52		1.59

Source (Saaty, 2008)

The consistency ratio (CR) is given by

$$CR = CI/RI \qquad (2.9)$$

The consistency ratio is calculated by substituting CI value from Equation 2.8 and RI value from Table 2.4. As a rule of thumb, a CR of ≤ 0.1 is acceptable, above which respondents are asked to revise their pairwise comparison ratings. However, it is reasonable to accept CR ratio up to 0.15, but above that would be too incosistent (R. Saaty, personal communication, December 1, 2011).

The inconsistency in cardinal ranking is partly explained by Arrow's "impossibility theorem" which states that 'when voters have three or more distinct alternative, no rank-order voting system can convert the ranked preferences of individuals into a complete and transitive community-wide ranking' (Arrow, 1950). In other words, it is impossible that group choice would be consistent to individual choices. As opposed to ordinal rankings, Saaty showed that individual preferences can be close to group preferences when cardinal rankings are used, and when a person or a group are allowed to adjust their judgements and inconsistency to a ceratin level (Saaty, 1994b).

Determination of weights of criteria and alternatives

A simple hierarchy with 3 criteria and 3 alternatives is shown in Figure 2.3. The calculation of weights follows a downward direction in the hierarchy. First, weights are calculated for each criterion at level 2, and then for alternatives (level 3) with reference to criterion in level 2. For this purpose, each criterion weight is multiplied by weights of alternatives. The sum of weights at each level should equal to 1.

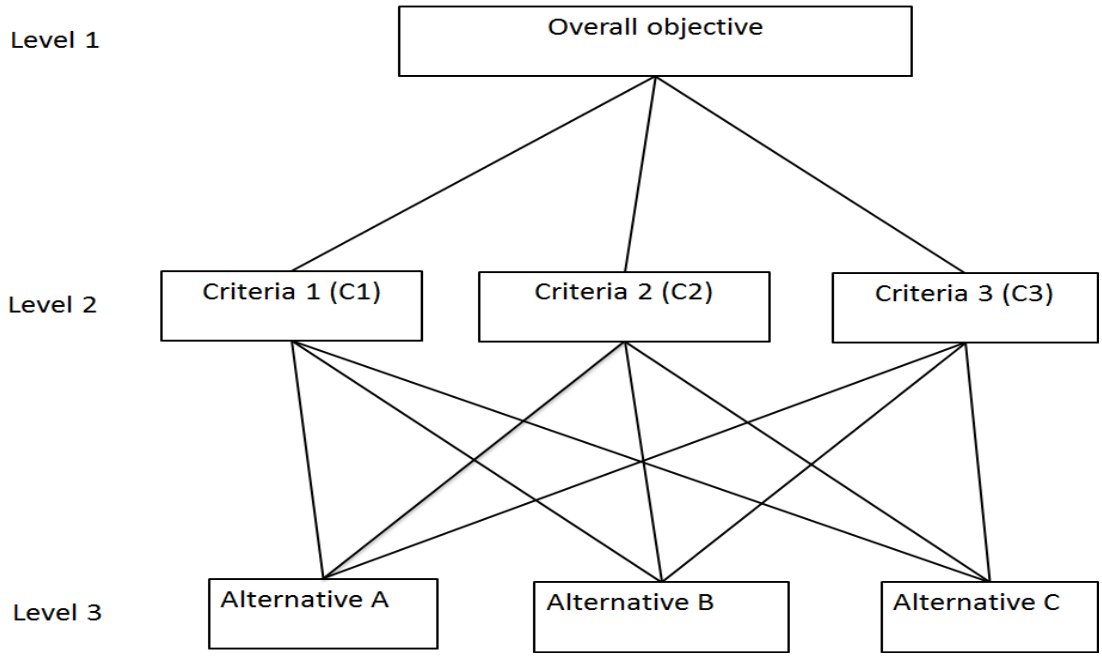

Figure 2.3 Decision hierarchy model in AHP (adapted from Zhang & Lu*,* 2010, p. 1466)

The main advantage of AHP is that it can solve multi-objective problems by arranging the problem in a systematic way as shown in Figure 2.3. The use of verbal judgements (qualitative criteria) and the consistency check on qualitative judgements make it a popular tool in decision making (Ishizaka & Labib, 2009). It can be used for aggregating preferences of many experts or individuals, which makes it useful tool in decision making (Duke & Aull-Hyde, 2002). However, AHP is criticised as flawed theory for analysing decisions due to the lack of a theoretical basis and strong axiomatic foundation like MAUT (Belton & Gear, 1983). In response, Saaty (1986) has introduced four axioms to validate the theoretical basis of AHP which are reciprocity, homogeneity, dependency and expectation in the hierarchy. Other criticisms are the lack of sound statistical theory behind the method (Alho *et al.*, 1996; Kuusipalo *et al.*, 1997), lengthy process of calculating priorities with the large number of alternatives, and rank reversal problem (Belton & Gear, 1983; Dyer, 1990). Rank reversal is a phenomenon of changing rank of alternatives when an alternative is added or dropped in the AHP analysis. However, (Saaty, 1990a) pointed out that rank reversal will not occur with the absolute measurement of the AHP.

Although AHP was first developed in the marketing sector, its application has extended to other areas including defence, waste disposal, agriculture and forestry. It has been widely used for planning and managing forests in Finland (Kangas, 1993; Kangas & Kangas, 2005; Kangas & Kuusipalo, 1993; Kangas *et al.*, 2000) and to a lesser extent in Australia (Ananda & Herath, 2003). Kangas & Kuusipalo (1993) used AHP in estimating a biodiversity index by decomposing it into three components: species richness, rarity, and vulnerability of species and then included it into forest management planning as decision criterion along with timber management and game management criteria. Herath (2004) used AHP for comparing public’s relative values for conservation, recreation, and business attributes of Wonga wetlands on the Murray River of Australia, and concluded that the preferences of stakeholders vary. On the other hand, Qureshi & Harrison (2001) used an innovative feature of using prompt cards for pair-wise comparisons for finding out group’s preference out of four riparian vegetation options for the Johnston River Catchment in North Queensland, Australia. Recently, Zhang & Lu (2010) used AHP for eliciting social weights for calculating economic value of ES provided by Ruoergai Plateau Marshes in China. In New Zealand context, Hearnshaw & Cullen (2010) used AHP for deriving preferential weights of all ES provided by Opihi River in Canterbury.

Among the various methods available to solve multi-objective decision making problems, AHP, MAUT/MAVT are more frequently used in natural resources management. AHP uses ratio scales to elicit preferences for alternative course of action, whereas MAVT and MAUT respectively use values and utility functions for finding a desirable course of action. The value function describes a person’s preferences regarding different levels of attributes under certainty, whereas utility function uses probabilities and expectations to deal with uncertainty (Belton & Stewart, 2002). In MAUT, individual’s utility on each attribute is aggregated for deriving global utility based on all attributes. Hence, MAUT is more suited to ex-ante evaluations for multiple objective problems with risky outcomes (Montis *et al.*, 2005). For deriving preference weights, AHP can be used as it is a valid method developed to reflect the way people behave and think naturally (Saaty, 2001).

2.7 Chapter summary

Plantation forests have an important role in the New Zealand's landscape as they provide timber (provisioning ES); soil erosion control, water purification and climate regulation services (regulating ES) and aesthetic, recreational and natural habitat services (cultural ES). Land-use/cover changes modify ecosystem structures and functions or processes which in turn affects flows of ES. The changes in ES flows can be studied with the help of ecological production functions that help to understand how ecosystem services change with respect to changes in ecological variables in a smaller area. Spatial explicit models can analyse changes in ES over larger area and can incorporate more variables in the analysis. The use of these models depends upon the context and scale of study. For mapping, modelling, and identifying areas of services and disservices from land-use changes, global and national level models are appropriate. However, for analysing impact of land-use on flows of ES at a smaller area, farm and regional level models are more appropriate, and this is where district and regional councils regulate land-use decisions so as to accommodate interests of different stakeholders. This research used biophysical models as they help to measure ES flows quite easily and non-monetary valuation method for finding importance people attach on ES rather than asking people to assign a dollar value on ES.

Once flows of ES are estimated with the help of models, economic methods can be used for valuing provisioning, regulating and some cultural ES, but as explained earlier there are limits to its use, and in some cases, it may give erroneous values for ES. This can be seen in the use of benefit transfer method (Bateman *et al.*, 2002), damage cost methods (Liu *et al.*, 2010), or SP methods where large disparity between willingness to pay and willingness to accept was observed (Guria *et al.*, 2005). The large disparities between WTP and WTA is partly attributable to the endowment effect (Kahneman *et al.*, 1990) that explains why markets often do not work as predicted by equilibrium models. In contrast, there are a range of non-economic methods available for valuing ES that use ordinal and/or cardinal rankings. People express their preferences using a ratio scale which reflect their value on a particular ES relative to other ES under comparison. However, like monetary valuations, these methods also have their own limitations. Subjective judgements, representativeness of the sample and power dominance in a group can affect the results of such surveys. Hence, while collecting data in a group, researchers have to be vigilant in that no one is influencing or dominating others.

In eliciting preference weights it is important that the method chosen should be easy to use and understandable to the general public. In this regard, the SWING and the Max100 methods are easy to use and more straight forward than other methods such as AHP which requires pair-wise comparison of each ES with all ES under investigation. This is where people might find it difficult to maintain transitivity in their order of preference for ES. Max100 method can be useful in situations where there is only one level in the hierarchy and repondents have to simply compare the importance of various attributes at one level of the hierarchy only.

Chapter 3

Methodology and Data

3.1 Introduction

The literature review in Chapter 2 identified the framework for assessing the impact of limited-focus land-use programmes in the provision of ES. It is based on the ESApp which links land-use programmes to ES flows and incorporates peoples' preferences in the decision making of ES. Further, Chapter 2 also concluded that biophysical models are appropriate for the purpose of the research as they predict changes in ES outputs due to changes in ecosystem structures and physical environment. This chapter describes biophysical models, procedures for data collection, and their sources. Section 3.2 presents a brief overview of the research process. This is followed by a conceptual model in Section 3.3 and biophysical models and equations for estimating flows of ES under different land-use scenarios in Section 3.4. Section 3.5 presents weight elicitation techniques used for finding out the importance people place on ES and procedures for normalisation of indicator scores. Sections 3.6 and 3.7 are dedicated to costs of land-use programmes and description of the research site, respectively. Section 3.8 describes in detail data collection as well as data requirements for the models. The basis for land-use simulation is explained in Section 3.9 followed by a summary of the chapter in Section 3.10.

3.2 An overview of the research process

The entire research process is depicted in Figure 3.1 which shows the data collection procedure and data sources, and methods used to answer research questions. To run the biophysical models, data on climate, landforms and soils were collected from secondary sources. Online survey methods were used for collecting preferences from members of the public, and data on landowners' costs of participating in limited focus land-use programmes. The biophysical models were used to estimate flows of ES in the Kaituna catchment, Banks Peninsula (research site). The indicators for ES were normalised which helped in calculation of indicator scores for each land-use scenario. Before adding these indicator scores, they were multiplied by ES weights. This was done as research has shown that people do not consider all ES equally valuable, and preferences for ES may vary between groups, sexes, ethnicity, etc. Therefore normalised indicator scores (weighted) were compared with the costs of limited-focus land-use programmes to find the least cost programme in the provision of ES. The main aim of the research was to find out if limited-focus land-use programmes provide an alternative to broad ecosystem service markets in the provision of ES as shown in Figure 3.1.

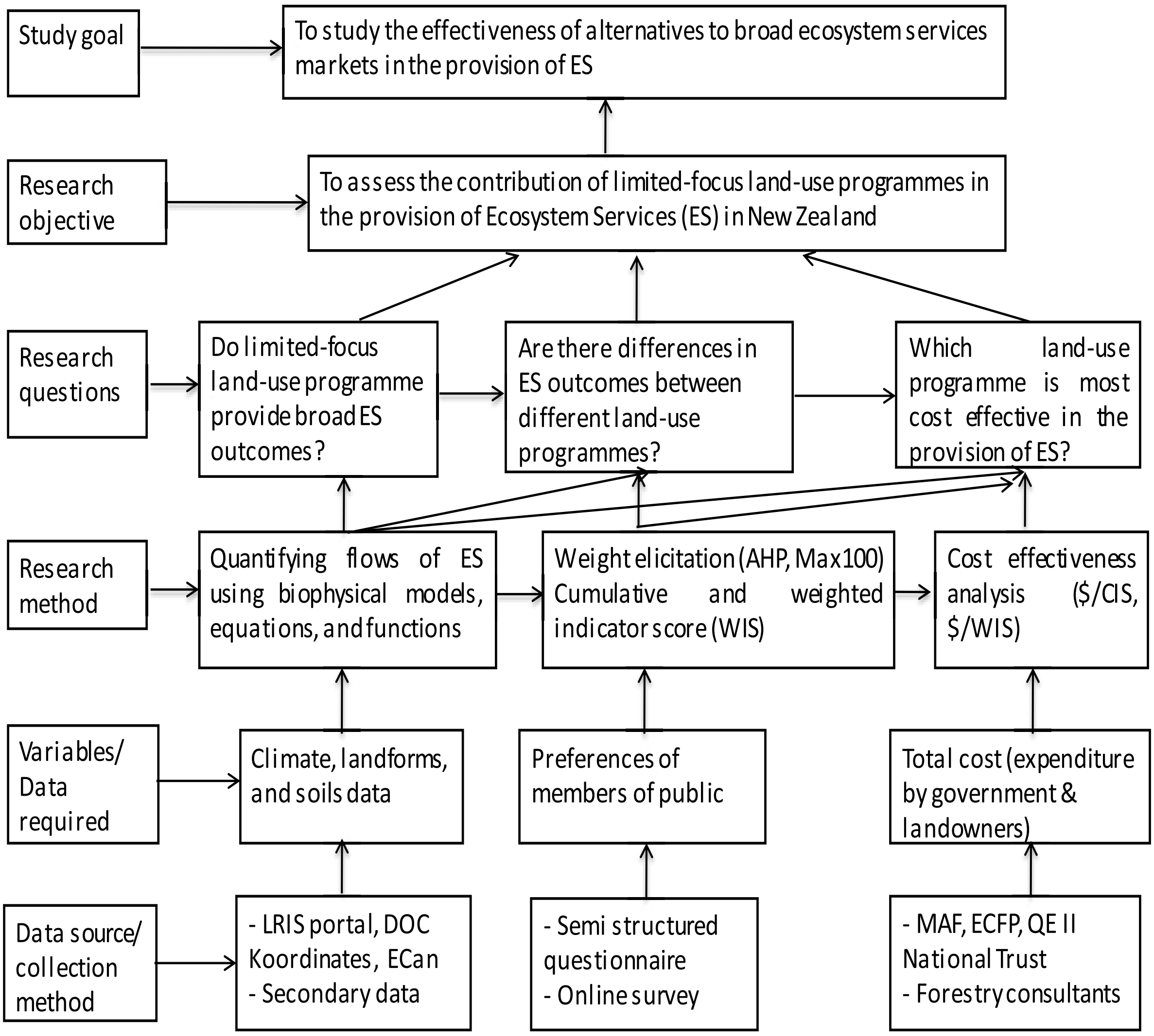

Figure 3.1 An overview of the research process

3.3 Conceptual model

The total flow of ecosystem services in a land environment can be modelled by the following equation (X. Zhang & Lu, 2010).

$$IS_t = \sum_{i=1}^{n} W_i \, . X_{it} \tag{3.1}$$

Where,

IS_t is the total weighted indicator score of ecosystem services in the catchment during period t; X_{it} is the normalised indicator score of the ith normal ecosystem service in period t; W_i is the weight assigned to the ith ecosystem service by the public; n is the number of ecosystem services being evaluated.

The flows of ES were estimated by use of biophysical models and the publics' preferences were estimated by AHP and Max100 method which elicit the relative importance of ES to members of the public. The flows of ES were normalised and integrated with ecosystem services weights for identifying total flow of ES under each land-use scenarios.

The conceptual framework for the study is presented in Figure 3.2. It is based on ESApp which has been widely used in ES studies (Ausseil & Dymond, 2010; Hearnshaw & Cullen, 2010; Posthumus *et al.*, 2010). Implementation of land-use programmes will have an impact on ecosystems, which through ecosystem structures and processes modify ES that are of concern to different stakeholders. For this research ES include all ecosystem structures, functions and processes that benefit humans, either directly or indirectly (Fisher *et al.*, 2009). This definition has two aspects, one ecosystem services are ecological products, and second they must provide benefits to humans, either directly or indirectly. According to this definition, water regulation service is an intermediate service and final ES for evaluation could be clean water provision, storm protection or constant stream flow depending upon the scope of the valuation (Fisher *et al.*, 2009).

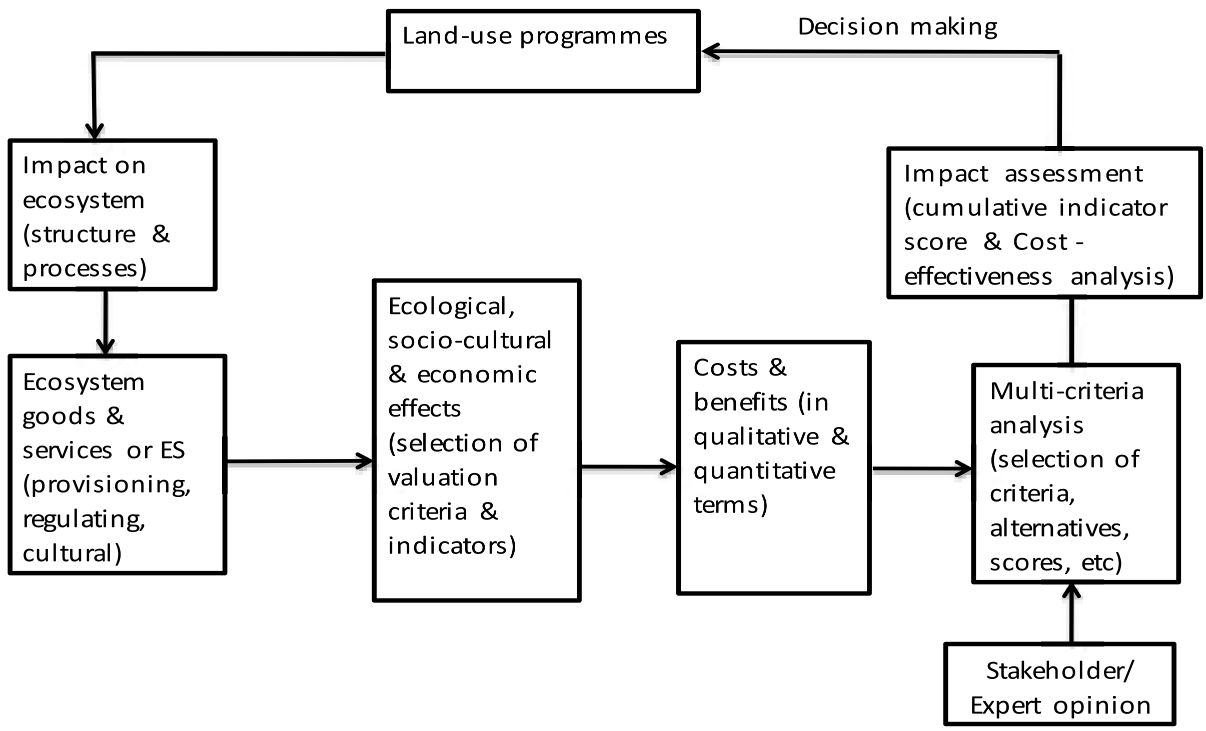

Figure 3.2 Conceptual framework for the study after Henkens *et al.* (2007)

The main steps in this framework include identification of ES that are affected by land-use programmes; selection of criteria and indicators; quantification of flows of ES; elicitation of preference weights for ES; aggregation of ES flows/outputs (cumulative indicator scores); and costs of producing ES per unit of area. These are described in the following sub-sections.

3.3.1 Ecosystem functions and services

The different land-uses in Kaituna catchment provide different functions and services. Land-use such as dairy, plantation forestry, and sheep and beef raising provide production ES functions. The forests and scrub also provide climate, water, and soil regulation functions. As well the catchment contributes to cultural and habitat functions as there are about 374 hectares of land protected by DOC. The Mount Herbert Scenic Reserve and Kaituna Spur Reserve provide walking tracks for recreationists. Further, Pack Horse Stone Hut which is just at the outer edge of north of catchment carries historic values. This hut was built in 1971 from local stones and people can buy tickets from DOC to stay in the hut and gain an outdoor recreation experience. As the catchment provides diverse functions, the beneficiaries of these services are local landowners, farm stay providers, recreationists, and global population due to carbon sink benefits from forests and scrubs. The stakeholders in the catchment include local landowners who grow food and timber in their farms, DOC and other conservation agencies such as Banks Peninsula Conservation Trust who are involved in the protection of indigenous species, and trampers and holiday seekers who want to stay in the historic stone house. As it is difficult to estimate historic values, this research only focused on the quantification of roundwood and carbon benefits, nutrient load, sediments load, annual water yield, and conservation goal for which indicators are available and biophysical models have been developed for the New Zealand context. These are some of the indicators used to measure benefits people derive from ES in the catchment.

3.3.2 Criteria and indicators for the estimation of ES

Indicators are a valuable tool as they can help to detect and measure state and trends in flow of ES. For this purpose, indicators for ES are underdeveloped and an agreed list of ES indicators is still lacking (Layke, 2009). It was recognised that indicators for cultural and regulating ES are less developed as compared to provisioning ES (Hearnshaw & Cullen, 2010; Layke, 2009). Despite the difficulty in establishing a comprehensive set of indicators for each ecosystem type, Hearnshaw & Cullen (2010) have recently used a set of indicators for assessing the impact of a water storage project on various ES provided by a Canterbury river system.

For measuring and quantifying ES, de Groot *et al.* (2010) have argued we need two types of indicators: state indicators that describe how much of ES is present and performance indicators which describe the sustainable use of ES. However, performance indicators are poorly developed due to challenges in quantifying the relationship between ecosystem components, processes and services (de Groot *et al.*, 2010; Heal & Barbier, 2006). For effectively capturing changes in ES of an ecosystem, multiple indicators from environmental and socio-economic perspectives should be considered. This is important as often socio-economic realities are inherently ignored in environmental valuations (Straton, 2006) which can lead to wrong policy advice (Barbier & Heal, 2006). Table 3.1 lists valuation criteria and examples of indicators used in the study.

Table 3.1 Valuation criteria and indicators

ES category	Examples	Indicators	Unit	Indicator type
Provisioning ES	Timber production	Roundwood harvested	m^3/ha/yr	Socio-economic
Regulating ES	CO_2 gas regulation	Carbon sequestered	tCO_2e/ha/yr	Environmental
	Maintenance of water quality	E. coli levels	10^{12}organisms/ha/yr	Environmental
		N & P cumulative yields	Kg/ha/yr	
	Water flow regulation	Water yield	L/s/ha	Environmental
	Erosion control	Sediment load	t/ha/yr	Environmental
Cultural ES	Conservation values	Conservation goal	Units/ha/yr	Socio-economic

3.4 Biophysical Models Estimating Flows of Ecosystem Services

Impact of limited focus land-use programmes namely ETS, ECFP, and QEII in this research means impact of afforestation, both plantation forestry and natural reversion, on the flows of ES. Switching from existing land-use to forestry in the catchment leads to modification of land environment which ultimately changes flows of ES. These changes have been estimated for different land-use scenarios by using biophysical models as they are easy to operate with readily available GIS data and are suited to farm and catchment level studies where land use decisions are implemented. These models are briefly described in the following sub-sections.

3.4.1 Water balance model (WATYIELD)

WATYIELD is basically a hydrological model designed to estimate the effect of land cover on annual water yields and low flows (Fahey *et al.*, 2004). It assumes that rain falling on the ground is retained until the soil reaches its field capacity after which excess water is lost as run-off. Therefore, when the soil is saturated, the daily drainage Q is obtained from the water balance equation:

$$Q = P - E - \Delta S \quad (3.2)$$

Where,

P is rainfall, *E* is evaporation, and *ΔS* is the change in water stored in the root zone. The monthly reference evaporation is equivalent to water lost over an area by well-watered medium grass, which is available in the New Zealand Meteorological Service Miscellaneous Publication 189 (NZMS, 1986). Further details about the model are contained in the user's guide freely available to download from Landcare Research - Manaaki Whenua. (http://icm.landcareresearch.co.nz/research/land/Landcovereffectsonwater.asp).

3.4.2 Catchment land use for environmental sustainability (CLUES) model

CLUES is a catchment modelling tool which predicts water quality and socio-economic indicators as a function of land-use. It is freely available from the website ftp://ftp.niwa.co.nz/clues/. The model is built within the ArcGIS platform and contains land use, soils, and livestock data connected to a streams and river networks. Due to this reason the impact of land-use change is reflected on water quality. As land use information in CLUES are connected to approximately 576,000 stream reaches and sub catchment details are available to an average area of 0.5 km^2, it is suitable for studies ranging from catchment scale to national scale. There are 19 different land-use types in the model such as dairy, sheep and beef intensive, kiwifruit, exotic forestry, for example. The combination of water quality and economic modelling, an easy-to-use interface, tools for creating land use change and land management scenarios makes it a powerful decision tool for spatial analysis of land-use simulation results (Semadeni-Davies *et al.*, 2011).

3.4.3 New Zealand emprical erosion model (NZeem®)

A web based model called NZeem® was used for estimating the impact of land use on sediment yields. The model calculates mean erosion rate $\bar{e}(x,y)$ as a function of mean annual rainfall $R(x,y)$, an erosion coefficient $a(x,y)$ which depends upon the erosion terrain, and a land cover factor $C(x,y)$ which shows long term mean erosion rate for a land cover at $C(x,y)$ relative to forest at the same point (Dymond *et al.*, 2010). Hence, value of $C(x,y)$ is equal to 1 if land is under woody vegetation or 10 if land is under herbaceous vegetation or bare ground.

$$\bar{e}(x,y) = a(x,y)\, C(x,y)\, R^2\,(x,y) \quad (3.3)$$

As the Kaituna catchment is rain-fed, it carries run-off from the surrounding hill country which depends upon the rainfall event, slope, and vegetative cover present in the catchment and along the river banks. The amount of sediments in the catchment affects the stream morphology and habitat for trout and native fish Bully and Inanga (Maw, 2007). The catchment is ideal for trout spawning due to its deep holes, good hydraulic variation, gravel riffles, and some riparian areas (Maw, 2007; Taylor & Good, 2006), but excessive sediments and nutrients loads due to land-use modifications will reduce the spawning of trout in the river. Further, this river is connected to Lake Ellesmere (Te Waihora) which has significant cultural values for Maori people. Therefore, sediment loads were assessed for different land-use scenarios which will indicate the likely impacts of land-use on ecology of Kaituna River and on the health of Lake Ellesmere.

3.4.4 Habitat function

For measuring natural habitat provision, a simple habitat function was used which calculates proportion of natural area remaining in a land environment weighted by a condition index.

$$\mathrm{HF} = \sum_{i=1}^{m} \mathrm{P_i} \sum_{j=1}^{n} \left(\frac{\mathrm{c_j a_{ij}}}{\mathrm{A_i}}\right)^{0.5} \qquad (3.4)$$

Where, HF is habitat function, a_{ij} is the natural land cover area j remaining in land environment i, c_j is the condition index of natural land cover j, A_i is the original area of land environment i, m is the number of land environments, n is the number of natural land cover types, and P_i is the biodiversity value of the ith land environment at its original extent.

3.4.5 Carbon calculator

Radiata pine calculator version 3 (hereafter the calculator) was used for estimating quantity of timber and carbon stored in plantation forests. The reason for using it was twofold, one it was freely available on campus, and second it is specifically designed for stand-alone modelling of Radiata pine at the one hectare level (Maclaren *et al.*, 2005). Main features of the calculator include its easy to use interface, built-in growth models, log quality predictors, carbon accumulation and decay functions which runs with Microsoft Office Excel. The calculator estimates carbon in all pools (above and below ground biomass, dead wood and litter) except soils which is consistent with the procedure of calculating carbon credits for ETS forests.

The calculator has an easy to use interface which allows users to enter site specific stand information, pruning and thinning requirements. The New Zealand average 300 index and site index values are given in the model, but again they can be manually entered if those values are available for the site of interest. The output of the model is displayed in spreadsheets which shows year-wise values of Timber yield and carbon stock at a particular site. Timber yield is obtained in m^3/ha and carbon sequestered by trees in tCO_2e/ha. The calculator can display carbon stock for two rotations only and it assumes that there is no carbon from an earlier crop and a proportion of biomass from a previous crop which in New Zealand condition decays completely in 10 years (Ministry for the Environment).

3.5 Methods to elicit peoples'preferences for ES

Two methods, namely Analytical Hierarchy Process and Max100 were used for collecting data on the importance people attach to each ecosystem services. These are briefly described in the following sub-sections.

3.5.1 Analytical Hierarchy Process (AHP)

The AHP, which is based on mathematical and psychological foundations, decomposes decision problems into decision schema and elements (Kangas, 1993). Respondents judge them qualitatively by making pair-wise comparisons within each level with reference to above level in the hierarchy as depicted in Figure 2.3 (Section 2.6.3). As the aim of the research was not to ask members of the public which land-use programme they prefer but to know their preferences for ecosystem services, the AHP model for this research is simple and it had six ES (C1 to C6) for members of the public to compare as shown in Figure 3.3.

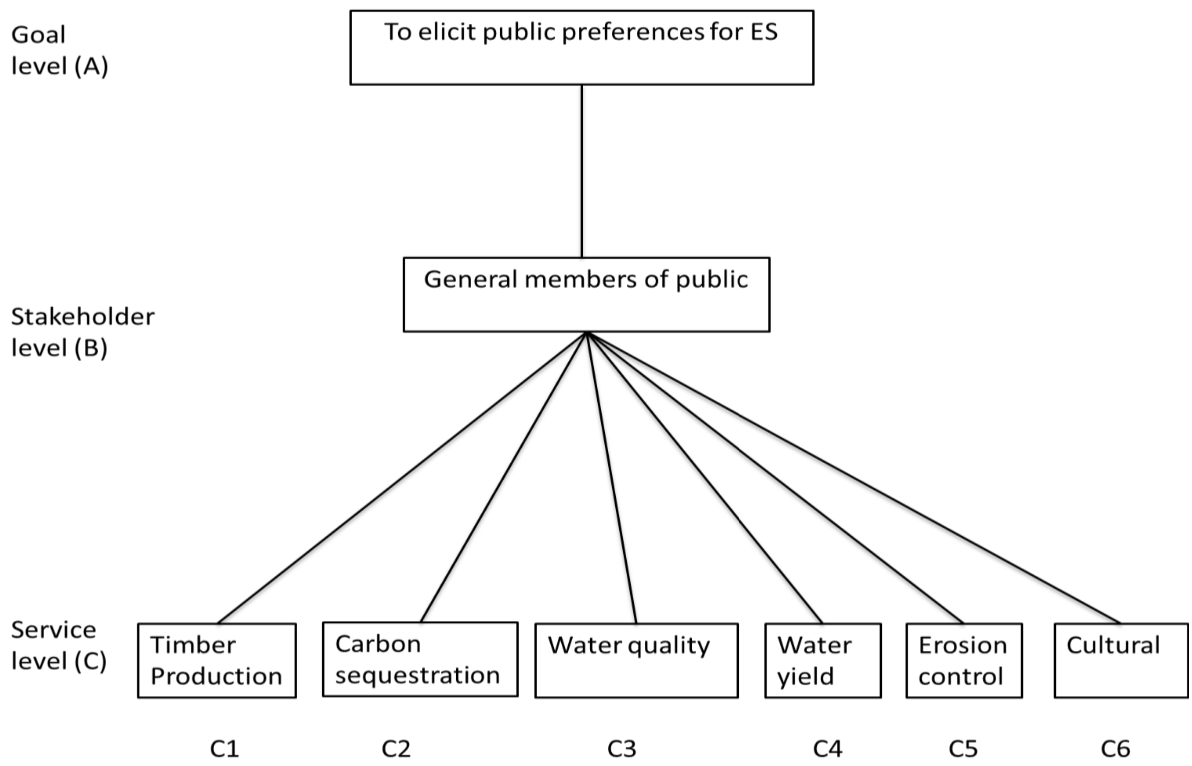

Figure 3.3 AHP model for the research

3.5.2 Max100 method

In this method, respondents were first asked to choose the ES which they think is the most important and then assign to it the highest score of 100 using a sliding scale bar (see Appendix B). Then they were asked to assign other ecosystem services a relative score of less than 100 in decreasing order, that is the second highest score to the second most preferred ES and so on until the least preferred ES was assigned a minimum score. The actual weights were calculated by normalising the sum of the given scores which adds to 1.

3.5.3 Indicator score normalisation and weights integration

ES were normalised using the procedure developed by Posthumus *et al.* (2010). This was done by dividing the outcome for indicator x of scenario i by the maximum value of xi which gave normalised values within the range of zero to one. This process expresses the observed value as a percentage of the maximum possible value. For desirable indicators, such as timber and water yield, the normalised value for the scenario with the best performance has a maximum indicator score of one and for other scenarios it lies within zero to one. On the other hand, normalised values for indicators such as nitrogen load and sediment load are undesirable. Accordingly the normalised values for these indicators are negative, ranging from zero to minus one, minus one for the scenario with the worst performance. The normalised indicator scores were then substituted in Equation 3.1 to derive weighted indicator scores which show total ES benefits for different land-use scenarios.

3.6 Costs of land-use programmes

The costs collected in this research are the total costs to the government of running land-use programmes and extra or incremental costs to landowners of participating in those programmes. Therefore landowners' costs on regular forestry operations were excluded from the analysis as the aim of this research was to work out all the costs that accrue because of running and participating in those programmes. To obtain landowners' costs, an online survey was developed on the web-based Qualtrics platform. The survey was designed for landowners and consultants who have been involved in at least one of the land-use programmes - the ETS, the ECFP, or the QEII National Trust (see Appendix C for the questionnaire). The survey was advertised in the NZIF Newsletter and also displayed at the New Zealand Institute of Forestry (NZIF) conference held at the University of Canterbury from 1 to 3 July 2012. The persons responsible for ETS programme and the ECFP were contacted for landowners' addresses but without success. Two consultants provided landowners' extra costs of participating in ETS, one consulting firm provided landowners' extra costs of participating in ECFP, and the QEII Trust representative in Christchurch provided costs of five covenantors in the Banks Peninsula region, Canterbury. Due to these reasons, the total costs of land-use programmes estimated in the research are indicative only and should be used with caution. The programme and administrative costs are based on published and unpublished reports, and information provided by persons working in these programmes.

3.6.1 ETS costs

The costs to the government of implementing the ETS programmes were extracted from MPI's annual reports. Every year MPI publishes an Annual Report which shows MPI's expenditure on various programmes and activities for the fiscal year ending in June. Although the forestry programmes was brought into ETS effective from 1 January 2008, the expenditure incurred on ETS was reported under 'vote agriculture and forestry appropriations for output expenses-implementation of the emissions trading scheme and indigenous forestry' from the year 2010/11 (1 July 2010 to 30 June 2011). The ETS costs were assumed to be 60 percent of costs reported for 'implementation of the emissions trading scheme and indigenous forestry' (P. Lough, personal communication, October 24, 2012).

The government collects revenue from landowners for various activities related to ETS which are compiled and presented in Table 3.2. As explained in Table 3.2, landowners' costs vary depending upon the number of times emissions returns are filed per commitment period (CP), size of the forest (a forest size of less than 100 hectares does not require establishing field measurement plots), number of Carbon Accounting Area (CAA[1]) added or transferred, and costs charged by consultants which vary from standard rates to a certain percentage of carbon credits (H. Vern, personal communication, May 15, 2013).

[1] CAA is the carbon accounting area determined by the participant during ETS registration on which accounting of carbon is done. It must be at least one hectare size but there are no restrictions on the numbers of CAAs or forest locations.

Table 3.2 Summary of ETS costs for landowners (NZ$ GST exclusive)

Activities	Costs/unit $	Explanation	Frequency of cost
Costs payable to ETS (government)			
Registering in ETS	489 per Application	Includes up to 4.25 hours of processing. Extra time will be charged at 115 per hour plus actual and reasonable travel costs (if applicable)	Once
Filing emissions return (voluntary)	89 per Filing	Includes up to 0.75 hours of processing. Extra time will be charged at 115 per hour plus travel costs at 115 per hour (if applicable)	Once a year or any combination of years from one to five
Filing emissions return (compulsory)	89 per Filing	Includes up to 0.75 hours of processing and above this time will be charged at 115 per hour plus travel costs at 111 per hour (if applicable)	Once per CP
Adding a (CAA)	89 per CAA	Includes up to 0.75 hours of processing and above this time will be charged at 115 per hour plus travel costs at 115 per hour (if applicable)	
Removing CAAs	No charge		
Lodging transfer notification	89	Includes up to 0.75 hours processing. Extra time will be charged at 115 per hour plus travel costs at 115 per hour (if applicable)	
Open NZEUR account	89 per account		Once
FMA plotting (only for forests ≥100 hectares	89 per application		
Costs payable to consultants			
Consultants charge	700-1500 per application	For filling application forms, liaise with MPI, etc.	Once
Creating shape file	700-3500 per file	Includes costs of drafting service providers and consultant's charge	Once
Open New Zealand Emission Unit Register (NZEUR) Account	100-120 per account		Once
Site inspection	300-1000 per visit	Consultants visit site to check the forest boundaries and trees	Usually once
Filing emission Returns	120-500 per return	Consultant's charge	Once a year or any combination of years from one to five

Source: ETS publications and a forestry consultant

3.6.2 QEII Trust costs

The costs of administering QEII Trust programmes were derived from QEII Trust annual reports. These reports list expenditures by various cost categories which are summarised in Table 3.3. The costs of maintaining QEII Trust properties were excluded from analysis as these are not related to establishing and monitoring covenants on private lands. Similarly, depreciation costs and public relations costs were also dropped from the analysis as these costs were not available for ETS and ECFP. All other costs shown in Table 3.3 made up the cost of implementing and monitoring QEII Trust programmes on private lands and open spaces.

Table 3.3 QEII Trust annual expenditures and their explanation

Cost categories	**Explanation**
Administration	Costs incurred on director's fees, audit fees, rents, loss on disposal of fixed assets and other administrative expenses
Contestable funds	Grant money, usually the Biodiversity Condition Fund, administered by Department of Conservation for specific projects.
Covenant expenditures	Costs of fencing, surveying and legal costs.
Field Operations	This covers the expenditure on regional representative costs, fencing, weed and pest control and revegetation (where applicable).
Property operations	Cost of up-keeping the QEII Trust properties. By the end of 30 June 2012, it owned29 properties around New Zealand.
Public relations	The costs of producing the Open Space magazine and other QEII Trust - related media like the website.
Depreciation	Depreciation of buildings, equipment, and fences.

With regards to landowners' costs, the QEII Trust representative in Christchurch managed to get consent from five covenantors for disclosing their costs. Hence, the landowners' costs of involving in QEII Trust programmes were based on average expenditures of those five covenantors. The main cost for the QEII Trust covenantor is the fencings costs which are shared equally between the landowner and the QEII Trust. The costs associated with lodging application including legal costs are borne by the QEII Trust. Similarly QEII Trust supports pest and weed control costs with their own funding or funding from other organisations such as ECan or DOC. The QEII Trust representative visits the site every two years to make sure that the fence is intact and pest control measures are undertaken. These costs are captured in the annual expenditures of QEII Trust under 'field operations'. There is an involvement of family labour in pest and weed control activities and in the routine inspection of the property as and when required. However, due to lack of information on family labour devoted to the QEII Trust programmes these costs were ignored in the analysis. Table 3.4 explains these costs.

Table 3.4 Landowners' costs of involvement in QEII Trust programmes

Cost categories	Explanation
Fencing costs	Costs incurred on building fence and maintenance thereafter
Pest/weed control Costs	Costs involved on possum baits, deer shooting, willow control etc. Most of these costs are born by QEII Trust or other agencies such as regional/district councils, but landowners have to provide their family labour.
Property inspection	Family labour involved in routine check-up of the property.
Other activities	Costs involved in building, walking tracks, ponds for fire control wherever required.

3.6.3 ECFP costs

The costs to the Crown of implementing the ECFP were estimated based on information provided by ECFP office in Gisborne (R. Hambling, personal communication, October 2, 2012) and published in annual reports. The main costs of administering ECFP include grants and administrative costs. For the *Pinus radiata* planting, landowners get 70 percent of the approved grant rate after the trees are planted (year 0) and the remaining 30 percent after the final compulsory thinning at around eight years (Table 3.5). Pruning costs are borne by landowners and not reimbursed by ECFP office. Pruning costs and other costs associated with silvicultural operations were not included in the cost analysis as they are not additional costs of participating in these programmes.

Table 3.5 ECFP grant rates and payment schedule (NZ$, GST exclusive)

Treatment	Distance from the Gisborne Port* (km)	Grant rates	On establishment	Final payment
Forestry#	0-80	1,476/ha	1,033/ha (year 0)	443/ha (at final thin)
	150	2,014/ha	1,410/ha (year 0)	604/ha (at final thin)
	215	2,820/ha	1,974/ha (year 0)	846/ha (at final thin)
Reversion#	for all distances	1,512/ha	756/ha (year 0)	756/ha (year 5)
Poles/Wands	for all distances	70% of the actual	80% of the total grant (year 0)	20% of the total grant (year 3)

Source: (Ministry of Agriculture and Forestry, 2009a)

The grant rate provided for natural reversion helps landowners to manage natural regeneration by fencing the area and controlling weeds and pests. These costs are captured in the grant amount paid to landowners. Therefore, the costs reported in the research are annual expenditures of ECFP over the years inflated to 2012 costs. As the ECFP grants before 2007 were paid out in up to five instalments **,** the costs reported for a particular year shows money paid out for earlier plantings and the first instalment for newly planted trees in that year. However, over the years the cost should smooth out and the average cost should be close to the actual costs of establishing trees or scrubs per unit of area under the ECFP.

The landowners' extra costs of involvement in ECFP could not be collected due to difficulty of getting addresses of landowners participating in the programme. Also no one completed the online questionnaire advertised in the NZIF newsletter which is circulated each week among its members who are mostly foresters, consultants, and sawmill operators. However, there appears to be not much additional cost to landowners, other than normal silvicultural practices, as there is no cost of lodging grant applications due to a policy shift in 2007 from a tender based application to a grant based one. Also the present application form has been simplified to one page and does not require the input of external consultants as MPI staff helps landowners in filling out these forms**.** Before 2007, the average cost of preparing a grant application was around $3,000-$4,000 for a large block (and up to $150 for a smaller block), due to a lengthy application form with significant compliance costs (Bayfield & Meister, 2005). The costs of natural reversion is assumed to be equal to the grant provided for natural reversion which was $1,512/ha in 2012. All the costs were inflated to 2012 using a GDP deflator so that costs of planting and natural reversion can be compared across different land-use programmes.

3.6.4 Costs of delivering ES benefits

The costs of delivering ES benefits were calculated by dividing total costs of land-use programmes by their cumulative/weighted indicator score (Equation 3.5). The costs of implementing land-use programmes to the government and organisations have been estimated on a per hectare basis. The extra costs to landowners' of being involved in those programmes were also estimated on a per hectare basis, but based on the information provided by a forestry consultant and few farmers. Due to lack of information on landowners' exact costs and area under specific land-use programmes, the values reported in the research should be considered as indicative only.

$$\text{Cost/ES}_{\text{benefits}} = \frac{\text{Total costs (\$/ha)}}{\text{cumulative/weighted indicator score/ha}}$$

$$\text{or Cost/ES}_{\text{benefits}} = \frac{\$}{\text{cumulative/weighted indicator score}} \qquad (3.5)$$

3.7 Description of the Research Site

The Kaituna catchment (hereafter the catchment), with an area of approximately 4685 hectares, is located on the south-west of Banks Peninsula in Canterbury. It ranges from 1 m altitude in the south where it drains into Lake Ellesmere/Te Waihora to a maximum altitude of about 913m at Mount Herbert/Te Ahu Patiki, the highest point on Banks Peninsula (Figure 3.4). The Kaituna valley was formed as a result of volcanic activities which took place about 12 to 5.8 million years ago followed by a glacial period during the last 2 million years in which fine sand and silt were formed due to grinding action of ice on rocks and deposited as loess on much of the Banks Peninsula region including the Kaituna catchment. As a result the catchment is underlain by lava, ignimbrite, and other hard volcanic rocks. On the surface are loess (54%), volcanic rocks (34%), and alluvium (12%) (Christchurch City Council, 2007). Silt loam is the dominant soil in the catchment though some rich fertile alluvial soils are located on flat areas near the catchment outlet which indicates that Lake Ellesmere once might have extended to the mouth of the Kaituna valley. Small streams drain Kaituna slopes and feed water to the Kaituna River which flows in twists and turns before it reaches the bottom valley floor and drains into Lake Ellesmere in the south-west.

Figure 3.4 Location of Kaituna catchment (source: Land Cover Database 2)

3.7.1 Climate

Due to variation in topography (gentle southward dipping), the climate of the catchment is quite different from that of the surrounding Canterbury Plains. The western part of the catchment receives less rainfall and the eastern areas more with prevailing winds coming from the south and south-west. The higher parts of the catchment get rain from southerly winds which occur during winter and can extend into spring time. Summers are usually dry, and slopes facing north can dry up quickly following the rain due to high evaporation rates. The rainfall radar shows that (±SD), the annual rainfall in the catchment varies from 700 mm at lower altitudes to 1244 mm at higher altitudes (±118mm) (Figure 3.5). The temperature in the catchment is less variable due to its coastal location. The climate layer shows that average annual temperature varies from 7.7 ^{0}C at higher altitudes to 12.9 ^{0}C around the lower part of the catchment which are flat to rolling lands (Figure 3.5).

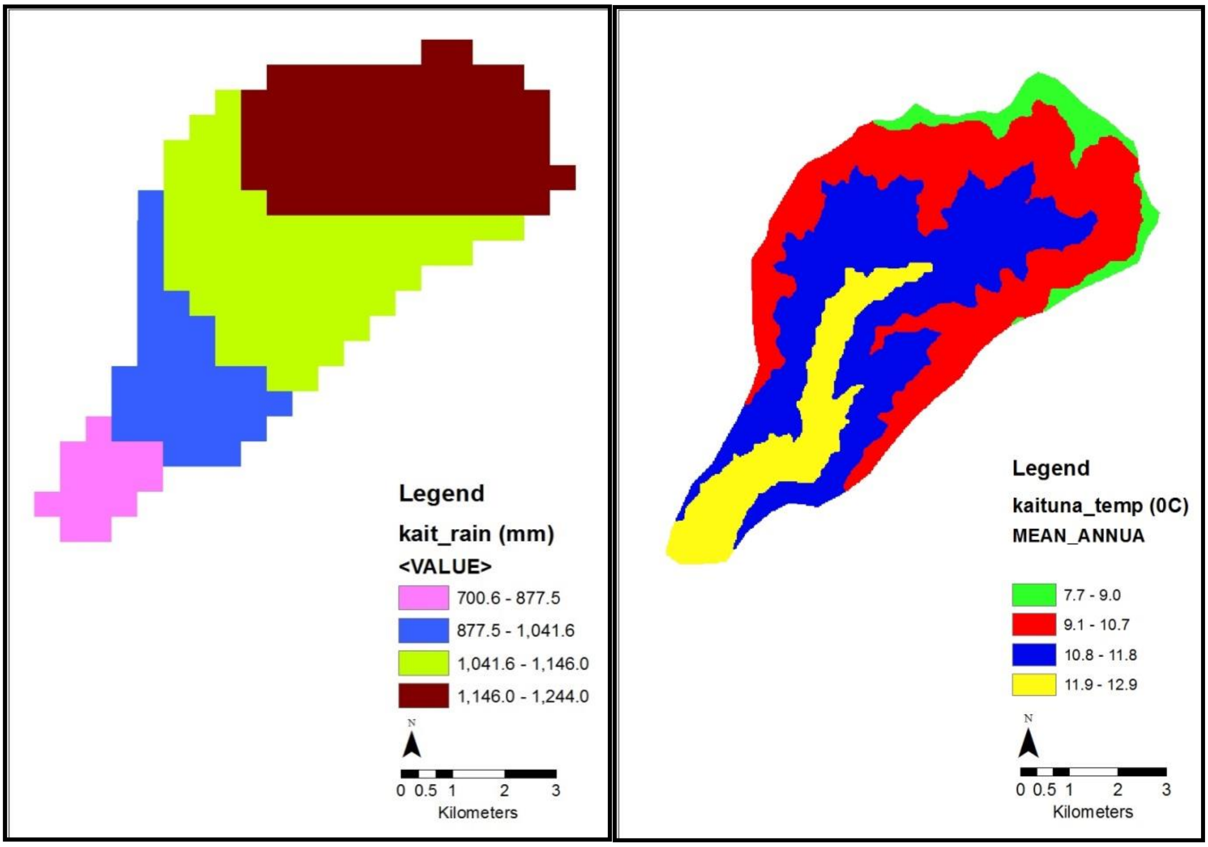

Figure 3.5 Average annual rainfall and mean annual temperature in Kaituna catchment (Source: Z drive, Lincoln University)

3.7.2 Vegetation/landuse

According to the Land Cover Database 2 (LCDB2), pasture is the dominant vegetation covering 71 percent of catchment area, followed by scrub and forest covering 20 percent and 7 percent respectively (Figure 3.6). Although much of the indigenous vegetation in the catchment has been cleared for farming and some settlements, indigenous forests and hardwoods, and Manuka/Kanuka together make up 20 percent of the catchment area. This is a lower value than the national average of 49.6 percent native vegetation cover remaining in the country. The Department of Conservation (DOC) manages about 373 hectares of land in the catchment which includes indigenous forests, scrub, and some grassland at the sites named Mount Herbert Scenic Reserve, Packhorse Scenic Reserve, and Kaituna Spur Scenic Reserve respectively. These reserves provide regulating (air and climate regulation, soil protection, water quality maintenance), and cultural services (recreational, educational, natural habitat and biodiversity, and amenity values) to people.

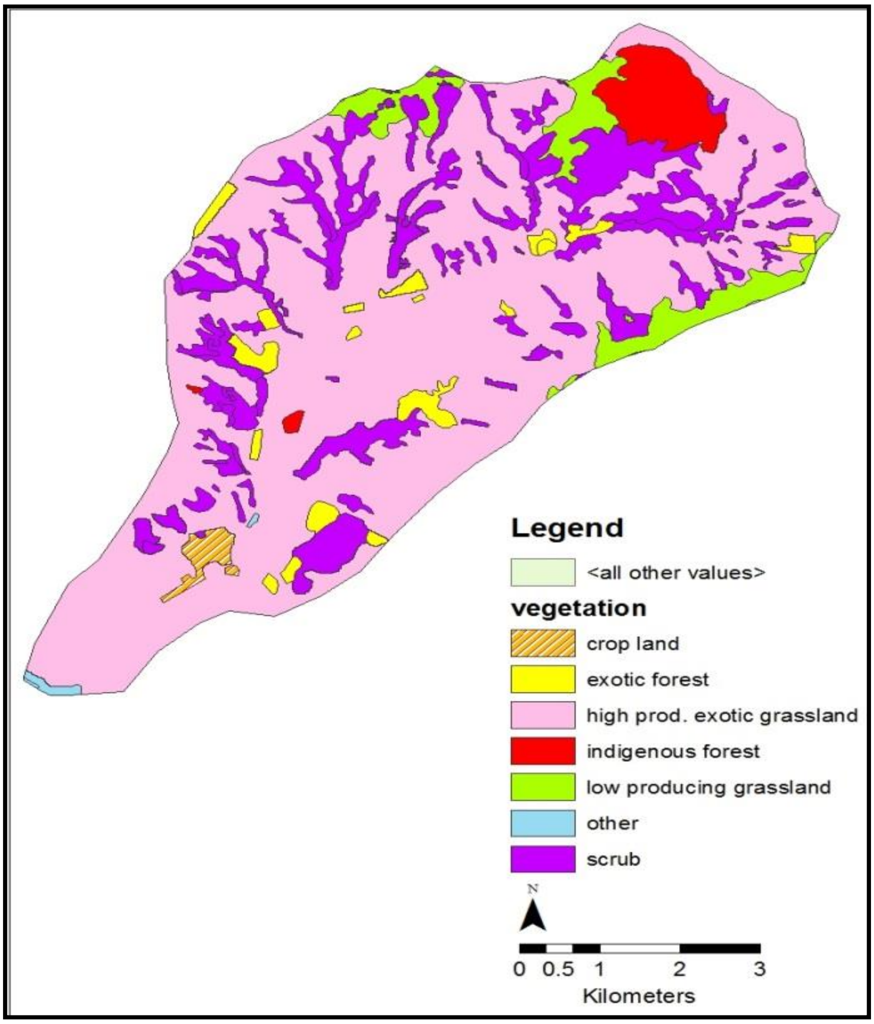

Figure 3.6 Vegetation in Kaituna catchment (Source: LCDB2)

The lower parts of the catchment (0-15^0 slope) are utilised for pastoral agriculture. According to the default land use in Catchment Land Use for Environmental Sustainability (CLUES), Sheep and Beef Hill is the dominant land use (57%), followed by scrub (19.5%), Sheep and Beef Intensive (7.4%), forests (7.1%), ungrazed pasture (4.7%), dairy (2.7%), annual crops (0.8%), others (0.7%), and deer (0.1%).

The modification of land from predominantly native vegetation in pre-human time to the present uses reflects peoples' desire to use the land to earn income from sale of consumable products such as timber, cereal crops, milk, meat, and wool; and their preferences for protection of land for recreational purposes (hiking, camping, and picnicking), biodiversity and habitat values. The change in vegetation cover or land-use in the catchment affects flows of ES which in turn affects wellbeing of people as they derive benefits from ES. This research has estimated changes in flows of ES as a result of land-use changes in the catchment.

3.8 Data

Although the research is primarily based on secondary data, it also utilises some primary data. The data collection methods and sources of data are discussed briefly in the following sub-sections.

3.8.1 Preference data

This study collected preferences of members of the public for six ecosystem services - production, carbon sequestration, water yield, water quality, soil erosion control, and cultural. For this purpose, a survey was designed with the help of a freely available online survey builder tool called Qualtrics (https://www.qualtrics.com/). The survey was subsequently approved by the Lincoln University Human Ethics Committee (see Appendix A). It was pre-tested among some postgraduate students of Faculty of Commerce at Lincoln University to determine if the questionnaire is clear and easily understood to a person who may or may not have heard about ES. This exercise helped to refine the questionnaire which is presented in Appendix B. It was then uploaded in Qualtrics and made available online to members of the public visiting the Lincoln University stand at the Canterbury Agricultural and Pastoral (A & P) show during 9-11 November 2011. Altogether 80 people voluntarily took part in the survey and completed the questionnaire online at the show.

A questionnaire was developed using a slightly different approach than usually found in AHP surveys (Leung *et al.*, 1998). Instead of choosing one ES purposively and then listing its comparison with all other ES under investigation, this research first assigned the numbers 1 to 6 to six ecosystem services (1-production, 2-carbon sequestration, 3-water yield, 4-water quality, 5-erosion control, and 6-cultural) and then listed possible pairs of combinations for each of the ES. These combinations were noted down on a piece of paper and drawn one at a time. The first number picked was 24 which represents a comparison between 2 (carbon sequestration) and 4 (water quality). Number 42 was ignored as that pair is identical to number 24. This procedure was followed until all 15 pair-wise comparisons were selected. This procedure avoided possible bias resulting from respondents considering production ES being more important than other ES if they were to appear on the first five rows of a traditional AHP questionnaire.

In the AHP questionnaire, the respondents were first asked to choose whether they preferred the ecosystem service that appears on their right side over the ES that appears on their left or vice versa (see Appendix B for the questionnaire). They were then asked to quantify the relative degree of importance using the 1 to 9 scale developed by Saaty (Table 2.3). The scale value 1 means the respondent is indifferent between the two ES under comparison whereas a scale value from 2 to 9 shows increasing importance with 9 indicating absolute importance of one ES over the other.

The pair-wise comparison data can be analysed in an Excel spread sheet using an Eigen-value technique that constructs a matrix using reciprocals of pair-wise comparison. The process requires raising the power of the matrix, summing the rows and normalising to one, and when this vector converges it is called a priority vector. An inconsistency index can be calculated using the maximum value of the Eigen vector (principal Eigen value) and a random index for 1 to 10 order matrices found in Saaty (1994a). However, this research downloaded the freely available Superdecisions software (http://www.superdecisions.com/) and ran it with the code supplied by its founders. It converted peoples' responses into ES weights and also calculated consistency ratios. The consistency ratio shows the limit up to which inconsistency in subjective judgement is accepted. For this research, the consistency ratio was set at 0.15 (R. Saaty, personal communication, December 1, 2011) which should be considered as the upper limit to be used in subjective judgements as responses that are too inconsistent will not truly represent peoples' preferences and will produce misleading results.

3.8.2 Costs data

The research also developed a 'Costs Survey' in Qualtrics to help find out landowners' costs of participating in ETS, ECFP, and QEII Trust programme (see Appendix C for the questionnaire). However, the research could not readily collect data on those costs as Ministry for Primary Industries (MPI), citing privacy issues, did not provide landowners' addresses. An appeal was advertised in the New Zealand Institute of Foresters weekly newsletter starting from number 2012/08–02 March through to number 2012/14-13 April, and a request made to participants at the New Zealand Institute of Forestry (NZIF) conference in Christchurch during 2 to 4 July 2012. However these efforts had little success as only one person filled-in the questionnaire online and another person returned it by post. The QEII Trust representative in Christchurch provided costs figure for six covenantors who gave their consent to disclose the information (costs).

The costs collected in this research include incremental costs that were added because of land-use programmes. They include extra costs to government of running those programmes and to landowners of being involved in those programmes. The landowners' costs on regular forestry activities were excluded in cost analysis as they were not borne as a result of land-use programmes.

3.8.3 Biophysical data

The biophysical data were downloaded from the land resources information system (LRIS) portal of Landcare Research and Koordinates Limited which contains GIS datsets and information about New Zealand. The information on vegetation cover are contained in the LCDB2 and its main strength is that it gives internally consistent results at a nominal resolution of 1 hectare. However, it does not tell us what stock are present on those areas of vegetation. To determine stock types and on-farm crops, the AgriBase data set is useful but its spatial detail is limited to whole farm enterprises (Newsome *et al.*, 2010). Hence, to ensure better data are available, the strengths of LCDB2 and AgriBase have been combined in the CLUES model developed by Landcare Research which has also extracted information from MPI farm monitoring reports and Land Environments of New Zealand (Woods *et al.*, 2006). The default land use for Canterbury region provided in the CLUES model was chosen as a base file for studying impact of land use change on water quality parameters as it shows percentage of area covered by 19 different land-use types per polygon which is useful for simulating impact of landuse change on water quality parameters. However, it is not useful for estimating other ecosystem services such as soil erosion or water yield which require information on vegetation cover. For this reason, LCDB2 was used for estimating ecosystem services other than water quality. The research could not utilise more recent Land Use and Carbon Analysis System data as recent AgriBase data were not freely available and it was beyond the scope of this research to integrate them into the CLUES model.

Other sources for secondary data were as follows:

- New Zealand Land Resources Information and Fundamental Soil Layers from LRIS portal (http://lris.scinfo.org.nz/)
- LCDB2, Land Use and Carbon Analysis System (LUCAS), LENZ and DOC area boundaries from Koordinates (http://koordinates.com/)
- Rainfall and river flows data from Environment Canterbury (ECan)
- Reports of MPI, MfE, QEII National Trust, and Landcare Research

- Personal contacts to forestry consultants and staff in MPI, QEII National Trust, ECan, and Landcare Research

WATYIELD model

The main data requirements for the model are the daily rainfall series and evaporation for the site which are obtainable from nearby meteorological stations. For calculating change in water stored in the root zone (ΔS) in Equation 3.2, information on vegetation and soil parameters are needed. These include rainfall intercepted by the vegetation or interception fraction (IF), crop coefficient (k), profile available water (PAW) and profile readily available water (PRAW). Further, for examining the effects of land-use on low flows, two base flow parameters - base flow index (BFI) and base flow recession coefficient (k) – are required. BFI is the proportion of total flow that appears as base flow (Hewlett & Hibbert, 1967; Jowett & Duncan, 1990) and k is the rate of base flow recession from the base flow store.

ECan supplied the daily rainfall and river flow data which comes from Kaituna Valley recorder located near the bottom of the catchment (Alt 70 m). For the evapotranspiration (Et) data, the nearest measuring station is at Lincoln which has an annual Et of 867 mm. However, Et for Kaituna should be lower than the Et value recorded at Lincoln station due to its varied altitude and greater cloud cover associated with its coastal location (B. Fahey, personal communication, March 6, 2012). For this reason, evapotranspiration for Kaituna was estimated using a regression equation derived by Namjou (1988).

$$\mathrm{C1} = 0.307 + 0.931\mathrm{C2} \qquad (3.6)$$

Where, C1 is Evaporation at Kaituna station and C2 is Evaporation at Lincoln station.

Substituting Et data for Lincoln from New Zealand Meteorological Service Miscellaneous Publication 189 in equation 3.6, the average annual Et for the catchment was estimated at 810 mm. The research used rainfall and flow data for the period 1 July 1990 to 30 June 2010. Gaps in the rainfall series were filled by importing rainfall values for missing dates recorded at nearby Cooper's Knob station (Alt 400m) and gaps in daily flows were filled by importing average values for missing dates in earlier years recorded at Kaituna valley recorder as there was unavailability of flow data for Cooper's Knob.

To analyse the impact of land-use on annual water yield, the catchment was divided into five sub-areas as shown in Figure 3.7. The division of area in Figure 3.7 was made based on average rainfall, but any other criteria such as vegetation or soil types can be adopted. The average rainfall decreases from sub-area 1 to 5. Vegetation and soil parameters were extracted from LCDB2 and FSL respectively. PAW values were calculated as mean of maximum TAW values contained in FSL, and PRAW and initial water content (IWC) were set at 50 and 20 percent of TAW values respectively (Fahey *et al.*, 2010). The IF values and k values were derived by summarising default values given in the model for each sub-area based on proportion of vegetative cover contained in those areas. The rainfall map was clipped for the catchment and mean annual rainfall for each sub-area was calculated with the help of the zonal statistics as table tool. The average annual rainfall (±SD) for the lower part of the catchment (sub-area 5) was 869 mm (±86mm) and for the upper part of the catchment (sub-area 1) was 1197 mm (±26mm) (see Appendix D) whereas the average rainfall recorded for Kaituna over the period of 1 January 1991 to 31 December 2010 was 761 mm. As the rainfall recorder was at a lower altitude, the rainfall figures were weighted with reference to a rainfall map. The BFI was calculated as the proportion of total flow that appears as base flow and k was calculated by taking average value for the days over which the flow halves (Fahey *et al.*, 2010). Table 3.6 shows input parameters used in the model.

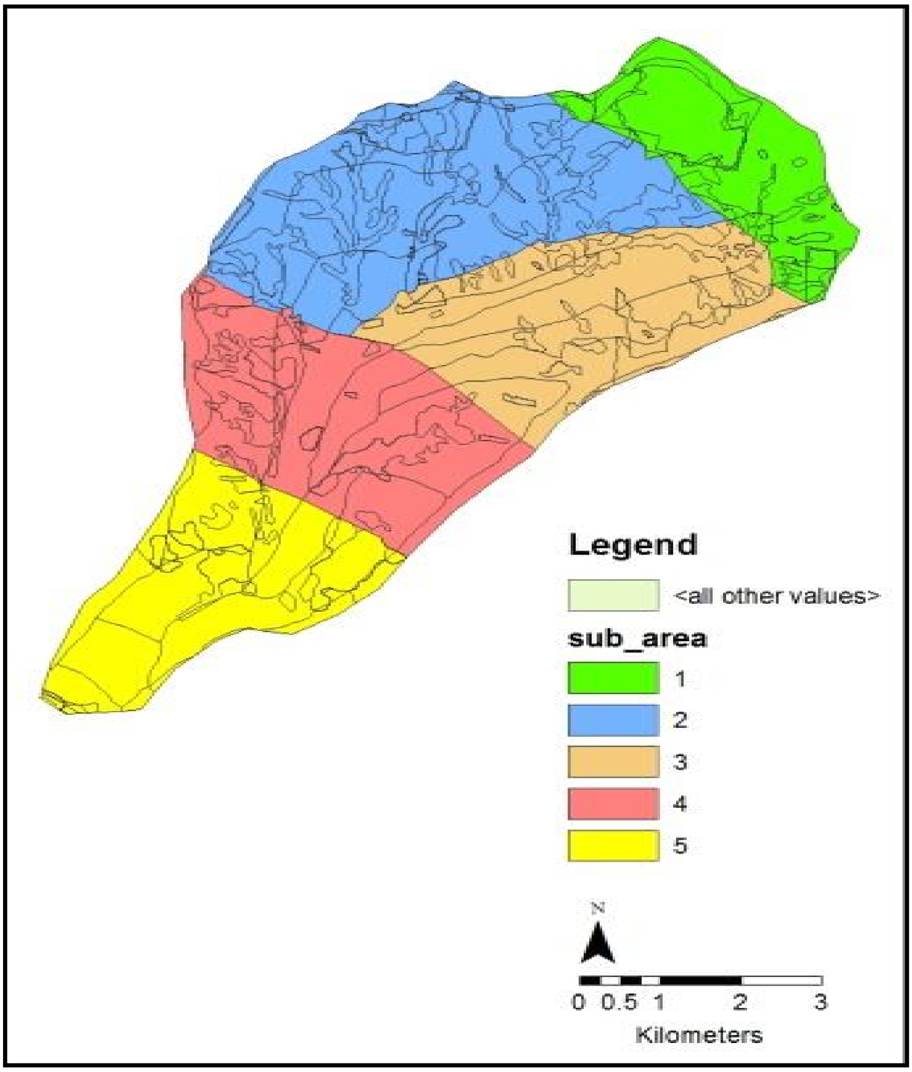

Figure 3.7 Sub-areas in the catchment for estimating annual water yields

Table 3.6 Input parameters used in the model calculations for mean annual water yield for the Kaituna catchment, Canterbury.

Sub-area	Land-cover	Rainfall weighting	IF	Crop k	TAW (mm)	PRAW (mm)	IWC (mm)
1	Pa - 59%, F - 30%, Sc - 11%	1.57	0.11	0.87	138	69	27.6
2	Pa - 68%, F - 1%, Sc - 31%	1.51	0.06	0.90	115	57.5	23
3	Pa - 82%, F - 4%, Sc - 15%	1.50	0.04	0.94	123	66.5	24.6
4	Pa (76%) F (7%) Sc (18%)	1.39	0.05	0.93	110	55	22
5	Pa (83%) F (3%) Sc (12%)	1.14	0.03	0.95	122	61	24.4

The model's goodness of fit was tested by the statistical measure Root Mean Square Error (RMSE) and Modelling Efficiency (MEF). A good model should show minimum error and maximum modelling efficiency value (Martin, 1973).

$$\mathrm{RMSE} = \left[\sum_{i=1}^{i=n} \frac{(\mathrm{Pi}-\mathrm{Oi})^2}{n}\right]^{0.5} \frac{100}{\bar{O}} \qquad (3.7)$$

$$\mathrm{MEF} = \frac{\sum_{i=1}^{i=n} (\mathrm{Oi}-\bar{O})^2 - \sum_{i=1}^{i=n} (\mathrm{Pi}-\mathrm{Oi})^2}{\sum_{i=1}^{i=n} (\mathrm{Oi}-\bar{O})^2} \qquad (3.8)$$

Where, Pi is the predicted value, Oi is the observed value, n is the number of samples, and Ō is the mean observed value.

CLUES model

The default land use in CLUES was clipped for the catchment but it showed missing polygons towards the outlet of the catchment (Figure 3.8).

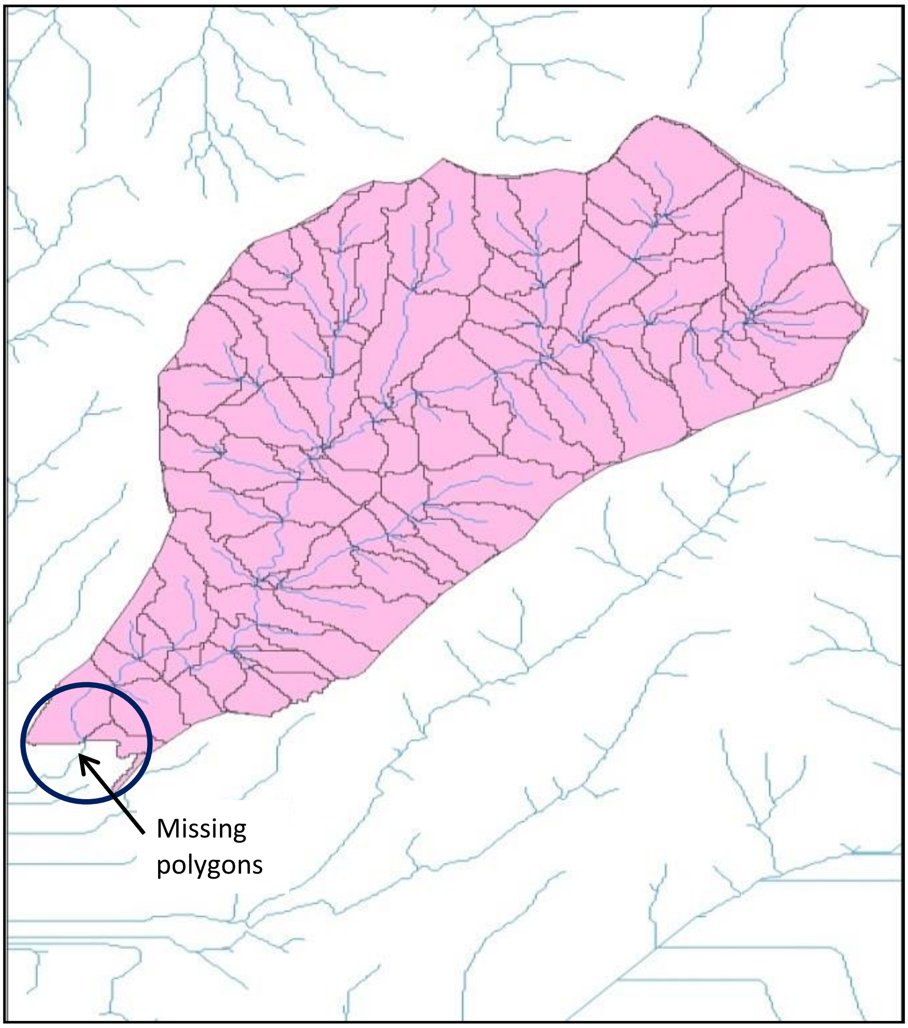

Figure 3.8 Default land-use in the CLUES model with missing polygons at the catchment outlet

The missing polygons in the above figure were created with the help of ArcGIS auto-complete polygon tool and proportional land use areas were assigned to those polygons based on land-use information contained in the hydroedge layer highlighted by blue colour in Figure 3.9. Then CLUES was run for the existing land-use scenario and for the afforestation scenarios in which it was assumed that landowners will enter forestry schemes (e.g. ETS or ECFP) and convert their hill country sheep and beef and ungrazed pasture areas to exotic forests, or sign a covenant with QEII Trust or ECFP and retire their hill country sheep and beef lands which will regenerate to Manuka/Kanuka scrubland. In New Zealand abandoned agricultural land can regenerate to Manuka/Kanuka in about 10 years if a seed source is available in the area, there is adequate soil moisture and only low grass cover (Sullivan *et al.*, 2007). Otherwise, natural regeneration process can be accelerated by fencing and removing livestock, managing pests, spraying the grass and planting nurse crops if required. The CLUES model was used to predict nitrogen, phosphorus, sediment, and bacterial loads to indicate several of the impacts of land use in the catchment.

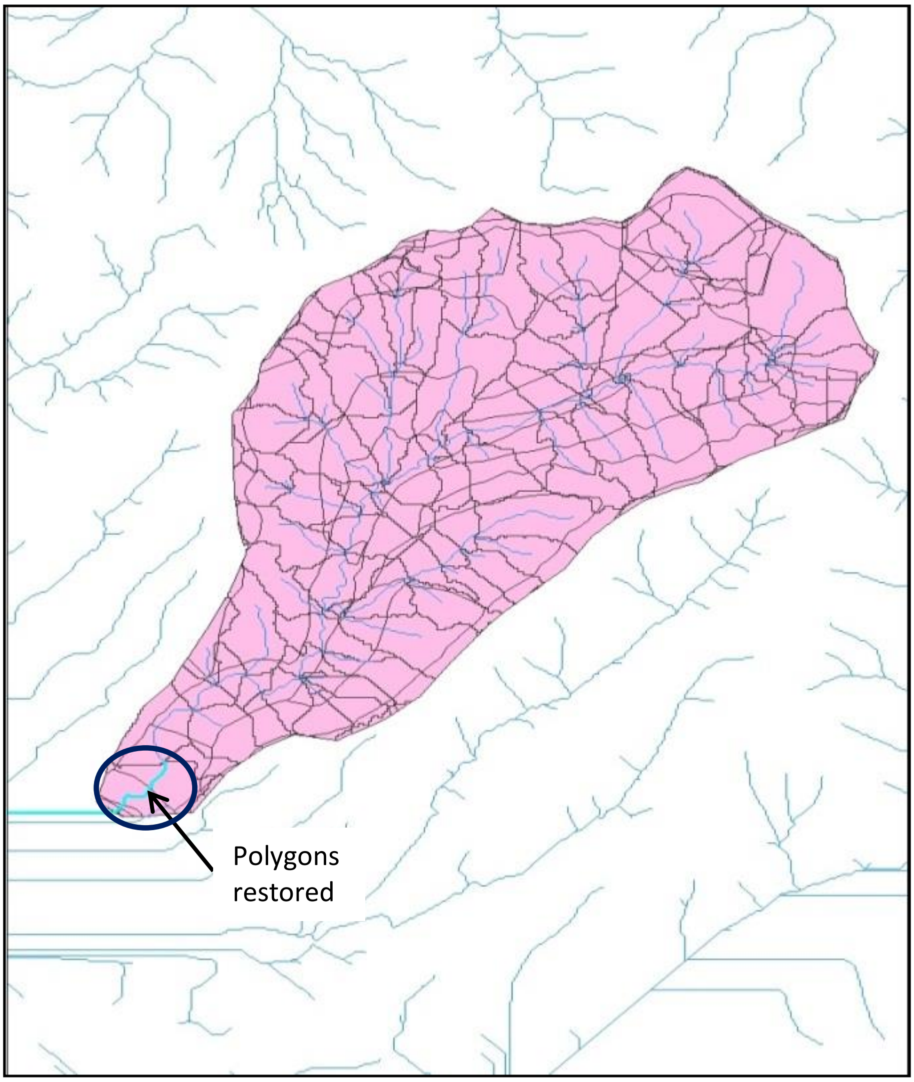

Figure 3.9 Default land-use created for the research to run CLUES model

Erosion model

For running the NZeem® model, a map of land cover is required for each land-use scenario (Dymond *et al.*, 2010). For this purpose, the LCDB2 was clipped for the Kaituna catchment which was then coded with three classes of vegetation - woody vegetation, herbaceous vegetation, and bare ground. This land cover map was used for estimating sediment yield in the all pasture and all scrub scenarios. For the sediment yield in existing land use, target land into plantation forestry and scrublands scenarios, NZeem harvest model was used as it takes into account soil loss during harvesting of trees. For these scenarios, vegetation classes were woody vegetation other than exotic forest, herbaceous vegetation, bare ground, and exotic forest.

Land cover maps were produced for different land-use scenarios and then uploaded in the online model platform which produced maps of mean erosion rates (t/km^2/year) for each land-use scenarios. An example is presented in Figure 3.10 which shows mean erosion rate for the existing land-use. The mean erosion rate obtained in this way is not the actual mean erosion rate for the catchment as it also covers map area outside the catchment as shown by pink colour in figure 3.10. The actual erosion rates for the catchment were calculated by the spatial analyst tool which summarised the mean erosion rate for the catchment.

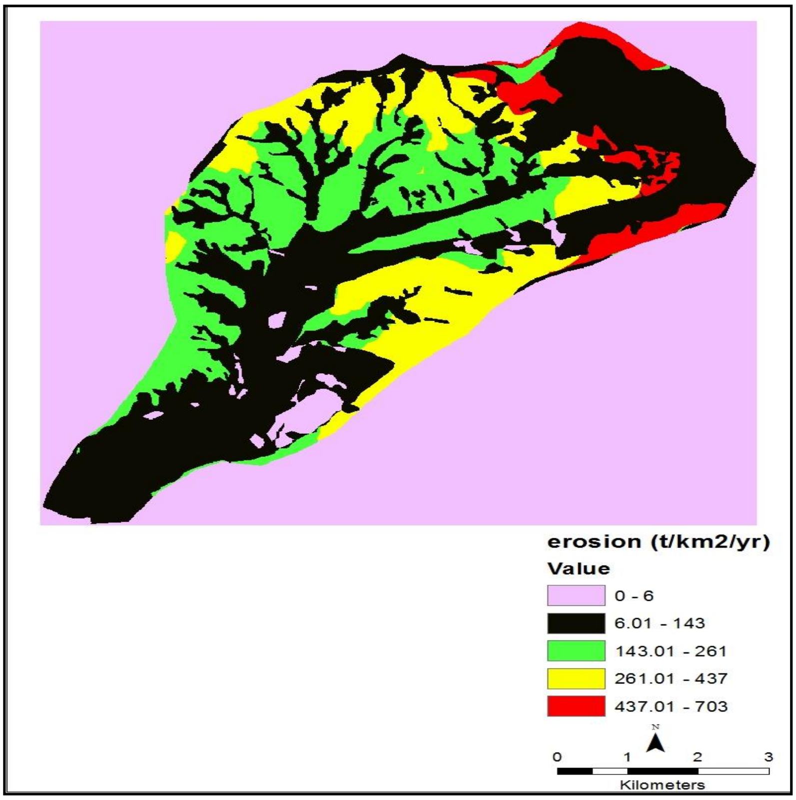

Figure 3.10 Raw map obtained from NZeem model for the existing land-use (the legend values show mean erosion rate for the catchment which also includes pink coloured area)

Habitat function

The main source of data for the habitat function was from LENZ which contains information on climate, landforms, and soils. It has been divided into four levels; level I and II are classified at more broader spatial scales for their application at national-regional level whereas level III and IV are classified in more detail (higher spatial resolution) suited for district-local level studies. For this research, LENZ level III data were used as LENZ level IV data is reaching its spatial resolution limit at 1:50000 scale. LENZ level III contains historical or unique habitats data for indigenous forests and grasslands and is suitable for use in regional geographic contexts (Leathwick *et al.*, 2003). The default land cover map created for the catchment, by intersecting LCDB2 and Kaituna catchment, was coded with four vegetation classes – plantation forests, indigenous forests, pasture, and scrub. This layer was intersected by LENZ level III layer and the resulting attribute table was exported into an Excel worksheet and vegetation contained in each land environment was calculated with the help of the pivot table function in Arc Map10. Finally, habitat provision index was derived by substituting these data in the habitat function.

In Equation 3.4 (Section 3.4.4), the natural habitat value of a land environment at original extent was calculated as $P_i = (A_i)^{0.4}$ (Connor & McCoy, 2001). The 0.5 power index used in Equation 3.4 shows that the function is monotonically increasing between 0 and 1 with its derivative decreasing between 0 and 1 to represent higher biodiversity value of natural areas. The condition index value for natural areas is 1 and values for other land cover/uses are based on their contribution to habitat provision relative to the natural state (Table 3.7). For example the condition index value for pasture is 0 as fields with grazed pasture are very low in biodiversity. On the other hand, the condition index value for exotic forest is set at 0.3 to reflect some contribution of exotic forest to habitat provision and biodiversity as studies in New Zealand have indicated this occurs (O'Loughlin, 2005; Pawson *et al.*, 2010). The condition index value for scrub is 0.5, midway between the two extreme values of 1 and 0.

Table 3.7 Condition index per land use type

Land use	Condition index c_j
Natural areas	1.00
Plantation forest	0.30
Scrub	0.50
Pasture	0.00

Source: (Dymond *et al.*, 2008)

Radiata Pine calculator

Pinus radiata was chosen as the preferred species for afforestation of target land as it occupies 90 percent of planted production forest area in New Zealand (Ministry for Primary Industries, 2012). It was assumed that a certain area of the catchment will be planted every year until the whole target land is planted (estate establishment). Hence, two scenarios were considered:

(a) Plant 84 hectares per year and harvest at age 28 years (ECFP and ETS forests)

(b) Revert 84 hectares per year with support from QEII Trust or ECFP

For ETS and ECFP forests, 84 hectares will be planted every year for 28 consecutive years and continuously harvested after 28 years in rotation. The estate level planting was preferred over a clearwood regime for a number of reasons. First, though not a requirement, it will minimise sediment, biodiversity, and carbon losses due to harvesting of only small patches of plantation forest. This means flows of ecosystem services estimated by biophysical models will be more representative of the study site as the results shown by those models are for mature trees which are present in a majority of plots except the one that is harvested. Second, it represents a realistic scenario for the catchment given the fact that only a limited number of landowners can be awarded afforestation incentives such as ECFP grants with the available annual budget for forestry programmes.

Trees sequester atmospheric carbon in their branches, twigs, and logs as they grow, but when trees are harvested about 70 percent of the stored carbon is released back into the atmosphere and the rest (30%) transferred to the dead organic matter pool which usually decays within ten years (Ministry for the Environment). So, in order to make carbon sequestration permanent, trees need to be grown either permanently or on a strategy of continually replanting following harvesting (clear wood regime or estate regime). If trees are grown in these ways, there will be a permanent stock of carbon at a site which includes carbon in all pools; that is living biomass pool (above and below ground biomass), dead organic matter pool (dead wood and litter), and soils. Further, a significant proportion of carbon is permanently stored in wood derived products such as poles and furniture until they decay. Hence, in order to find out total carbon storage benefits of trees, we need to calculate carbon stored in all pools including carbon in mineral soils and wood derived products. However, due to lack of data and resources, this research has excluded carbon stored in wood derived products and mineral soils from analysis. This is in line with the ETS which does not require measuring forest soil carbon (NZ Forest Owners Association, 2013) and with Kyoto protocol accounting system which simply assumes that all carbon in a forest is instantly oxidised at harvest (Buchanan, 2007). Also forest soil carbon doesn't change that much in the long run with continued forestry (Ministry for the Environment, 2010).

Carbon credits in New Zealand ETS are determined on the basis of carbon stored in above and below ground biomass, coarse woody debris (CWD), and fine litter leaving aside soil carbon as it is expensive as well as difficult to measure changes to soil carbon. These pools have been included in carbon look-up tables for pre 1990 and post 1989 forest land for *Pinus radiata*, Douglas fir, exotic hardwoods, exotic softwoods, and indigenous forests. This research used the calculator for calculating carbon stock in *Pinus radiata* forests and equation 3.9 for estimating carbon in Manuka/Kanuka dominated scrubland. The calculator estimates carbon in all pools except soils but equation 3.9 gives carbon in above ground biomass only. Therefore, carbon in below ground biomass contained in scrub was derived following Coomes *et al.* (2002) that the carbon in below ground biomass is approximately 25 percent of carbon in above ground biomass. This method has been used in the reporting of New Zealand's Greenhouse Gas Inventory for the period 1990 to 2008 under United Nations Framework Convention on Climate Change (Ministry for the Environment, 2010). However, the carbon in deadwood pool was set at 25 percent of carbon in living biomass pool - that is total of above and below ground biomass as shown in Table 3.8.

Table 3.8 Summary of methods used for estimating carbon in scrub

Carbon pools	**Method used**	**Reference**
Living biomass pool		
Above ground biomass	Gompertz equation	(Funk, 2009; Trotter *et al.*, 2005)
Below ground biomass	25% of carbon in above ground biomass	(Coomes *et al.*, 2002)
Dead organic matter pool		
Dead wood and Litter	25% of carbon in living biomass	(IPCC, 2003)
Soils pool	Not estimated	

Scrub carbon

The carbon contained in the scrub is calculated using a Gompertz function which has sigmoidal growth curve form adjusted for Manuka/Kanuka growth parameters (Funk, 2009; Trotter *et al.*, 2005). This equation was used on the basis that it has not been replaced since it was published.

$$\mathrm{F(t) = Cf \times 2.93 \times exp\left(\frac{(0.46 \times (1 - e^{-0.07 \times t}))}{0.1}\right)} \qquad (3.9)$$

Where,

F*(t)* is accumulated CO_2e in tonnes/ha

t is the age of Manuka/Kanuka in years

Cf is the cover factor calculated using the following equation which calculates full coverage of land by scrub in 10 years.

$$\mathrm{Cf = 0.1 + \frac{0.85}{1 + e^{(5-t)}}} \qquad (3.10)$$

As this model is standard for high rainfall (1500 mm) and soil class of average productivity (site index 25-29), the carbon estimated by Equation 3.9 was adjusted to average annual rainfall value of 1100 mm for the sub-areas 1 to 4 where target land is located. The soil productivity class for these areas is

4 (site index 20-24). Hence, carbon estimated by the model is decreased by 20 percent and 6 percent to account for lower annual rainfall and soil productivity class respectively (Trotter *et al.*, 2005).

3.9 Basis for land-use change

To study the impact of land-use programmes on ES, the focus of the research, 'target land' was identified for testing afforestation scenarios on the basis of Land Use Capability (LUC) class. This tool kit has been widely used in New Zealand for managing land at various levels, ranging from small properties and farms to catchment, regional, and national levels. Using information on LUC class in land use decisions can help managers to achieve long-term sustained production because it takes into account the physical limitations of land by considering rock types, soils, erosion types and severities, land form and slopes, and vegetation cover (Lynn *et al.*, 2009). Target land is hypothesized as areas in the catchment that are likely to transition to plantation forestry with incentive from either ETS or ECFP or scrublands with incentive from the ECFP or QEII Trust programme. Two afforestation scenarios were considered, one in which target land was planted in *Pinus radiata* on an estate level strategy on a 28 years rotation and the other in which target land was reverted to scrubland. For each of these new land-use scenarios and the existing scenario, flows of ES were estimated and compared to each other.

For these purpose two types of GIS layers were used. For estimating water quality parameters, the default land-use provided in the CLUES 10.1 package was used as it simulates the impact of land use on water quality for the whole catchment or sub-catchments as land-use information contained in each polygon are connected to a river network. The strength of the model is based on information derived from LCDB2, Agribase 2003, MAF farm monitoring reports, and LENZ (Lynn *et al.*, 2009; Todd & Kerr, 2009). The other GIS layer is LCDB2 which contains information on vegetative cover required for estimating timber production, carbon sequestration, water yield, sediment load, and natural habitat provision. Both default land-use in CLUES and land-cover in LCDB2 were clipped for the Kaituna catchment and intersected by DOC public conservation areas for delineating conservation areas and areas that are more suitable for pastoral use (LUC class I to IV). Finally this layer was intersected by the NZLRI layer which has LUC and slope attributes required for land use simulations and FSL layer containing information on profile and readily available water required for running a water balance model.

With the DOC land set aside from the land use simulation, identification of target land and future land-use changes are based on some assumptions. All the land use/cover in LUC class I to IV was excluded from the set of target land as these lands are utilised for annual crops and dairying which are unlikely to change to plantation forestry due to lower returns in forestry as compared to pastoral land uses. Plantation and natural forest areas were also excluded from the target land as plantation forests are likely to be practiced on a rotational basis, and natural forests will be conserved due to indigenous forestry legislation and regulations governing deforestation of natural trees, as well as opportunities to earn Kyoto-compliant carbon credits by registering forests in ETS. Further, some landowners may conserve natural forests for their own satisfaction or for social recognition in that they are protecting New Zealand's unique indigenous species on their lands. Areas under scrub present in LUC class I to IV are likely to transition to dairy or arable, but not to planted forests and those contained in the higher LUC classes are likely to remain in their present form due to the potential of earning Kyoto-compliant carbon credits from EBEX21® programme (http://www.ebex21.co.nz/index.asp). Another reason for not including areas of scrub in target land is they are not eligible for ECFP grants (Ministry of Agriculture and Forestry, 2007). This leaves high and low producing grassland as potential land (target land) for testing afforestation scenarios and their impact on ES. Hence, the target land for the research is high and low producing grassland on LUC class >IV as highlighted in Tables 3.9 and 3.10 and in Figures 3.11 and 3.12 respectively.

Table 3.9 Target land for studying impact of afforestation on timber, carbon sequestration, water yield, soil erosion control, and natural habitat provision.

LCDB2 Name	Area (ha)	Target land (ha)	Land-use for Figure 3.11	Criteria
High and low producing exotic grassland	2,354	2,354	Suitable for afforestation /reversion	LUC>IV but excluding DOC land, dairy, deer, and intensive sheep and beef farms
High and low producing exotic grassland	1,053		Suitable for pastoral farming	Mostly LUC<IV but some areas were on LUC>4 class. Includes DOC land, dairy, deer, and intensive sheep and beef farms.
Short rotation crop land	38.0		Suitable for pastoral	
Pine forest open canopy	20.3		DOC land, forests and scrub	
Pine forest closed canopy	89.0			
Afforestation-imaged and not imaged	23.5			
Other exotic forest	13.1			
Gorse and broom	158.0			
Indigenous forest	175.3			
Manuka and Kanuka	328.2			
Broad leaved indigenous hardwoods	431			
Lake and pond	1.5		Estuary	
Total	**4,685**	**2,354.0**		

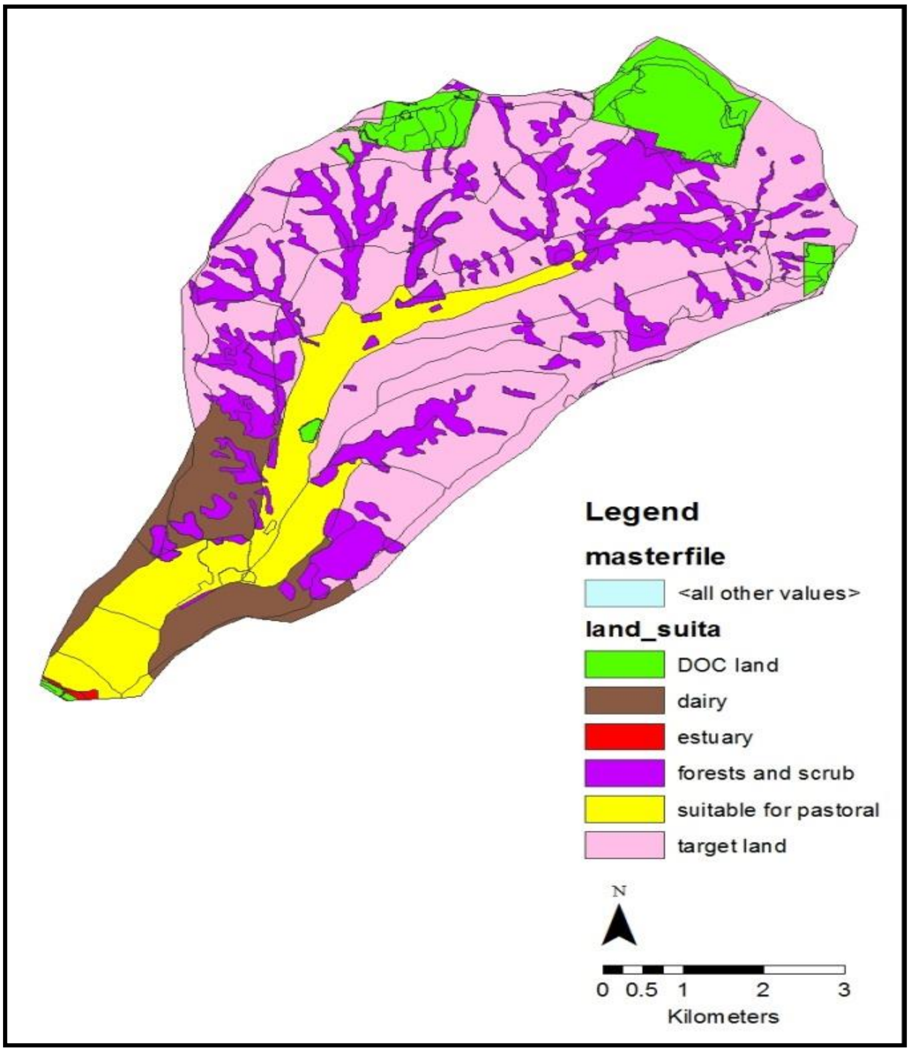

Figure 3.11 Target land for studying impact of afforestation on timber, carbon sequestration, water yield, soil erosion control, and natural habitat provision.

The CLUES model presents land-use information by farm types as shown in Table 3.10. The target land mainly consists of sheep and beef hill land use that are in LUC class>IV. Some ungrazed pasture areas are also identified as potential areas for testing afforestation scenarios. As the CLUES model contains land-use information in polygons in which area in each polygon is proportionately assigned to each farm type, it was not possible to show exact target areas in Figure 3.12. In this figure, all areas represented by pink coloured polygons are not the actual target land for the research as in each polygon only sheep and beef hill, ungrazed pasture and other land use which are in LUC class>IV were tested for afforestation scenarios by changing vegetation codes. So, the target land for the CLUES model comprised of sheep and beef hill (2,164 ha), ungrazed pasture (151 ha), and other (44 ha) as shown in Table 3.10.

Table 3.10 Target land for studying impact of afforestation on water quality

Land use class in CLUES model	Area (ha)	Target land (ha)	Criteria
Dairy	127.9		
Sheep and beef hill	2663.5	2164	LUC>IV
Sheep and beef intensive	344.8		
Sheep and beef high	0.2		
Deer	5.7		
Ungrazed pasture	219.9	151	LUC>IV
Planted Forest	156.2		
Natural Forest	175.8		
Scrub	915.8		
Other	70.8	37	LUC>IV
Total	**4680.6**	**2352**	

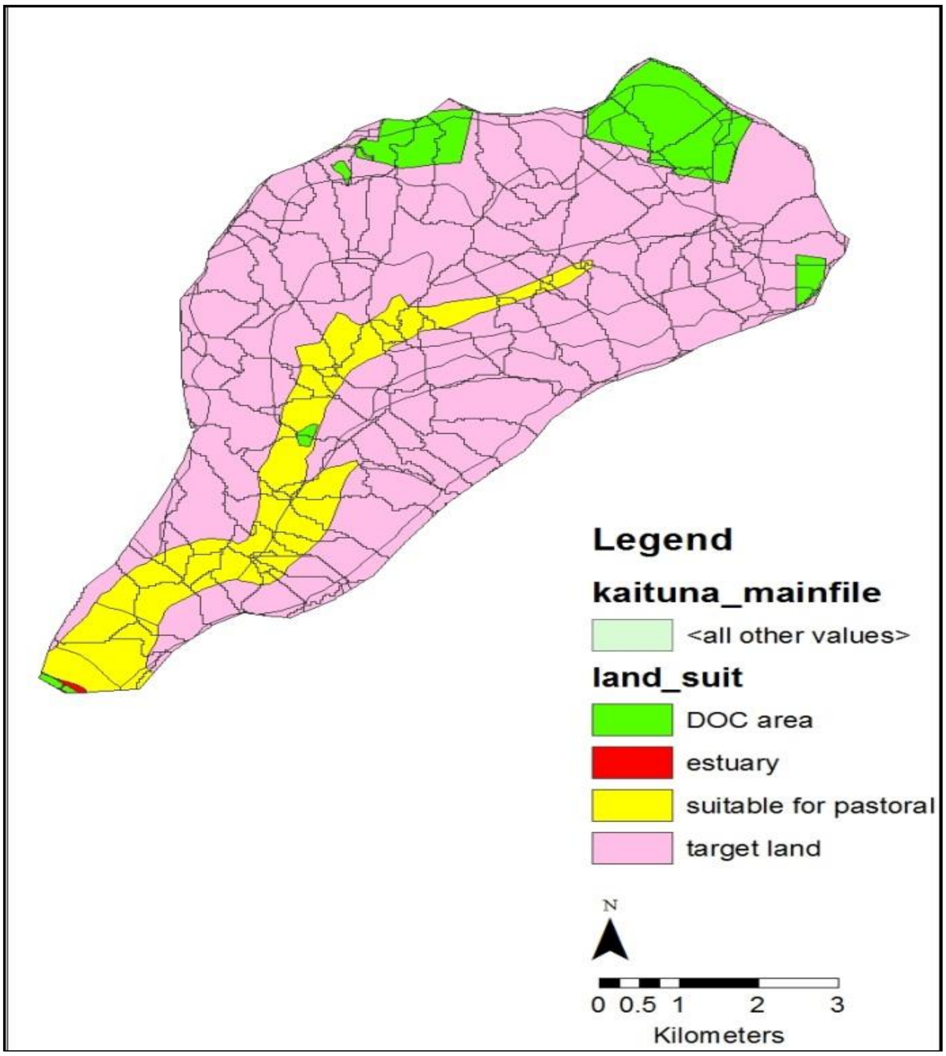

Figure 3.12 Target land for studying impact of afforestation on water quality

3.10 Chapter summary

This chapter has described the methodology, research site, and data used in the study. The sources for data were GIS portals, published reports, personal contacts, and online surveys. Online surveys were used for collecting peoples' preferences for ES and landowners' extra costs of participating in land-use programmes. A total of 80 members of the public voluntarily took part in the preference weight elicitation survey. The valid responses were converted to ES weights by AHP and Max100 methods.

The Kaituna catchment in the Banks Peninsula region was selected as the research site as this catchment is on the list of flow sensitive catchments. It has not previously been studied or evaluated for the provision of ES; that is what are the impacts of land-use change on flows of ES at the plot level and catchment level? For this purpose, target land was identified with the help of LUC class and possible afforestation scenarios were evaluated for their likely impacts on the flows of ES using biophysical models. It is relatively easy to use biophysical models with the readily available GIS data; they are designed for the New Zealand context and are appropriate for catchment level studies. The flows of ES were normalised following method used by Posthumus *et al.* (2010) which expresses each raw indicator score as a percentage of maximum raw indicator score across alternate land-use scenarios. Finally, total weighted flow of ecosystem services for the catchment was estimated by integrating ES outputs with social weights. This was compared with total costs of land-use programmes for deriving ES benefits at the catchment level as it shows costs required to generate one unit of ES benefit (cumulative indicator score).

The next chapter presents the results of ES modelling using biophysical models. Specifically, it presents ES flows in physical quantities.

Chapter 4

Impact of land-use change on flows of ecosystem services

This study investigated benefits of limited focus land-use programmes using the ESApp. The impacts of land-use on the flows of ES were estimated and the preferences members of the public attached to ES were derived. For this purpose, biophysical models were used as they are appropriate for modelling flows of ES due to land-use changes at property, farm or catchment levels. This chapter presents the main results of the study using methodology outlined in Chapter 3. Section 4.1 presents the prevailing land-use/cover in the Kaituna catchment (hereafter the catchment) as at 2002, and Section 4.2 presents the land-cover changes in the catchment from 2002 to 2008. Section 4.3 presents the flows of ES for the existing and proposed afforestation scenarios. Finally, Section 4.4 presents a summary of the chapter.

4.1 Prevailing land cover in the catchment

The Land Cover Date Base2 (LCDB2) was used to document the prevailing land cover in the catchment as it would provide internally consistent national coverage at a high spatial precision of one hectare units. Figure 4.1 is derived by applying LCDB2 layer to the Kaituna catchment. It shows grassland as the prevailing land use (73%), with scrub and forests making up 20 percent and 7 percent of the catchment area respectively. Scrub is scattered throughout the catchment while indigenous forest is mainly confined to the upper part of the catchment and exotic forests are found in the middle part of the catchment (Figure 4.1).

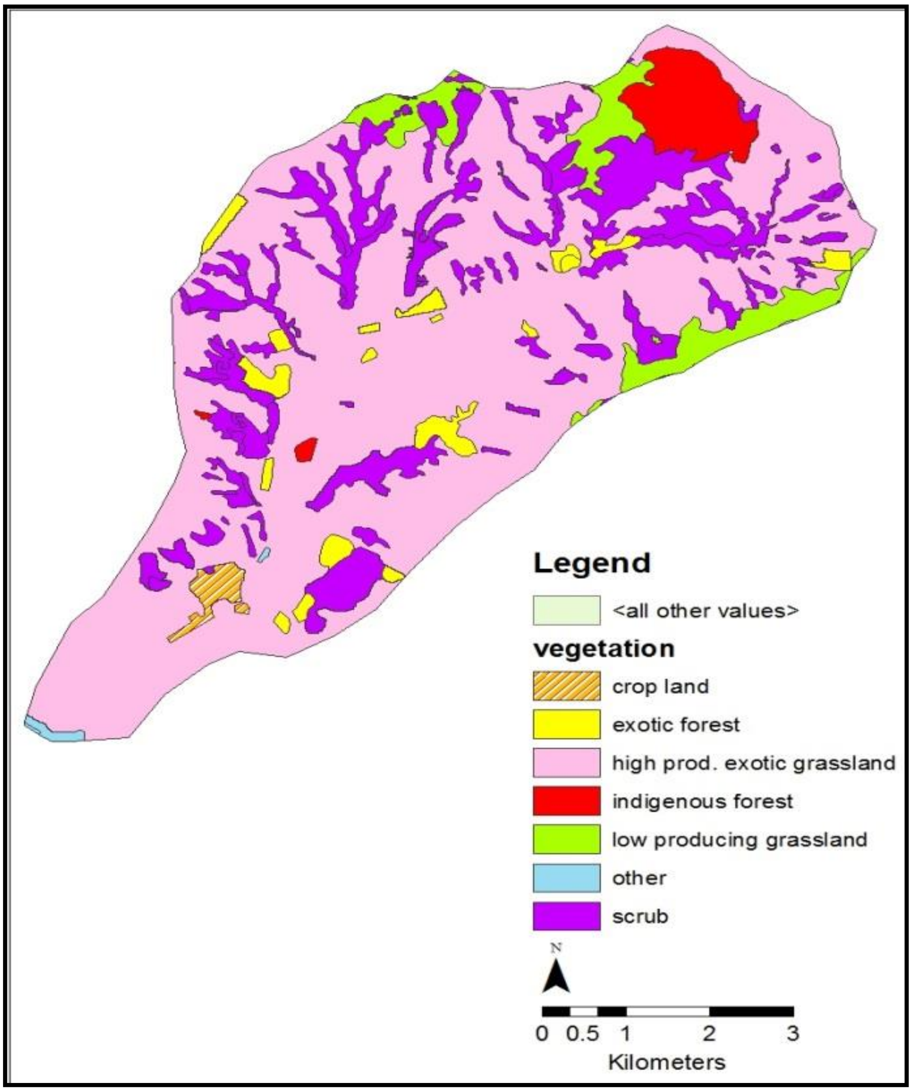

Figure 4.1 Land-cover in Kaituna catchment in 2002

The Figures 4.2 and 4.3 show distributions of land cover and farm type in the Kaituna catchment in terms of LUC class in the year 2002. As the Figure 4.2 shows about 83 percent of the catchment area lies in LUC class VI and contains grasslands, scrub and planted forests. High quality pastures and crop lands are located in LUC class III whereas the low producing grassland, scrub and planted forests are located in LUC class VI. The indigenous forests are located on steeper land (LUC class VII), which are under protection by DOC.

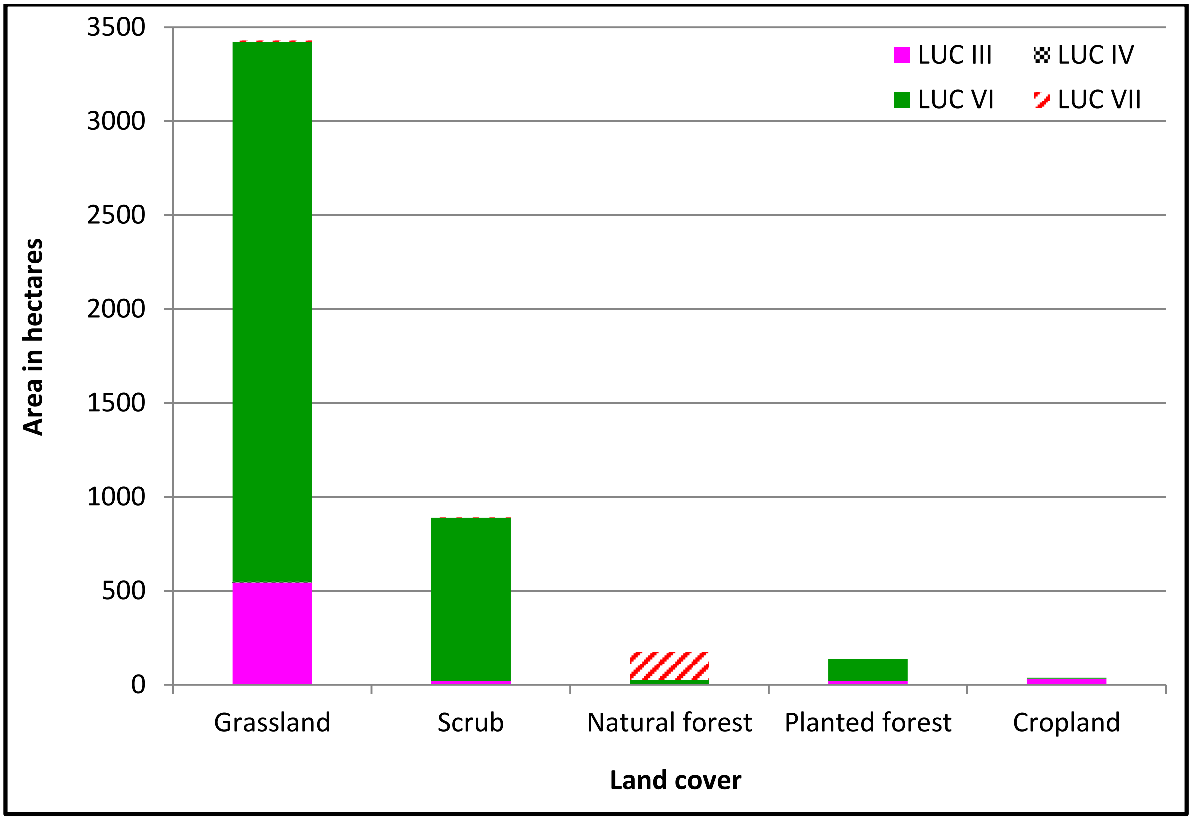

Figure 4.2 Distribution of land in Kaituna catchment by land cover and LUC class in 2002

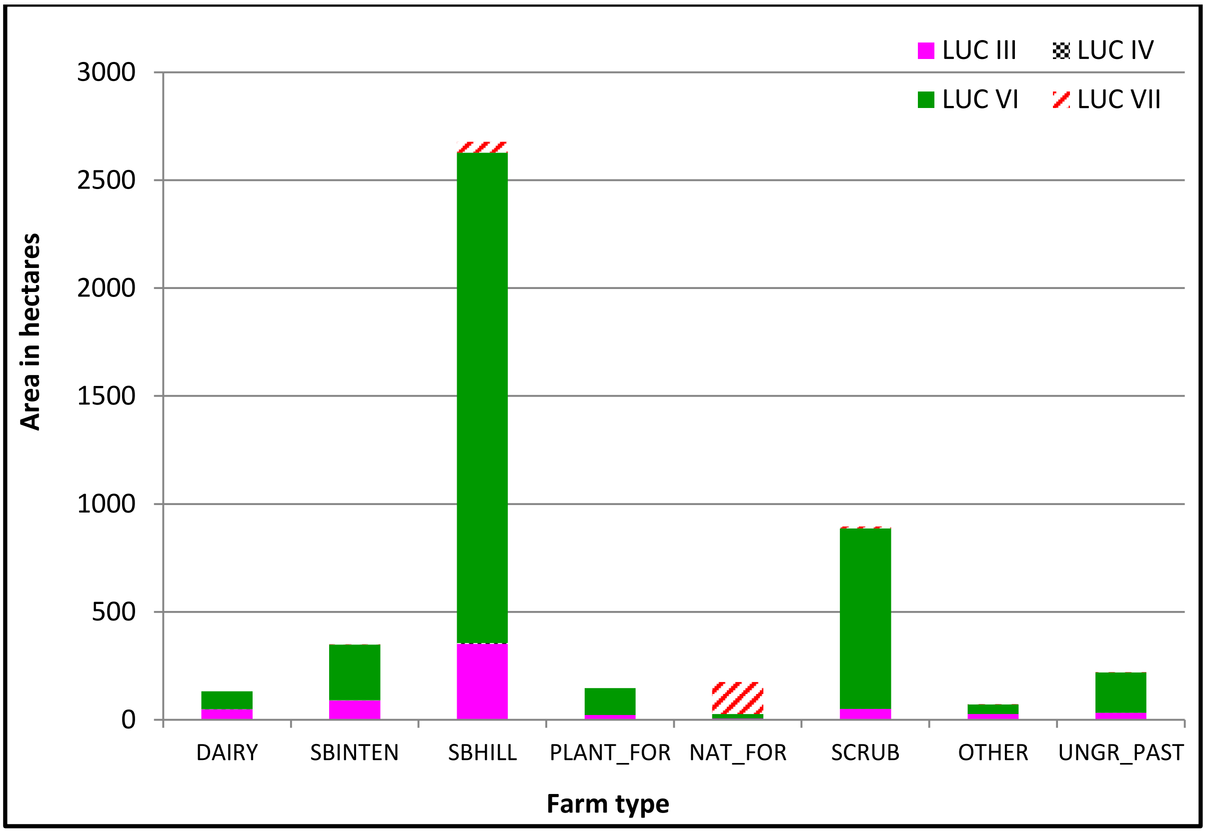

Figure 4.3 Distribution of land in Kaituna catchment by farm type and LUC class in 2002

Figure 4.3 is derived from default land use provided in the CLUES model. It shows sheep and beef hill as the dominant land use in the catchment followed by scrub, sheep and beef intensive and ungrazed pasture lands. About two thirds of the dairy land and nearly three fourths of the sheep and beef intensive areas lie in LUC class VI, which shows land-use intensification areas that have irrigation facilities. The 'other' land use category also includes annual crop land which is located in LUC class III. The land-use in the catchment generally follows a LUC rule that dairy and crops are located in high quality flat to rolling lands whereas scrubs and forests are typically located on lower quality land with exceptions of some dairy and sheep and beef intensive farms, which are located on LUC class VI as mentioned earlier.

4.2 Land-cover change from 2002 to 2008

In order to find out how land-cover changes are taking place in the catchment, LUCAS data sets developed for international reporting of New Zealand's greenhouse gases were used. Land-use maps in LUCAS were derived from 10m resolution SPOT 5 satellite imagery taken during the summer periods between 2006 and 2008 (Ministry for the Environment, 2012a). This was done by clipping LUCAS layer for the catchment and land cover changes are summarised in Table 4.1. During the period from 2002 to 2008, 138 hectares of land were transitioned from grassland to other land cover types, mainly scrub (92 ha), exotic forests (30 ha), and indigenous forest (16 ha). The increase in scrub areas may have come from the programmes like QEII Trust and Banks Peninsula Conservation Trust, which encourage people to protect indigenous species and other important features on their lands.

Table 4.1 Land cover in Kaituna catchment during 2002 and 2008

	Land-use in hectares		
Land-cover class	**2002**	**2008**	**Change**
Grassland	3429	3291	-138
Natural forest	175	191	+16
Planted forest	139	169	+30
Scrub	891	983	+92
Cropland	38	40	+2
Others (including estuary)	13	11	-2
Total	**4685**	**4685**	**0**

Source: LCDB2 and LUCAS

Table 4.2 shows the land-cover transition between 2002 to 2008 by LUC class. LUC class V and VIII were excluded from the table as there was no land-cover in these classes. As Table 4.2 illustrates, land use in LUC class IV has not changed at all, but about 26.4 hectares of grassland and 6.3 hectares of natural forest in LUC class III have transitioned into scrub and exotic forest. This is against LUC classification which indicates that class III land is to be utilised for pastoral purposes for long-term sustained production. Dairy must have expanded in this area, probably on existing grassland, but that could not be confirmed due to a lack of access to recent Agribase data. The increase in scrub area may have come from QEII Trust or similar programmes working in the area. On LUC class VI, about 108 hectares of grassland have been transformed to scrub (64 ha), natural forest (20 ha), and plantation forest (23 ha), respectively. Out of 156 hectares of land in LUC class VII, about 3 hectares of grassland have been converted to indigenous forest and the remaining 152 hectares of indigenous forests remained intact as they were protected by DOC.

Table 4.2 Land cover transition from 2002 to 2008 by LUC class (area in hectares)

Land cover	**LUC III**		**LUC IV**		**LUC VI**		**LUC VII**	
	2002	**2008**	**2002**	**2008**	**2002**	**2008**	**2002**	**2008**
Grassland	542.8	516.4	6.9	6.9	2874.4	2766.0	5.2	2.3
Scrub	19.4	46.2			870.8	934.7	1.0	1.7
Natural forest	6.3				19.6	39.8	149.3	151.5
Planted forest	20.1	26.7			118.7	142.0		
Cropland	33.4	34.2			4.6	5.5		
Others (excluding estuary)	1.5				3.5	3.7		
Total	623.5	623.5	6.9	6.9	3891.6	3891.7	155.5	155.5

In summary, about 136 hectares of land that changed from grassland to scrub and forest were on LUC class VI. Analysing land-use change on the basis of LUC class helps to identify land cover/use transitions taking place in a land environment. It also indicates suitability of such changes for long term sustained production which is beneficial for land managers responsible for planning and managing natural resources.

4.2.1 Impact of limited-focus land-use programmes on flows of ecosystem services

Land-use changes alter flows of ecosystem services. These changes have been estimated for the existing land-use scenario and for the scenarios under forestry schemes (e.g. ETS or ECFP) where landowners will convert their hill country sheep and beef and ungrazed pasture areas to plantation forests or sign covenants with QEII Trust or ECFP and retire their lands which would regenerate to Manuka/Kanuka dominated scrublands. Under these scenarios, flows of six ecosystem services, namely, timber, carbon sequestration, water yield, water quality, soil erosion, and natural habitat provision have been estimated.

4.2.2 Carbon and timber

Using the methodology outlined in Chapter 3, timber yield and carbon stock for Pinus r*adiata* and scrub were estimated. The results are displayed in Figure 4.4. As can be seen in Figure 4.4, Radiata pine trees sequester carbon dioxide (CO_2) as they grow and reach a maximum value of 878 tonnes of carbon dioxide equivalent (CO_{2e}) per hectare at the age of 28 years. If the trees are clear-felled at this age, much of the CO_2 stored in trees will eventually be released back into the atmosphere and some is transferred into the dead organic matter pool. The carbon in this pool is also lost over a certain time due to decaying of dead branches, twigs, stumps, and leaves. However, if plantation forestry is practiced on a rotational basis, there would be a minimum carbon stock of 205 tCO_2e/ha as represented by the red coloured line in Figure 4.4. This would be the minimum carbon stock from plantation forests grown on a clearwood regime which takes into account carbon in all pools except soils.

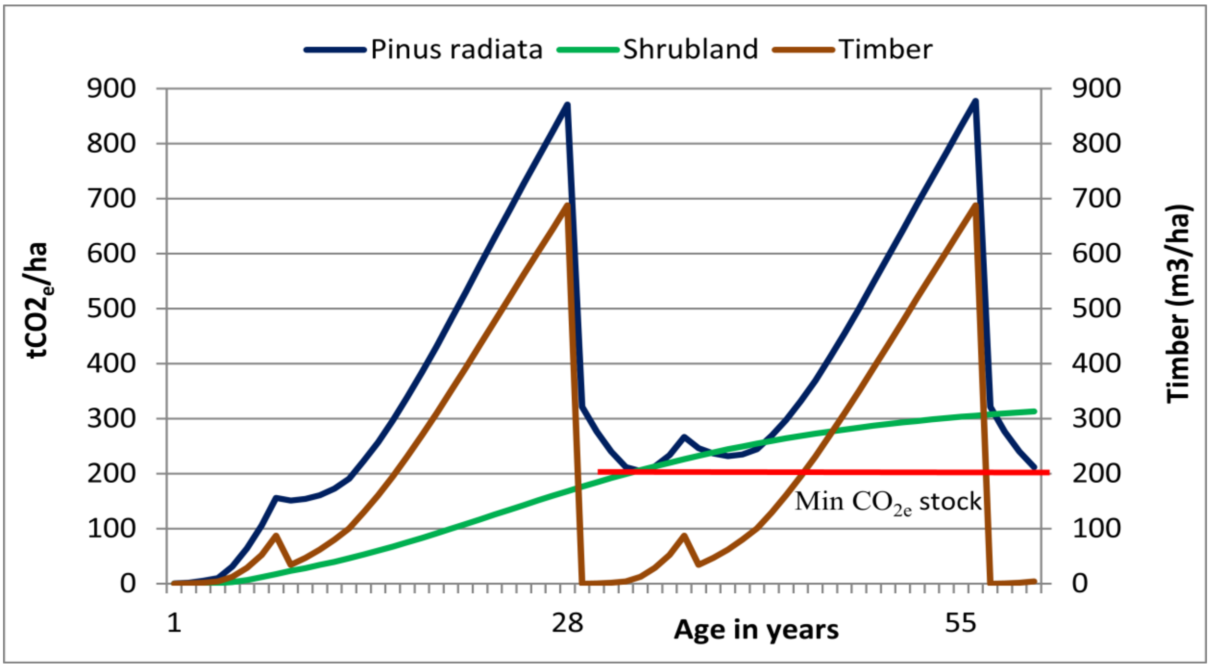

Figure 4.4 Timber yield and carbon stock in each plots of the target land (*Pinus radiata* clearwood regime grown on a 28 year rotation)

For scrub, carbon sequestration is slow during the early stage of growth but later it picks up and reaches approximately 305.6 $tCo2_e$/ha in 56 years. After this age, scrub continues to sequester carbon and the amount depends upon what type of vegetation succession will occur. Due to availability of plenty of seed source in the catchment, it is likely that scrub will be replaced by broad leaved indigenous trees in about 60 to 70 years. However, it may be possible that some part of target land will have another rotation of scrub before it develops into a native forest.

Figure 4.5 shows the average carbon stock for the target land and total flow of timber from each block in a forest estate. In this research estate planting was assumed in which a block of 84 hectares will be planted each year till the whole target land is planted in 28 years. The harvesting of trees from each block (84 ha) begins at age 28 years. With a forest estate, there will be continual flow of 57,792 m^3 of timber each year after 28 years. However, carbon stock is the average of carbon per hectare for the whole target land (2352 ha) in a steady state. So, at the steady state, which is reached after two rotations, *Pinus radiata* would be stock at approximately 411 tCO_2e/ha. As a result, an estate-level strategy stocks 1.6 times more carbon than a stand-level strategy (411 tCO_2e/ha vs. 255 tCO_2e/ha). The carbon stock represents average carbon in all pools, except soils, taking into account carbon losses during harvesting of trees from 84 hectares each year. Figure 4.5 clearly shows that plantation forests store more carbon than does scrub.

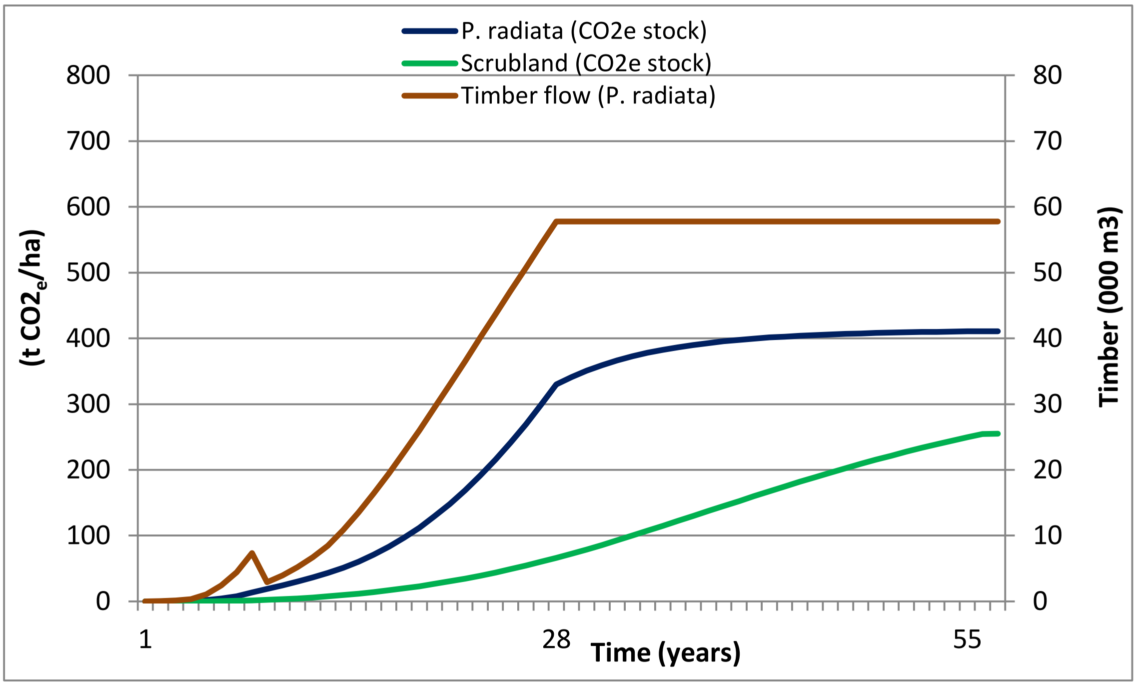

Figure 4.5 Timber flow and carbon stock from target land at the steady state (*Pinus radiata* estate regime grown on a 28 year rotation)

Figure 4.6 shows timber flow and carbon stock for the whole catchment. It shows that timber yield and carbon stock increase if some parts of existing land use (target land) are converted to either of the afforestation scenarios. Among the more realistic scenarios, in which target land is either converted to plantation forestry or allowed to revert to scrubland, timber and carbon benefits are higher in plantation forestry than in scrubland as the latter does not produce timber and it is a slow process for abandoned agricultural land to regenerate to Manuka and Kanuka. If we consider the extreme land-use change scenarios, which are less likely, converting all land available in the catchment (except DOC land) to pasture for dairy purpose, yields zero timber and forest carbon benefits. However, dairy land-use provides provisioning ES (milk, butter, cheese, etc.) that are valuable to human wellbeing, but it also produces disservices from emissions of methane and nitrous oxide gases, and pollution of waterways, which are not included here as this research has assessed benefits of afforestation on lands that are best suited for this purpose (based on LUC class) and are likely to change to plantation forestry or scrubs with available incentives (land-use programmes). On the other hand, converting all those available lands to scrub will only produce carbon benefits whereas both carbon and timber benefits are maximised under an all plantation forestry scenario (Figure 4.6).

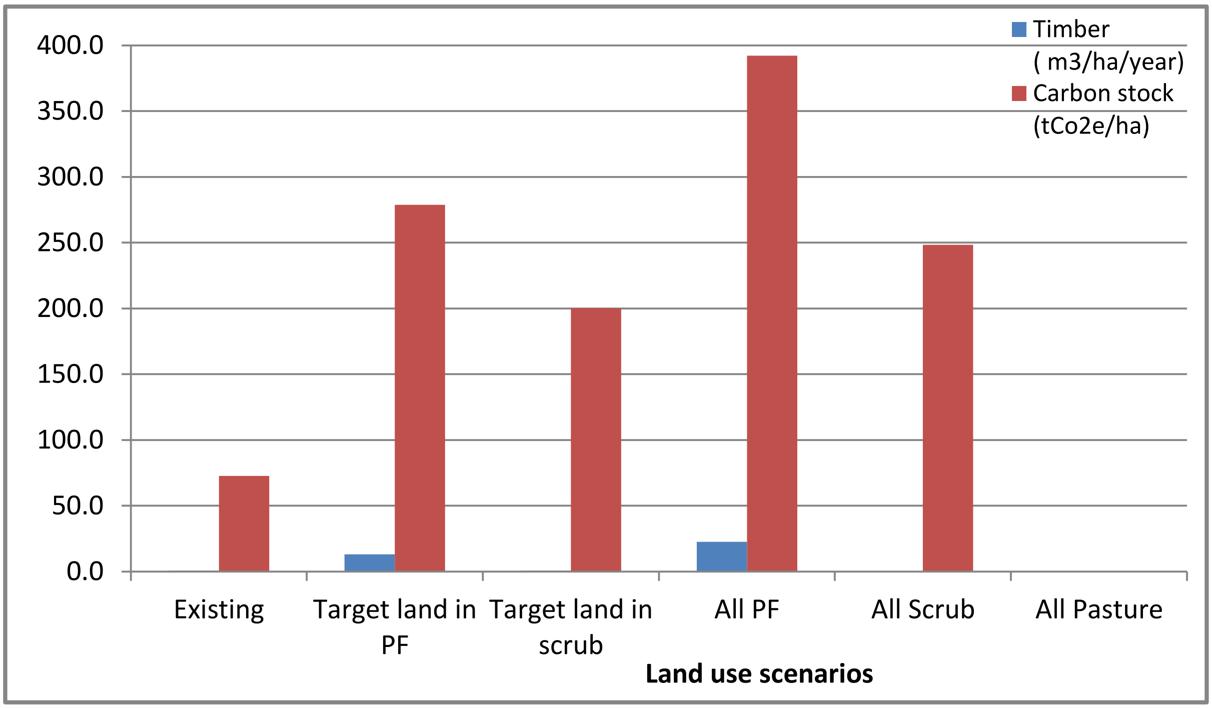

Figure 4.6 Timber flow and carbon stock for the catchment at the steady state

4.2.3 Water yield

WATYIELD model was used to analyse impact of land-use changes on annual water yield. For this, an Excel spreadsheet was produced that contained information on daily rainfall, vegetation classes (forest, scrub, tussock and pasture), evapotranspiration, crop coefficient, interception fraction, profile available water and profile readily available water, base flow index and recession coefficient (refer to Table 3.8 in Section 3) for running the WATYIELD model. The model predicted annual water yield for the catchment which is summarised in Table 4.3 and displayed in Figure 4.7.

Table 4.3 shows that over the 20-year period, from 1991 to 2010, the modelled annual water yields averaged 426 mm (±151mm), and the measured equivalents averaged 393 mm (±150mm). So, the WATYIELD model overestimated the annual water yield by 8.4 percent, but as Figure 4.7 shows, modelled and measured values for annual water yields closely resemble each other. The model was a good estimator of mean annual water yields as reflected by modelling efficiency of 0.7 and the root mean square error of 20.2. These calculations are presented in Appendix E.

Table 4.3 Summary statistics for annual water yields for the Kaituna catchment, 1991 to 2010.

Parameters	Unit	Measured	Modelled	Difference %
Mean annual run-off	mm	393	426	+8.4
Maximum run-off	mm	682	732	+7.3
Minimum run-off	mm	156	196	+20.4
Standard deviation		150	151	+0.6
Root mean square error			20.2	
Modelling efficiency			0.70	

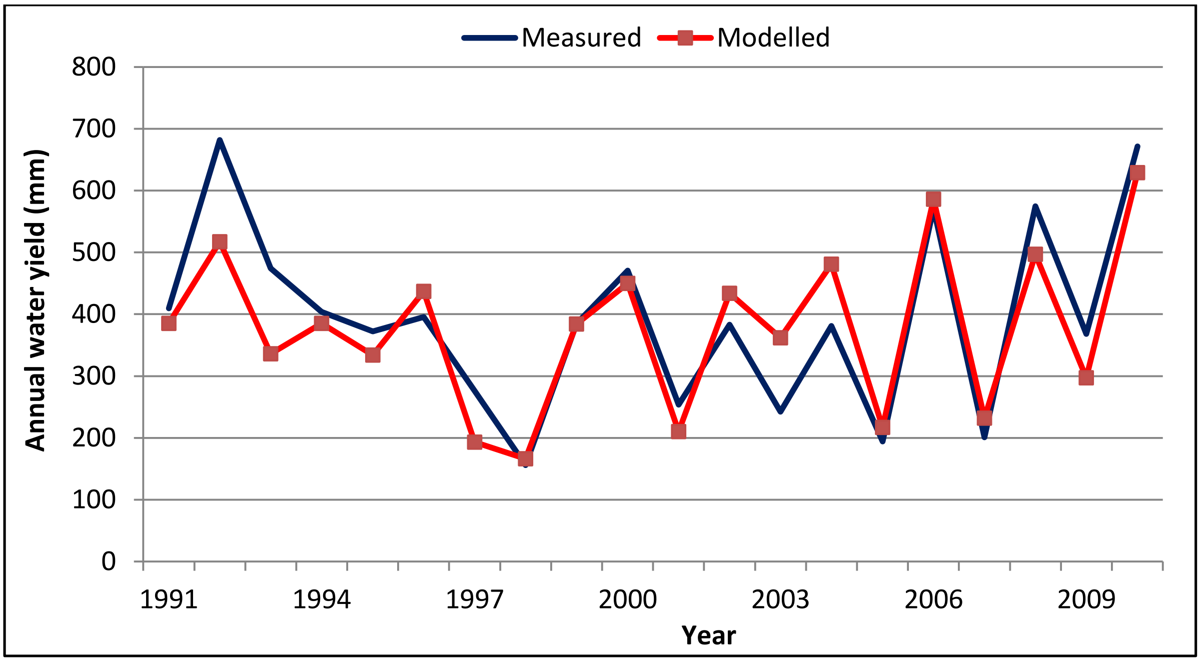

Figure 4.7 Measured and modelled values for mean annual water yield for the Kaituna catchment, 1991 to 2010.

In order to find out the effect on water yield of converting target land into plantation forest and scrubland, the values for the interception fraction and crop coefficient were adjusted to 0.3 and 0.7 for mature trees, and to 0.2 and 0.7 for scrub respectively. They were used to predict annual average water yield for the catchment (Table 4.4). The annual average water yield fell by 20.9 percent to 337 mm and by 9.6 percent to 385 mm under the plantation forestry and under the scrubland scenario. Converting all of the catchment area into plantation forest leads to a 31.2 percent reduction in mean annual water yield and converting the catchment entirely to scrubland reduced mean annual water yield by 12.0 percent compared to mean annual average water yield predicted under the existing land-use scenario. Converting all of the land in the catchment to pasture will increase the annual average water yield by 4.9 percent as interception loss for pastures is considered negligible (Rowe *et al.*, 2002). The model predicted average water yields in millimetre per year which were then calculated in litres per second per hectare (L/s/ha) using the conversion factor 1 L/s/ha = 8.64 mm/day. This was done to compare ES flow (water yield) per unit of area across selected land-use scenarios.

Table 4.4 Impact of land-use on annual water yield

Land-use scenario	Predicted average water yield (mm/yr)	Predicted average water yield (L/s/ha)	Difference from existing %
Existing	426 (±151mm)	0.1351	
Target land in PF	337 (±125mm)	0.1069	-20.9
Target land in Scrub	385 (±136mm)	0.1221	-9.6
All PF	293 (±114mm)	0.0929	-31.2
All scrub	375 (±131mm)	0.1189	-12.0
All pasture	447 (±159mm)	0.1417	+4.9

Note: The figures in brackets are standard deviations in each land-use scenarios

4.2.4 Water quality

CLUES 10.1 was used to assess the implications of land use change on water quality as it is an integrated catchment model designed for this purpose (Semadeni-Davies *et al.*, 2011). The model estimated values for nitrogen, phosphorus, sediments, and bacterial counts (Table 4.5).

Table 4.5 Impact of land use on water quality parameters

Indicators	Unit	Land-use scenario					
		Existing	Target land in PF	Target land in scrub	All PF	All scrub	All pasture (dairy)
N cumulative yield	kg/ha/yr	2.771	2.347 (-15.30)	2.347 (-15.30)	1.938 (-30.07)	1.938 (-30.07)	14.746 (+432.22)
P cumulative yield	kg/ha/yr	0.272	0.245 (-10.06)	0.245 (-10.06)	0.229 (-16.01)	0.229 (-16.01)	0.785 (+188.03)
Sediment Load	t/ha/yr	0.4778	0.2299 (-51.88)	0.2299 (-51.88)	0.1687 (-64.69)	0.1687 (-64.69)	0.5973 (+25.01)
E. coli load	TeraE. coli/ha/yr	0.1625	0.1114 (-31.45)	0.1114 (-31.45)	0.0154 (-90.52)	0.0154 (-90.52)	0.1923 (+18.34)

Note: Figures in the parenthesis indicate percentage change in ES values as compared to ES values in existing land-use

Table 4.5 shows that afforestation of target land will decrease nitrogen, phosphorus, sediment, and bacterial loads in the catchment by approximately 15 percent, 10 percent, 52 percent, and 31 percent respectively. The model gave reductions in phosphorus values only when the model was run for the final time in June, 2013 when CLUES underwent final update for the Overseer model which estimates N, P, and bacteria. In the previous runs, the model repeatedly gave increased values for the phosphorus which was not convincing in view of the fact that reducing animal numbers would normally decrease phosphorus loads in the catchment and improve water quality. The researcher’s personal experience suggests that results obtained from the CLUES model should be used with some caution, especially for phosphorus and bacteria. However, it is evident that water quality in the catchment will improve if the target land is afforested. The all-pasture scenario is the most undesirable as it would cause the most deterioration in water quality (432% increase in N cumulative yield, 188% increase in P cumulative yield, 25% increase in sediment load, and 18% increase in bacterial count).

The values for bacterial loads obtained by CLUES 10.1 are doubtful because conversion of hill country sheep and beef land on LUC>4, where the stock density is low, should result in a small reduction in bacterial load (Ausseil & Dymond, 2010), not a 31 percent reduction as indicated by the model. On the other hand, converting all available land in the catchment (except DOC land) to pasture (dairy), which means increasing dairy area from 128 hectares to 2480 hectares, increased bacterial loads only by 18 percent. Due to these reasons, the research only used cumulative nitrogen and phosphorus yields in further analysis. It is a common practice to use nitrogen and phosphorus concentrations in the assessment of water purification service and E. coli as a health indicator for recreational purposes (Hearnshaw & Cullen, 2010). Further, sediment load values obtained by CLUES were also not used in further analysis as it was estimated by a soil erosion model called NZeem, which is presented in the next section. The NZeem is a good estimator of soil erosion due to integration of geology, rainfall and land cover factor that determines hill scale erosion in New Zealand (Dymond *et al.*, 2006).

4.2.5 Soil Erosion

The web based model NZeem® was used for estimating soil erosion as it produces more accurate estimates of erosion and sediment yield than the CLUES model. This is because NZeem integrates, in addition to geology and rainfall, land cover factors which determine the rate of erosion in hills and mountains (Dymond *et al.*, 2010). Table 4.6 displays mean erosion rates and total amount of sediments for each land-use scenario.

Table 4.6 Impact of land-use on sediment yield

Land-use scenario	Erosion rate ($t/km^2/yr$)			Erosion rate for the catchment (t/ha/yr)	Total sediment from the catchment (t/yr)	Net change in sediment with reference to existing land-use (%)
	Min	Maximum	Mean			
Existing	0	703	151.96	1.5196	7119.33	
Target land in PF	0	691	56.68	0.5668	2655.46	-62.70
Target land in Scrub	0	691	47.01	0.4701	2202.42	-69.06
All PF	0	691	47.44	0.4744	2222.56	-68.78
All scrub	0	691	29.43	0.2943	1378.80	-80.63
All pasture	0	703	193.35	1.9335	9058.45	+27.24

As Table 4.6 shows, the existing land-use in Kaituna catchment is contributing 7119 tonnes of sediments per year, which will be reduced by at least 63 percent if half of the catchment area (2352 ha) is converted to plantation forestry or scrubland. This shows that most of the ES benefits are gained in the plantation forestry scenario. Converting the whole of the catchment area into either plantation forestry or scrubland was found beneficial as sediment loads will be reduced by at least 69 percent. In contrast, converting all of the land in the catchment to pasture is harmful as it would increase the sediment loads in the catchment by approximately 27 percent. Thus, with regards to soil erosion, converting target land into either scrubland or plantation forestry is beneficial as evidenced by lower sediment loads under these land-uses.

4.2.6 Natural habitat provision

Natural habitat provision index was calculated using a benefit function developed by Dymond *et al.* (2008). It shows proportion of natural area remaining in a land environment. The result for the existing land-use scenario is presented in Table 4.7. As can be seen from Table 4.7, only land environment B3.1 has achieved the target of maintaining 20 percent area in permanent vegetative cover. Land environment F3.3 was very close to this threshold (19%). As these two land environments make up less than one third of the catchment area, there is a scope for targeting afforestation/natural reversion in other land environments that have less than 20 percent area remaining in natural vegetation. This kind of analysis helps to measure the progress of a programme, project or policy in terms of its contribution in restoring natural vegetation and biodiversity.

The natural habitat provision index reflects the proportion of natural area (pre-human) remaining in a land environment weighted by the condition index *ci*. For the existing land-use it was 16.73 units. Hence, when the forests and scrub mature, the annual flow of natural habitat provision in the existing land-use will be 0.0036 units per hectare over the catchment area. Following this procedure, the natural habitat provision index was calculated for different land-use scenarios and the flows were summarised over the catchment; the results are displayed in Figure 4.8. As Figure 4.8 shows, the natural habitat provision index is lower in the current land-use which will improve if we convert target land to plantation forestry. It will be the highest under the all scrubland scenario and the lowest under the all pasture scenario as pasture fields are very low in biodiversity (*ci*=0).

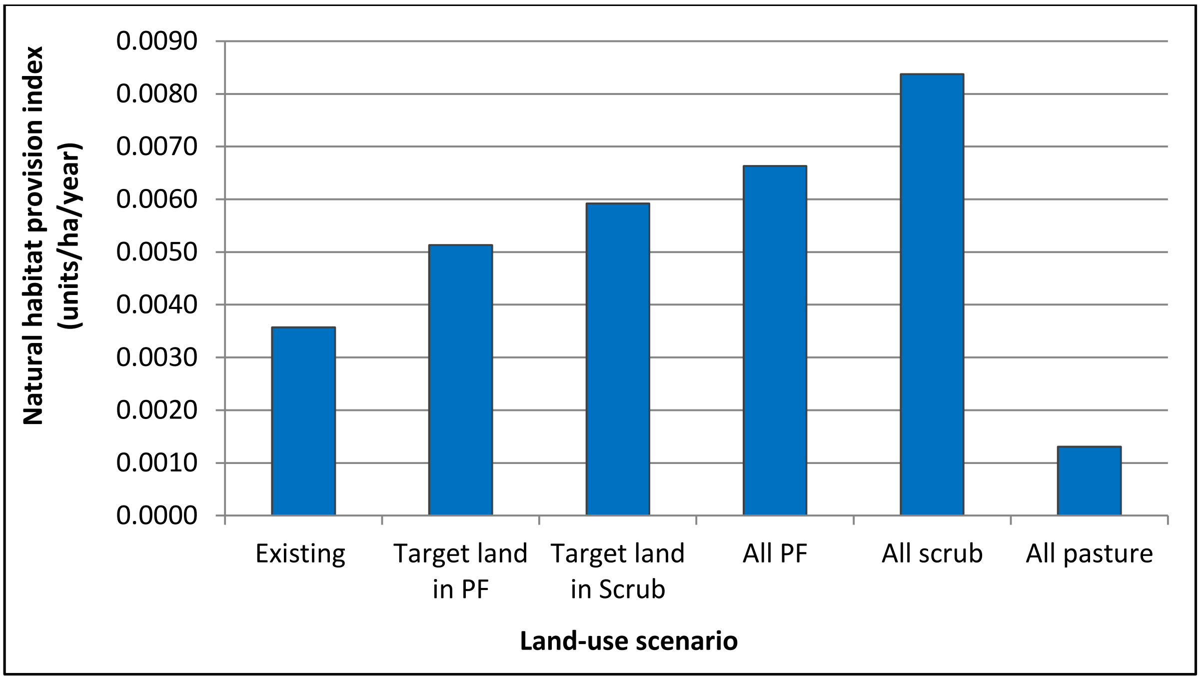

Figure 4.8 Natural habitat provision index values for different land-use scenarios at steady state

Table 4.7 Natural habitat provision index for the current land-use scenario

Land environ-ments in LENZ level 3	Area of land cover in LENZ level 3 (ha) *ai*					Total LENZ area in level 3 (ha), *Ai*	$(Ai)^{0.4} \times \sum(c\, i.ai/Ai)^{0.5}$	Total *ai*	Historic *ci*	Mean *ci* (weighted average per area)	Target (20%)
	Other	Exotic forest	Indigenous forest	Pasture	Scrub						
Null	7.59	0.0	0.0	0.1	0.0	0.00	0.00				
B3.1	0	0.0	0.0	0.5	0.4	103171.19	0.14	0.94	0.31	0.22	Achieved
B6.1	0	0.0	0.0	43.1	0.3	29235.25	0.15	43.39	2.36	0.00	
B8.1	0	0.3	0.0	4.7	0.0	85450.18	0.10	5.03	0.72	0.02	
F3.1	0	78.9	2.5	1404.7	600.4	54710.88	6.07	2086.46	15.34	0.16	
F3.2	0	18.4	0.0	351.5	78.6	11165.69	2.64	448.54	8.34	0.10	
F3.3	3.41	25.2	164.7	1072.5	198.8	30518.75	5.87	1464.54	13.63	0.19	Near to target
I3.3		0.0	0.0	128.3	0.0	9777.75	0.00	128.31	4.52	0.00	
J2.1	1.5	16.0	6.3	389.4	12.6	77536.31	1.35	425.72	6.69	0.04	
N1.1				2.1		225805.94	0.00	2.07	0.42	0.00	
N1.2				28.5		177244.88	0.00	28.52	1.59	0.00	
N2.1				1.3		367093.88	0.00	1.31	0.32	0.00	
P5.1				0.4		302500.75	0.00	0.44	0.19	0.00	
P5.2			1.9	40.1	0.2	186678.69	0.42	42.21	1.93	0.05	
condition index (*ci*)	0	0.3	1.0	0.0	0.5						
Historic (*ci*)	1	1	1	1	1						
Habitat provision index (ci)							**16.73**				

4.3 ES flows from the catchment at the steady state

The quantities of ES estimated in the previous sections are flows of ES except carbon stocks which need to be converted to flows. This was done by multiplying steady state carbon stock using the prevailing market price \$5.7/tCO_{2e} (Ministry for the Environment, 2012b) and real interest rate[2] in 2011/12 using Equation 4.1.

$$\text{Carbon benefit flows} = \text{Carbon stock (Qc) x price of carbon (Pc)x real interest rate (i)} \qquad (4.1)$$

The price of carbon at 2011/12 was used in Equation 4.1 assuming that if there is inflation in future it will affect every commodity in the same way. The real interest rate in 2012 was 2.3 percent based on a nominal interest rate in savings deposit which was 3.25 percent and an average inflation of 0.95 percent over four quarters in 2012 (Statistics New Zealand, 2012b). However, the price of carbon and real interest rate are not important in the normalisation exercise as they cancel out during normalisation (refer to section 3.8 in Chapter 3) which means carbon benefit flow is directly proportional to the stock of carbon.

For analysing ES flows at the catchment level, land-use scenarios are grouped into land-use scenarios which are possible likely, and extreme land-use scenarios which are less likely, but presented here to compare results (ES flows) among different land-uses and later for normalisation of indicator scores (Chapter 7). It shows that each land-use practice alters flows of each ecosystem service which is either positive or negative depending upon whether it is more or less than the indicator values in the existing land-use. Indicator scores for these ES are compiled in Table 4.8.

The time required for these ecosystem services to reach a steady state varies. As an example, for the 'target land into plantation forestry' scenario, a continuous flow of timber at the rate 13.3 m^3/ha/year will be available from 28 years onwards, whereas a continuous flow of carbon benefit at the rate \$1,626.3/ha/year will be available from 56 years onwards. On the other hand, water will flow at the rate 0.1069 L/s/ha after pine trees reach full canopy cover in about 10 years (Fahey *et al.*, 2010). Likewise water quality and erosion control will be greatly improved after 14 years of planting when *Pinus radiata* can decrease soil erosion by 90 percent (Bergin & Kimberley, 1995; Dymond *et al.*, 2006) and naturally reverting scrub will take 20 years to control the same amount of erosion (Bergin & Kimberley, 1995). Flow of natural habitat provision, which measures contribution of a site in providing habitat for different species, requires that trees are well established. For *Pinus radita* it

[2] Real interest rate is approximately equal to the nominal interest rate minus the annual inflation rate.

will be 10 years after planting, whereas it may take 10-15 years for naturally reverting scrub to increase biodiversity by providing habitat, food, space and connectivity for different species.

Table 4.8 Average flows of ES under different land-use scenarios at the steady state

Ecosystem service	Indicator	Possible land-use scenarios (likely)			Extreme land-use scenarios (less likely)		
		Existing	Target land into PF	Target land into scrub	All PF	All Scrub	All pasture
Timber production	Roundwood harvested (m3/ha/yr)	0.7	13.1 (+1771.4)	0.7 (0.0)	22.6 (+3128.6)	0 (-100.0)	0 (-100.0)
CO_2 gas regulation	Carbon benefit ($/ha/yr)	423.3	1,626.3 (+284.2)	1,168.0 (+175.9)	2,287.0 (+440.2)	1,447.9 (+242.0)	0.0 (-100.0)
Water regulation	Water yield (L/s/ha)	0.1351	0.1069 (-20.9)	0.1221 (-9.6)	0.0929 (-31.2)	0.1189 (-12.0)	0.1417 (+5.0)
Maintenance of water quality	N cumulative yield (Kg/ha/yr)	2.771	2.347 (-15.3)	2.347 (-15.3)	1.938 (-30.1)	1.938 (-30.1)	14.746 (+432.2)
	P cumulative yield (kg/ha/yr)	0.272	0.245 (-9.9)	0.245 (-9.9)	0.229 (-15.8)	0.229 (-15.8)	0.785 (+188.6)
	E. coli (10^{12} organisms/ ha/yr)	0.163	0.111 (-31.9)	0.111 (-31.9)	0.015 (-90.8)	0.015 (-90.8)	0.192 (+17.8)
Soil erosion control	Sediment load (t/ha/yr)	1.520	0.567 (-62.7)	0.470 (-69.1)	0.474 (-68.8)	0.294 (-80.6)	1.934 (+27.2)
Natural habitat provision	Conservation goal (units/ha/yr)	0.0036	0.0051 (+41.7)	0.0059 (+63.9)	0.0066 (+83.3)	0.0084 (+133.3)	0.0013 (-63.9)

Note: Figures in the parenthesis indicate percentage change in ES values as compared to ES values in existing land-use (percentage figure rounded to one decimal value).

In the case of 'target land into scrub' scenario, a continuous flow of carbon benefits at the rate $1,168/ha/yr will be realised, but timber benefits are forgone. Water quality benefits are similar to those obtained in 'target land into plantation forestry' scenario. However, water yield, soil erosion control and natural habitat provision benefits are higher than in the 'target land into plantation forestry' scenario.

4.4 Chapter summary

In this chapter flows of ecosystem services were estimated for two possible land-use change scenarios, one in which *Pinus radiata* was planted on Sheep and Beef Hill and ungrazed pasture land that are in LUC>4 (target land), and the other managed regeneration of those areas into

Manuka/Kanuka dominated scrubland. The ecosystem services quantified in the research were timber production, carbon sequestration (climate regulation), water regulation, maintenance of water quality, soil erosion control, and conservation values. The results show that in both of the afforestation scenarios, some of the ecosystem services increase while others decrease. For example, plantation forests sequester more carbon than do scrubland, but scrubland provides higher score for natural habitat provision than do plantation forests. As compared to sediment flows in the existing land-use, plantation forestry will reduce sediment by 63 percent against a 69 percent reduction under the scrubland scenario. Timber yield is foregone in the scrubland scenario, but may be preferred to plantation forests in catchments that have water shortages during summer as it reduces annual water yield in the catchment by only 10 percent against 21 percent reduction in annual water yield under the target land into plantation forestry scenario.

Although less likely to occur, three extreme scenarios were considered in which all available land in the catchment (except DOC land) was converted to plantation forest, scrubland, and pasture and flows of ecosystem services were estimated for each of those scenarios. The results showed that there will be an even bigger improvement in ES under all plantation forestry and all scrubland scenarios. However, the all pasture scenario, on one hand, increases nitrogen, phosphorus, and sediment loads by many folds which are undesirable, and, on the other hand, greatly reduces desirable ecosystem services, namely, timber, carbon, and natural habitat, except water yield, which would increase by the highest amount (4.9%) of all land uses (Table 4.8).

As the ES flows listed in Table 4.8 are in different physical units, they cannot be used directly to draw conclusions about the impacts of land-use change on flows of ecosystem services. Hence, ES flows (outputs) have to be normalised and integrated with public preferences as people are central to the definition of ES adopted in the research. The next chapter discusses in brief the methods used to collect public preferences and presents ecosystem service weights derived from those preferences.

Chapter 5

Public preferences for ecosystem services

This chapter presents and discusses results of an analysis of public preferences for selected types of ES. The changes in flows of ES presented in Chapter 4 form one part of the ES assessment. The other part is to establish the relative importance that members of the public place on selected ES and to integrate their preferences into land-use decisions. This research has collected public preferences by an online survey method and calculated preference weights by implementing the AHP and Max100 methods. The chapter is organised as follows: Section 5.1 presents demographic characteristics of the respondents who gave valid response followed by preference weights obtained by AHP in Sections 5.2. Section 5.3 presents preference weights obtained by Max100 method and also exhibits a comparison of preference weights by these two methods. Section 5.4 concludes the chapter.

5.1 Socio-demographic characteristics of the respondents

Although 80 respondents voluntarily took part in the preference weight elicitation survey, this section describes the socio-demographic characteristics of respondents who gave valid responses (Table 5.1).

Table 5.1 Socio-demographic characteristics of (valid) respondents in Christchurch in 2011

Profile	Characteristics	AHP survey		Max100 survey		National census 2013	
		Frequency	%	Frequency	%	Frequency	%
Gender	Male	16	50.0	28	52	2,064,018	48.7
	Female	16	50.0	26	48	2,178,033	51.3
Age	18-30 year	8	25.0	10	18	865,635	20.4
	31-44 year	14	44	16	30	1,368,651	32.3
	45-64 year	9	28	21	39	1,400,736	33.0
	> 64 year	1	3	7	13.0	607,032	14.3
Dwelling	Urban	19	59	32	59		
	Rural	13	41	22	41		
Total		32	100	54	100	4,242,051	

As can be seen from Table 5.1, out of 32 respondents in the AHP survey, male and female were equal, but in terms of their dwelling, nearly 60 percent of them were living in urban areas. Fourteen respondents (43.8%) belong to the age group 31-44 years followed by 9 (28.1%) and 8 (25.0%) in the age groups 45-64 years and 18-30 years, respectively. Only one respondent was over 64 years old.

Out of 54 respondents who gave valid responses in the Max100 survey, the number of male and female respondents was almost equal, and the proportion of urban and rural respondents was similar to that found in AHP. However, Max100 had greater number of respondents over 64 years, but lesser number of them in 31-44 years old age group as compared to the AHP respondents in these age groups. The data from National census 2013 shows that the research sample is broadly representative of the National population in terms of sex and age. For example, the ratio of men to women and percentage of people in the middle (31-64 years) and older (≥64 years) age group in the sample were close to figures of National census survey (Statistics New Zealand, 2013a). Using preferences of these respondents, the ecosystem services weights were calculated by AHP and Max100 methods respectively.

5.2 Preference weights by AHP

In the AHP survey, a questionnaire consisting of all possible pair-wise combinations of the ES under investigation was developed. Respondents were asked to record their preferences for each ES relative to other ES using a 1 to 9 scale. A value of 1 indicates both ES under comparison are equally preferred, while a score >1 that is 2-9 means one ES is preferred over another by the chosen scale value with 9 being the extremely or absolutely preferred ES The scale values were converted to ES weights using 'Super Decisions' software (http://www.superdecisions.com/). It calculates weights using a reciprocal matrix and an Eigen value technique and also gives a consistency index ratio which measures the inconsistency present in human decisions (Saaty, 1990b). Only 32 out of the 80 responses were within the 0.15 consistency ratio set for this research. The high rate of inconsistent responses may have been resulted from a number of factors including, but not limited to, lack of information about ES being compared, difficulty of maintaining transitivity while making-pairwise comparisons, less concentration due to flapping of tents at the A and P show and people hurrying to complete the survey as their primary objective was to visit the show. Therefore, the results presented in this section are derived from the responses of 32 individuals. Instead of using an arithmetic averages, geometric means were used for ES weights as they are less affected by extreme values than arithmetic means.

Preference weights obtained by the AHP method are presented in Table 5.2. The result inferred from the geometric means of preference weights show that water quality ranked first and production service ranked fourth, while services that are essential for production, namely erosion control and water yield ranked second and third respectively. This order of preferences is not surprising given the fact that much of the land in Canterbury region consists of loess soils, which need protection on steep slopes for achieving long-term sustained production. The higher preferences for water quality and water yield (quantity) clearly reflect the importance of water in the region for driving its agriculture, hydroelectricity, and tourism industries, and these are vital to the regional economy and the wellbeing of people. On the other hand, carbon sequestration and cultural ES are found to be the least preferred ES. One thing which is clear from Table 5.2 is that provisioning ES are more preferred than cultural ES but less preferred than regulating ES. The only exception to this is carbon sequestration which is a regulating ecosystem service.

Table 5.2 Ecosystem services weights obtained by the AHP method

Ecosystem services	AHP weights (n=32)				
	MIN	MAX	AVG	GM	STDV
Water Quality	0.0586	0.5673	0.2817	0.2540	0.1226
Soil erosion control	0.0457	0.5021	0.1855	0.1527	0.1196
Water Yield	0.0331	0.2765	0.1501	0.1366	0.0602
Production	0.0258	0.3950	0.1619	0.1284	0.1065
Carbon Sequestration	0.0316	0.3593	0.1151	0.1002	0.0667
Cultural	0.0262	0.2273	0.1056	0.0869	0.0616

Note: MIN=Minimum; MAX=Maximum; AVG=Average; GM=Geometric mean; STDV=Standard deviation

In order to find out if demographic characteristics influence preference weights, the responses were analysed by sex, age groups, and dwelling categories. Figure 5.1 illustrates that respondents living in urban and rural areas gave the same ranking for water quality (1st), erosion control (2nd), carbon sequestration (5th), and cultural (6th), but different ranking for production and water yield. On the other hand, male and female and those in the 18-44 years and >44 years old age groups gave the same ranking for water quality (1st) but different rankings for other ES. For example, male respondents ranked erosion control, production, and cultural ES as 2nd most preferred, 4th most preferred and least preferred, whereas female respondents ranked them as, 3rd, 2nd and 5th most preferred ES respectively.

Respondents aged 18-44 years ranked erosion control, water yield and carbon sequestration as 3rd, 4thand 6th (least preferred), whereas those in the >44 years age group ranked them as 2nd, 3rd and 4th most preferred ES respectively. The biggest difference in preferences was noticed for production ES where respondents in the 18-44 years age group considered it as 2nd most preferred ES as opposed to 5th most preferred ES by those in the >44 years age group. The two tailed t-test carried out to examine if there were significant differences in ES weights between these demographics also confirmed that the preferences expressed for production ES by the 18-44 years age group differed significantly from those expressed by over 44 years age group (Table 5.3). The finding suggests the importance of considering a variety of people in ES surveys from different demographics since some of them may have completely different preferences for ES than their counterparts.

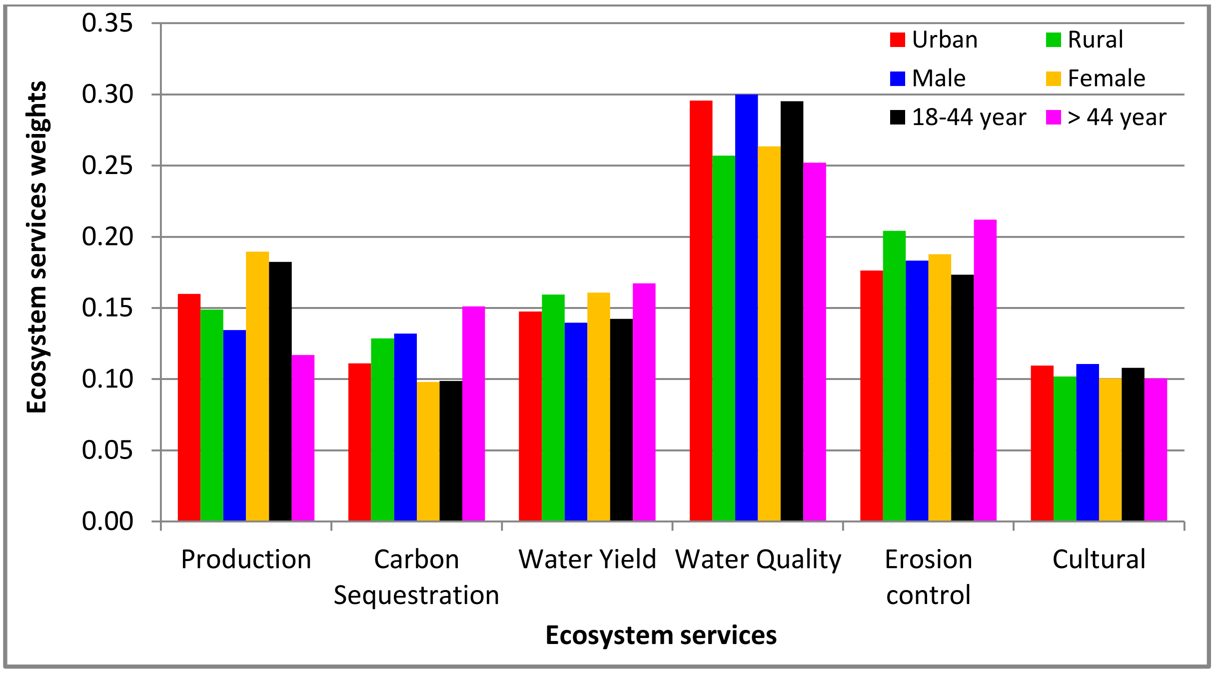

Figure 5.1 AHP weights by demographic characteristic

Table 5.3 Statistical significance of AHP weights by demographic features

Ecosystem services	Male vs. Female	Urban vs. Rural	18-44 year vs.>45 year
Production	0.14	0.74	**0.05**
Carbon sequestration	0.15	0.51	0.09
Water yield	0.33	0.59	0.33
Water quality	0.41	0.38	0.29
Erosion control	0.91	0.53	0.39
Cultural	0.64	0.73	0.76

* [P(T<=t) two-tail, α=0.05]

5.3 Preference weights by Max100

In addition to AHP, the Max100 method was used for assessing Canterbury residents' preferences for ES. The results are presented in Table 5.4. In this method, members of the public were asked to assign the highest score (100) to the ES they think is the most important, and then relative values to all other ES in a decreasing order, that is, assigning a score <100 to the second most important ES and so on in a descending order. These scores were then normalised and converted to ES weights. However, not all respondents correctly assigned the scale values to ecosystem services. 36 of 80 responses which either lacked highest score to the most preferred ES, or had more than one ES assigned the full score of 100, were dropped. Therefore, the result presented in Table 5.4 is the geometric mean of the 54 valid responses.

Table 5.4 Ecosystem services weights obtained by the Max100 method

Ecosystem services	Max100 weights (n=54)				
	MIN	MAX	AVG	GM	STDV
Water Quality	0.0833	0.3906	0.2252	**0.2175**	0.0591
Production	0.0220	0.4386	0.1927	**0.1772**	0.0710
Water Yield	0.0366	0.3114	0.1641	**0.1545**	0.0536
Soil erosion control	0.0508	0.2366	0.1615	**0.1539**	0.0453
Cultural	0.0252	0.2734	0.1368	**0.1221**	0.0559
Carbon Sequestration	0.0044	0.2404	0.1197	**0.0983**	0.0594

Note: MIN=Minimum; MAX=Maximum; AVG=Average; GM=Geometric mean; STDV=Standard deviation

The results in Table 5.4 show that based on average/geometric mean water quality is the most preferred ecosystem service followed by production, water yield, erosion control, cultural, and carbon sequestration respectively. The weights obtained by the Max100 method are not in the same order as the weights derived by the AHP method. The minimum, maximum, and average values of ecosystem services weights obtained by the AHP and Max100 methods show that the difference between the minimum and the maximum values for each ecosystem services is large which may dominate the values if averages are used (Ash *et al.*, 2010). For this reason geometric means were used in the analysis. Tables 5.2 and 5.4 also show that the weights obtained by using Max100 method are more consistent than are weights obtained by using AHP method because the standard deviation for all six ecosystem services is found to be less for Max100 weights than for AHP weights.

The Max100 preference weights were also analysed by demographic features and the results are presented in Figure 5.2. Figure 5.2 shows respondents from all classes ranked water quality and production as 1st and 2nd most preferred ES. Except respondents that are in the >44 years age group, all other demographic classes considered carbon sequestration as the least preferred ES. However, the ranking for water yield and erosion control varies according to the demographic distributions. For example, female respondents, respondents from urban areas, and those in the 18-44 year old age group considered water yield as the 3rd most preferred ES whereas male respondents, respondents living in rural areas, and those in the >44 year old age group considered it as the 4th most preferred ES. Erosion control is ranked 3rd by male respondents and by respondents from rural areas, but female and people from urban areas ranked it as 4th most preferred ES. Age had greater influence on preference weights as is seen from the observation that respondents in the 18-44 year old age group ranked erosion control and cultural ES as the 5th and 4th most preferred ES whereas those in the >44 year old age group ranked them as the 3rd and 6th (or least) preferred ES, respectively. The two tailed t-tests carried out to see if the demographic features such as sex, age, and dwelling had an impact on the preference weights, showed that preferences expressed by male and female or rural and urban for these ES do not differ significantly. Only preferences expressed for erosion control and cultural ES differed significantly between the 18 to 44 years old and >44 years old age groups (Table 5.5).

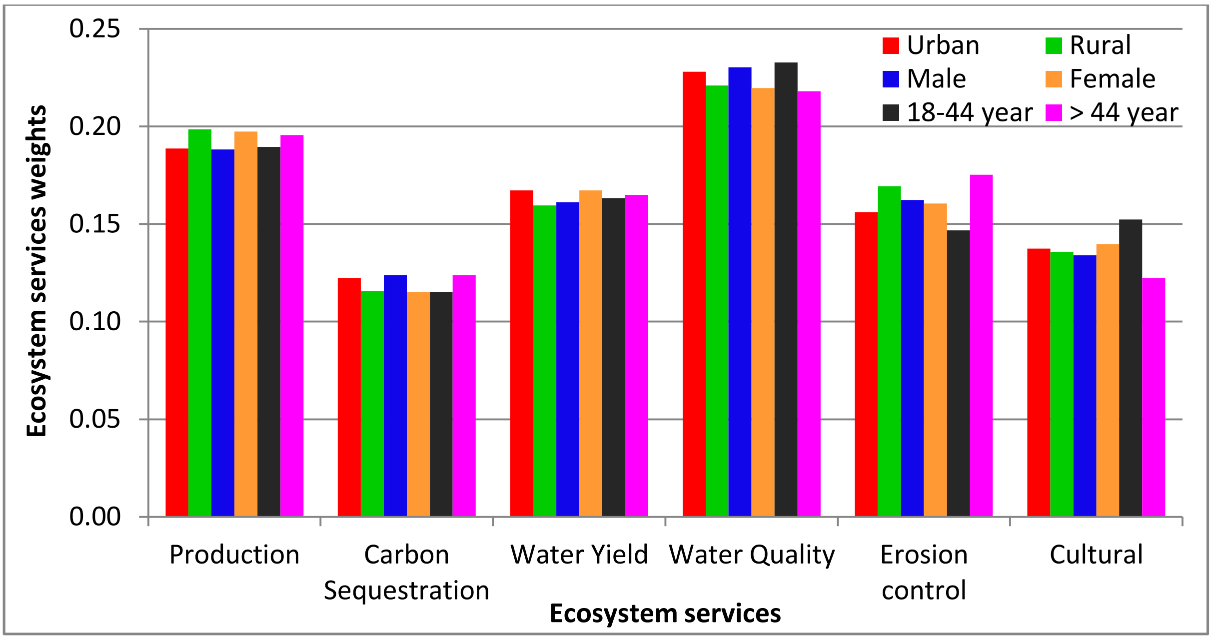

Figure 5.2 Max100 weights by demographic characteristics (geometric mean)

Table 5.5 Statistical significance of Max100 weights by demographic features

Ecosystem services	Male vs. Female	Urban vs. Rural	18-44 year vs. >44 year
Production	0.64	0.61	0.76
Carbon sequestration	0.59	0.69	0.60
Water yield	0.68	0.59	0.91
Water quality	0.51	0.64	0.37
Erosion control	0.88	0.30	**0.02**
Cultural	0.70	0.91	**0.04**

* [P(T<=t) two-tail, α=0.05]

A comparison of preference weights by AHP and Max100 methods is presented in Figure 5.3 which shows water quality as the most preferred ecosystem service. However, ranking of weights for other ES by these methods vary. For example, erosion control, water yield, and production ranked second, third, and fourth most preferred ecosystem services according to the AHP method, whereas the Max100 method ranks them as the fourth, third, and second most preferred ES, respectively. Likewise, ranking of carbon sequestration and cultural ecosystem service by these methods also vary. The preferential weights derived by these methods are different as the present study has indicated. However, one thing that is clear from the analysis is that Canterburians have higher preferences for regulating ES than for provisioning or cultural ecosystem services.

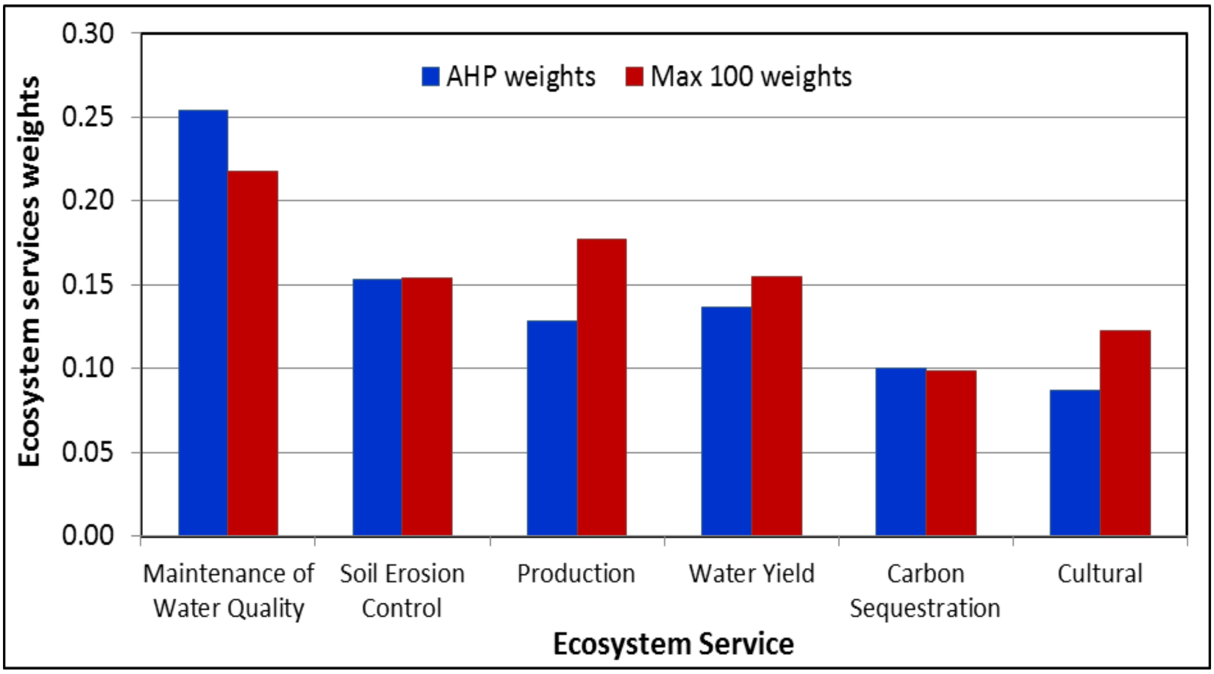

Figure 5.3 A comparison of preferential weights obtained by AHP and Max100 method

5.4 Chapter Summary

This chapter has presented data on public preferences for ecosystem services provided by natural systems in Canterbury. Two methods, namely the AHP and Max100 were used to convert public preferences into ecosystem services weights. Both of these methods produced water quality as the most preferred ecosystem service, while preferences for other ecosystem services varied. For example erosion control and production ranked the second and the fourth most preferred ecosystem service according to the AHP weights while the weights obtained by the Max100 method ranked them as the fourth and the second most preferred ecosystem services, respectively. Likewise, ranking for carbon sequestration and cultural ecosystem services are different with respect to the AHP and the Max100 weights (Figure 5.1). When ES weights were analysed by sexes, age groups, and dwellings, only age group showed significant differences in preferences for production, soil erosion control and cultural ES.

While the AHP has been employed for finding out preferential weights from experts and stakeholder representatives in Canterbury, the Max100 technique has not been previously used in a New Zealand context. This research helps to identify that Max100 weight elicitation method is more straightforward and easy to use as compared to the AHP method. The AHP is complex and often suffers from inconsistencies as the present research has indicated where 60 percent of responses could not pass a 0.15 percent consistency ratio.

Chapter 6

Normalisation of ES flows and integration by preference weights

This chapter presents an analysis of the effect of preference weights on ecosystem services flows from limited-focus land-use programmes in the provision of ES. For this purpose the flows of ES (outputs) were normalised and integrated with preference weights using the conceptual model outlined in Section 3 (Equation 3.1). The analysis uses the results of Chapter 4 and 5 and combines these by normalised and weighted indicator scores. Section 6.1 presents normalised indicator scores and Section 6.2 weighted indicator scores. Finally, Section 6.3 provides a summary of the chapter.

6.1 Normalisation of Ecosystem Services outputs

As the ES flows or outputs presented in Chapter 4 are in different measurement units, they cannot be aggregated as such. For this reason, ES outputs were normalised and converted to a unitless score for facilitating comparisons of land-use scenarios against indicators. This was done by dividing the outcome for indicator x of scenario i by the maximum value of x_i. This means the scenario with the best performance for indicator i has a maximum indicator score of +1 and the scenario with the worst performance, that is the worst value for the undesirable impact, has a maximum indicator score of -1. Relevant to these extreme values, the normalised values of each indicator for each scenario lies in the range of -1 to +1 as shown in Table 6.1.

As Table 6.1 shows, converting target land into either plantation forestry or scrubland improves the cumulative indicator score compared to existing land use patterns, but the ‘target land into plantation forestry’ scenario yields a higher indicator score (1.88) than does the 'target land into scrubland’ scenario (1.39). Among the extreme scenarios, converting all of the available land in the catchment to plantation forestry scored 2.77 and converting all of the target land into scrub scored 1.89, which is slightly higher than the indicator score for the 'target land into plantation forestry’ scenario. The reason for positive score for timber production under ‘target land into scrub’ scenario is due to presence of plantation forestry in existing land-use which was not changed in land-use simulations. If one would only consider marketed ES, in our case roundwood and carbon, then the 'all scrubland’ scenario would not yield a higher indicator score than obtained in 'target land into plantation forestry’ scenario. This finding has important implications in land-use decisions; relying only on marketed ES would lead to wrong policy guidance because if that were the case then 'target land into plantation forestry’ scenario would be chosen over 'all scrubland’ scenario’. However, when both marketed and non-marketed ES were included in the assessment of land uses, the 'all scrubland' scenario became more beneficial than the 'target land in plantation forestry' scenario although timber yield is forgone in the former. On the other hand, converting all of the available land into exotic pasture scored lowest at -1.84. The indicator scores presented in Table 6.1 are not weighted according to their importance. As members of the public have shown that all ecosystem services are not equally important to them, the next section presents weighted indicator scores for facilitating comparison of ecosystem services among land-uses.

Table 6.1 Normalised indicator scores for different land-use scenarios

Ecosystem service	Indicator	Likely scenarios			Extreme scenarios (less likely)		
		Existing	Target land into PF	Target land into scrub	All PF	All scrub	All pasture (dairy)
Timber production	Roundwood harvested	0.0310	0.5796	0.0310	1.0000	0.0000	0.0000
CO_2 gas regulation	Carbon benefits	0.1851	0.7111	0.5107	1.0000	0.6331	0.0000
Water Regulation	Water yield	0.9534	0.7544	0.8617	0.6556	0.8391	1.0000
Maintenance of water quality	Cumulative N yield	-0.1879	-0.1592	-0.1592	-0.1314	-0.1314	-1.0000
	Cumulative P yield	-0.3465	-0.3121	-0.3121	-0.2917	-0.2917	-1.0000
Soil erosion Control	Sediment load	-0.7859	-0.2932	-0.2430	-0.2451	-0.1520	-1.0000
Natural habitat provision	Conservation goal	0.4286	0.6071	0.7024	0.7857	1.0000	0.1548
∑ Indicator score		**0.2777**	**1.8879**	**1.3915**	**2.7731**	**1.8970**	**-1.8452**
Rank		**V**	**III**	**IV**	**I**	**II**	**VI**

Figure 6.1 is another representation of normalised indicator scores that illustrates potential synergies and conflicts in ecosystem services under different land-use scenarios for the catchment. It shows that afforestation scenarios (target land into PF or scrub) improves water quality, natural habitat provision, soil erosion control and carbon benefits, but water yield is a trade-off and timber yield is sacrificed in the scrub scenario. Converting target land into plantation forestry enhances five ecosystem services but reduces water yield as mature trees intercept greater amounts of rainfall and reduce water flow in catchments. On the other hand, converting all of the land available in the catchment except those under conservation (DOC area) to plantation forestry or scrub enhances carbon benefits, natural habitat provision, soil erosion control and water quality benefits. However, water yield is a trade-off in these scenarios and timber benefit is greatest in all plantation forestry, but greatly reduced in the all scrub scenario. The all pasture (dairy) scenario enhances water yield in

the catchment by the greatest amount but makes all other ES worse-off. Hence, which land-use is desirable in the catchment depends upon local peoples' preferences as they are the ones who will be affected by changes in flows of ES and have political standing. Therefore, recording peoples' preferences for ES and integrating them in land-use decisions can give a better picture of the impacts of land-use change on ES in particular, and on the wellbeing of people in general.

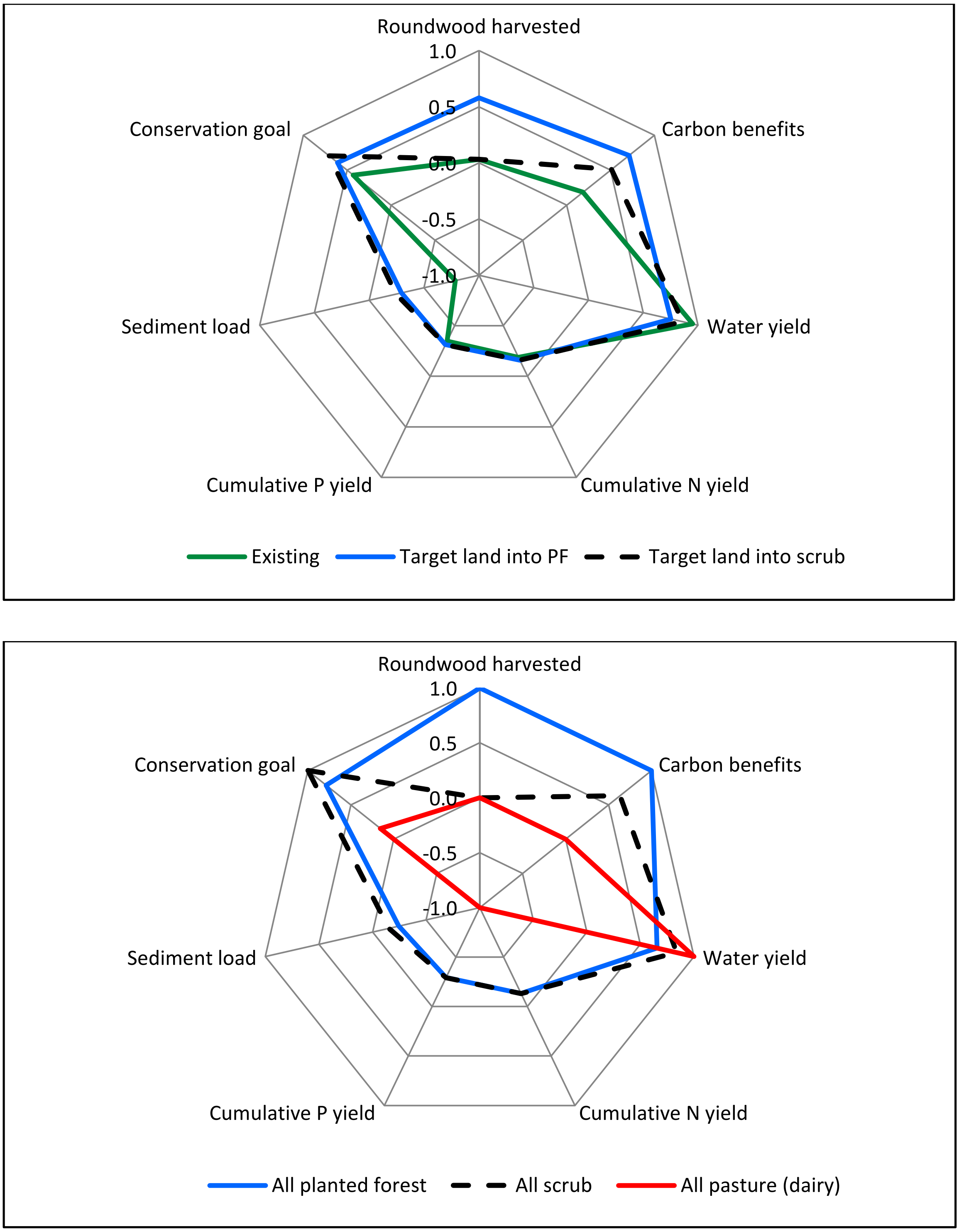

Figure 6.1 Synergies and conflicts between ecosystem services under different land-use scenarios.

6.2 Weighted Indicator Score

The normalised indicator scores were weighted by preference weights obtained using the results of Max100 and AHP method in Chapter 5. This was done by multiplying indicator scores for each scenario from Table 6.1 by the geometric mean of preference weights for each ecosystem service from Table 5.5 (Chapter 5), and the results are presented in Table 6.2. Table 6.2 shows that assigning weights to normalised indicator scores, according to their perceived importance, changed a land-use ranking. The 'all planted forestry' scenario scored highest indicator score and the 'all pasture' scenario scored the lowest. However, the 'all scrubland' scenario became the second most desirable land-use option after 'all plantation forestry' scenario with the application of preference weights. The remaining scenarios ranked in the same order as obtained in the absence of preference weights (or equal weights). This is because there is not much difference in indicator scores across other land-uses. However, if the variations in indicator scores are higher between land uses, the use of preference weights in land use decisions matters and it would change land use rankings. This is seen in the case of 'all scrubland' scenario.

Table 6.2 Weighted indicator scores for different land-use scenarios (Max100 weights)

Ecosystem service	Indicator	Likely scenarios			Extreme scenarios(less likely)		
		Existing	Target land into PF	Target land into scrub	All PF	All scrub	All pasture
Timber production	Roundwood harvested	0.0055	0.1027	0.0055	0.1772	0.0	0.0
CO_2 gas regulation	Carbon benefits	0.0182	0.0699	0.0502	0.0983	0.0622	0.0
Water regulation	Water yield	0.1473	0.1166	0.1331	0.1013	0.1296	0.1545
Maintenance of water quality	Cumulative N yield	-0.0409	-0.0346	-0.0346	-0.0286	-0.0286	-0.2175
	Cumulative P yield	-0.0754	-0.0679	-0.0679	-0.0634	-0.0634	-0.2175
Soil erosion control	Sediment load	-0.1210	-0.0451	-0.0374	-0.0377	-0.0234	-0.1539
Natural habitat provision	Conservation goal	0.0523	0.0741	0.0858	0.0959	0.1221	0.0189
∑ Indicator score (Max100 weights)		**-0.0139 (V)**	**0.2156 (II)**	**0.1346 (IV)**	**0.3429 (I)**	**0.1985 (III)**	**-0.4155 (VI)**
∑ Indicator score (AHP weights)		(-0.0657) **(V)**	(0.1371) **(II)**	(0.0771) **(IV)**	(0.2416) **(I)**	(0.1343) **(III)**	(-0.5107) **(VI)**
∑ Indicator score With equal ES weights		**0.2777 (V)**	**1.8879 (III)**	**1.3915 (IV)**	**2.7731 (I)**	**1.8970 (II)**	**-1.8452 (VI)**

Note: The values in the parenthesis show land-use rankings where (I) is the greatest and (VI) is the least ES flows

According to Table 6.2, converting all of the available land in the catchment to plantation forestry maximises flows of ecosystem services as indicated by its weighted indicator scores. However, it is unlikely that flat and less steep lands (LUC class I to IV) in the catchment will be converted to forestry as these are utilised for dairying, deer farming, and annual crops which are more profitable than is forestry. Also converting all of the land in the catchment to scrubland is also less likely as landowners would not get paid for their contributions in enhancing non-marketed ES. As the returns from sheep and beef hill country in South Island are not that attractive (farm profit before tax was $81.93/ha in 2011/12), from an ES perspective, converting target land into plantation forestry is a possible land-use option. This is because landowners can get both timber and carbon benefits. Also indigenous reversion could be a possible land-use, especially on steep lands due to the possibility of earning carbon credits from programmes like the ETS or PFSI (Ministry for Primary Industries, 2011). Both cumulative and weighted indicator score reveal that switching from existing land-use to either plantation forestry or scrubland would increase flows of ecosystem services, but the 'plantation forestry' scenario would produce more ecosystem services than would the 'scrubland' scenario when only target land is afforested. Table 6.2 clearly demonstrates that use of preference weights in land-use decisions matters as 'target land into plantation forestry' scenario changed from third best land-use option in the absence of ES weights (or equal ES weights) to second best land-use option with ES weights.

6.3 Assessment of limited-focus land-use programmes

In the section 6.2, the impact of land-use change on total weighted flows of ES were assessed. This was done by identifying target land and testing two afforestation scenarios, one in which landowners will plant *Pinus radiata*, and the other in which landowners will fence target land and control pests which will aid to regeneration of Manuka/Kanuka and other woody scrub. It was assumed that grants from ECFP or carbon benefits (NZUs) from ETS will motivate landowners to plant exotic trees on their land. Likewise, a grant from ECFP or partial assistance from the QEII National Trust will motivate landowners to manage natural regeneration processes on their lands. So, ES benefits were compared between ETS and ECFP for the plantation forestry scenario, and ECFP and QEII National Trust for the scrubland scenario.

6.3.1 Ecosystem services benefits in plantation forestry scenario

The results obtained in section 4.1 are applicable to plantation forestry under the ETS and ECFP as both of the programmes allow harvesting of timber. However, a major difference between these programmes is that landowners in the ETS have deforestation liabilities, whereas in ECFP harvesting should be immediately followed by replanting due to a 50 years covenant on the land title. Although the covenant does not stop deforestation liabilities, it binds the covenantor to maintain a continuous forest cover for at least 50 years. With the estate level strategy of planting 84 hectares each year with *Pinus radiata* on a 28 year rotation and enhancing natural regeneration on 84 hectares each year till it covers the whole target land, timber benefits will be realised after one rotation (28 years), whereas carbon will start to accumulate in each of the planted areas and reach a steady state after 2 rotations (56 years). Therefore, after 28 years timber will come from 84 hectares at the rate 688 m^3/ha, and carbon from the whole of the target land at the rate 410 $tCo2_e$/ha.

The other models used in the research, namely CLUES, WATYIELD, and NZeem lack a temporal dimension. The WATYIELD model predicts annual flows based on ground cover (pasture, scrub, tussock, and trees), soil types and annual rainfall. The NZeem model is based on terrain cover (vegetation) and annual rainfall, but NZeem_harvest model accounts for soil losses during harvesting of exotic trees. However, it does not trace the route of erosion and time taken by soils to reach a river mouth or catchment outlet. Both of the NZeem models simply assume that quantity of soil eroded in the catchment is equivalent to quantity of soil deposited at the catchment outlet in the long run (Dymond *et al.*, 2010). The CLUES model predicts nitrogen, phosphorus, and bacterial loads for the catchment and sub-catchments based on animal numbers and fertiliser use information for different land-uses, but does not take into consideration time of attenuation for nutrients. All of these models are calibrated for mature trees which for *Pinus radiata* and scrubs take about 10 to 15 years under New Zealand conditions. Due to this reason, ES values obtained by the biophysical models should closely represent ES values obtained in estate forest which minimises soil and biodiversity loss as harvesting is restricted to a smaller area.

6.3.2 Ecosystem services benefits in the natural reversion scenario

It was assumed that the ‘target land’, which mainly consists of the Sheep and Beef Hill category of land-use, will be retired and converted to scrubland with incentives from the ECFP or QEII National Trust. With the exclusion of animals, shrub species on the target land will start to regenerate, dominated by early succession species like Manuka and Kanuka which then get replaced by other longer-lived, slower-growing species and eventually by tall indigenous trees (Prato, 2007). The rate of early succession depends upon the availability of seed source in the area, soil moisture deficits, competition from grasses and woody weeds, but as Figure 6.2 shows, the ‘target land’ has plenty of seed source that consists of Manuka/Kanuka (328.3 hectares), broad leaf indigenous hardwoods (432.5 hectares), and gorse and broom (130.5 hectares). The presence of broadleaved indigenous hardwoods in the area is an indication of advanced stage of succession into indigenous forests

(Ministry for the Environment, 2003; Ward, 2010). However, this research estimated ecosystem services outputs for scrub as they are among the first successional species to appear in abandoned agricultural land where there is seed source available in the area (Trotter *et al.*, 2005).

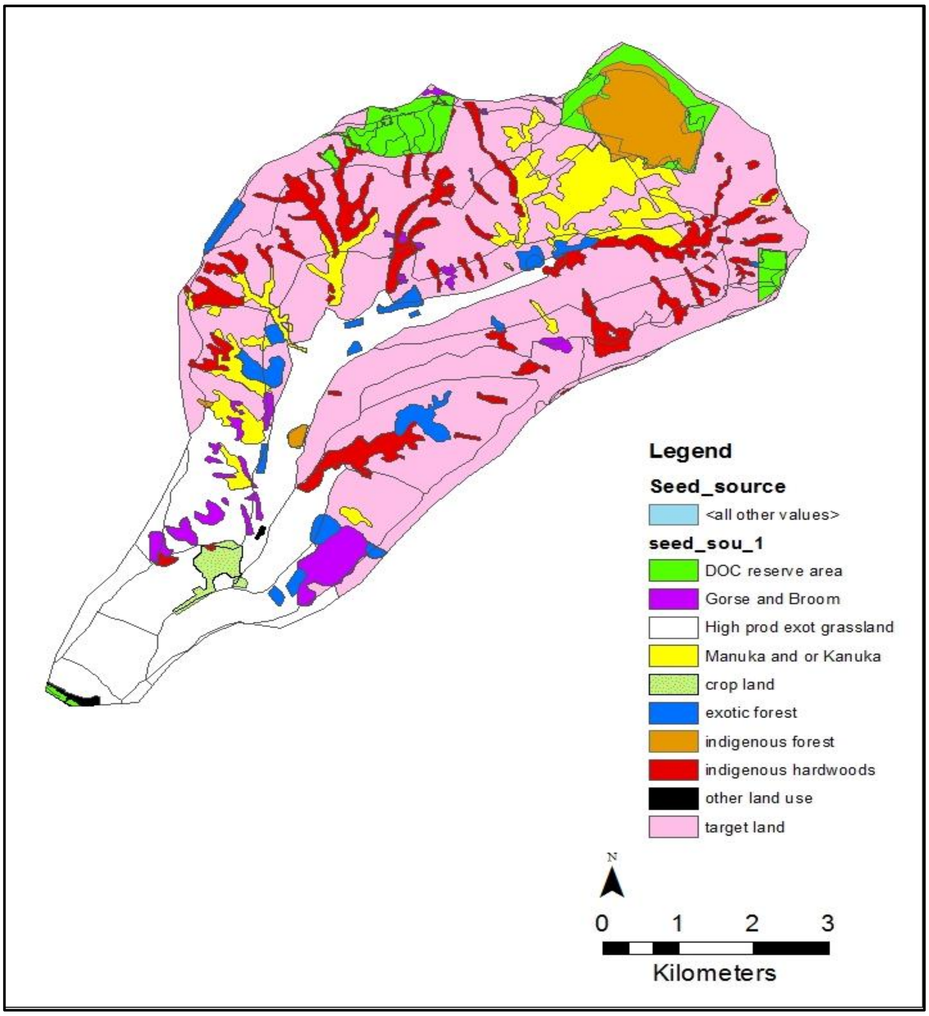

Figure 6.2 Seed source in the catchment (derieved from LCDB2 and DOC conservation boundaries)

Gorse (*Ulex europaeus*) has a hard coated seed which can remain dormant for decades and yet can germinate when exposed to the surface (Harrington *et al.*, 2011). If the site is undisturbed, gorse can provide a nursery for native seedlings and native trees such as Mahoe and Kanuka, but in other cases native trees can invade only after 25 to 30 years when gorse completes its first generation (Wardle, 2002). Although gorse can lead to native forest, it will be a different forest than one achieved through Kanuka (Sullivan *et al.*, 2007). Due to this reason it is important to protect patches of Manuka/Kanuka in any landscape. Kanuka and Manuka produce fine seeds which can be easily dispersed by winds. Given the climate of the catchment (moist and annual rainfall in the range of 760-1240 mm) and good seed source, scrub can cover the area in about ten to fifteen years. Manuka survives for 30-50 years whereas Kanuka can live longer, more than 100 years. By observing the native trees present in the catchment, earlier scrub could be replaced by Totara, Mahoe, Five Fingers, and Matai trees (A. Shanks, personal communication, 14 June, 2013). The middle part of catchment contains Totara trees that have been damaged by animals which can regenerate quickly if browsing animals are destocked.

Lloyd (1960) studied the natural regeneration process in Kauri-podocarp forest under a Kanuka nursery crop in the Russell Forest and concluded that Kanuka is very effective nursery crop. Rimu appeared first followed by Tanekaha and Kauri with an all aged stand under Kanuka between 60 to 80 years (Lloyd, 1960). However, Kanuka does not tolerate moist or very infertile soils which means they can appear on flat fertile soils in the catchment. As the catchment already contains small shrubs like Coprosma species and native trees like Mahoe, Five Fingers, and Totara which provide excellent seed source, birds feed on their berries and help to disseminate seeds of these native tress.

Table 6.3 presents normalised indicator scores for both 'target land into plantation forestry' and 'target land into scrub' scenarios. The flows of ecosystem services will be same under ECFP and QEII National Trust for at least 50 years as ECFP covenants last for this period. The main difference between these programmes should relate to costs due to differences in incentives offered by these programmes and their mode of implementation. ECFP is administered by MPI whereas QEII National Trust's programme is managed by QEII staff with funding coming from donations and various agencies including government. Similarly, as described earlier, both the ECFP and the ETS give the same indicator score as the ES flows are exactly the same under these programmes.

Table 6.3 Normalised and weighted indicator scores for likely afforestation scenarios

Ecosystem service	Indicator	Without preference weights		With preference weights (Max100)	
		ECFP/ETS (plantation forestry)	ECFP/QEII (natural reversion)	ECFP/ETS (plantation forestry)	ECFP/QEII (natural reversion)
Timber Production	Round wood harvested	0.5796	0.0310	0.1027	0.0055
CO_2 gas regulation	Carbon benefits	0.7111	0.5107	0.0699	0.0502
Water regulation	Water yield	0.7544	0.8617	0.1166	0.1331
Maintenance of clean water	Cumulative N yield	-0.1592	-0.1592	-0.0346	-0.0346
	Cumulative P yield	-0.3121	-0.3121	-0.0679	-0.0679
Soil erosion control	Sediment yield	-0.2932	-0.2430	-0.0451	-0.0374
Natural habitat provision	Conservation goal	0.6071	0.7024	0.0741	0.0858
∑ indicator score		**1.8879**	**1.3915**	**0.2156**	**0.1346**

6.4 Chapter summary

In this chapter limited-focus land-use programmes were evaluated for their impacts on flows of ecosystem services. For this purpose, flows of ecosystem services estimated by biophysical models in physical quantities were normalised to 0±1 and subsequently weighted by public preferences to derive weighted indicator scores. The land-use ranking for 'target land into plantation forestry' scenario changed from third most desirable in the absence of weights (or equal weights) to second most desirable when actual weightings were applied. This implies that preference weights should be integrated in land-use decisions as weightings can alter land-use rankings in those situations where there are sufficient differences in indicator scores across different land-use scenarios.

Chapter 7

Costs of Limited-focus Land-use Programmes

7.1 Introduction

Limited-focus land-use programmes provide different incentives to landowners for planting and/or conserving trees on their private lands. For example, the ETS gives landowners an incentive to earn carbon credits at the rate of one New Zealand Unit (NZU) for one tonne of carbon dioxide (CO_2) removed from the atmosphere (removals) or liability to surrender one NZU for release of one tonne of CO_2 to the atmosphere (emissions) (Ministry for Primary Industries, 2011). The NZUs are mainly for trading in the domestic market but some of these can be converted to Assigned Amount Units (AAUs) for selling overseas (Ministry for Primary Industries, 2011). The ECFP provides grants to landowners for planting trees or effectively managing natural reversion on severely eroding hills and adjacent lands in Gisborne region (Ministry of Agriculture and Forestry, 2007). The QEII National Trust provides partial support to those who are involved in the protection of natural and other areas of national significance on their lands (QEII National Trust, 2010). With the QEII Trust programme, the main driving force is a landowners' pride and satisfaction that they get from protecting unique native species as well as some cash support for fencing and pest control measures. Due to differences in incentive structures and the organisations involved in the administration of these programmes, the costs of administering these programmes should vary. This is the focus of this chapter. This chapter presents data and analysis on the costs of the three limited-focus land-use programmes used in the study, the East Coast Forestry Project, the Emissions Trading Scheme, and QEII National Trust. Costs of administering these programmes, which include programme and administrative costs, are explained in Section 7.2 followed by landowners' costs of involvement in these programmes in Section 7.3. A summary of the chapter is given in Section 7.4. The cost per unit of weighted indicator scores (ES benefits) could not be performed across land-uses as it is difficult know what proportion of new plantings will take place in the catchment.

7.2 Costs of administering limited-focus land-use programmes

The landowners' costs presented in this chapter include only incremental costs of participating in land-use programmes. Therefore, costs incurred on normal forestry activities such as planting and thinning were not included in the analysis. The incremental costs (subsidies/grants, administrative costs, etc.) to organisations include costs of running those land-use programme.

7.2.1 East Coast Forestry Project (ECFP)

The total costs for the ECFP include grants and administrative costs (Table 7.1). Landowners participating in the project receive grants from the government. The grants are currently paid out in two instalments, whereas the earlier grants were paid in up to five instalments over an eight year period (Bayfield & Meister, 2005). For example this means that grant funds paid out in 1993/94 were just for establishment but each one of those hectares received further funding in a later instalment or instalments. Because there were payment instalments over several years it is insufficient to calculate cost of the project on a yearly basis. The variation in average approved grant rate by application round is due to differences in grant rates for afforestation which range from $1,476 to $2,820 per hectare depending on distance to port, $1,512 per hectare for reversion treatment, and 70 percent of actual costs for pole planting (Ministry of Agriculture and Forestry, 2009a).

Table 7.1 East Coast Forestry Project expenditures (2011/12, NZ$, GST exclusive)

Year	Total area established (ha)	Costs ($)			Approved grant ($/ha)
		Grants	Administration	Total cost	Average
1993/94	1,911	1,235,320	219,969	1,455,289	2,484
1994/95	2,980	1,739,564	429,015	2,168,579	1,501
1995/96	2,464	1,262,856	422,475	1,685,331	1,519
1996/97	4,764	3,043,394	394,088	3,437,482	2,122
1997/98	4,266	2,865,488	428,390	3,293,878	1,669
1998/99	3,509	3,799,838	324,708	4,124,546	1,959
1999/00	3,725	3,887,072	507,202	4,394,274	1,779
2000/01	2,443	2,762,175	642,656	3,404,831	1,997
2001/02	932	2,029,058	596,774	2,625,832	1,129
2002/03	2,133	3,764,581	640,599	4,405,180	1,277
2003/04	1,102	3,747,167	631,728	4,378,895	1,817
2004/05	1,254	3,574,567	587,518	4,162,085	2,061
2005/06	579	2,432,368	515,077	2,947,445	2,021
2006/07	620	1,963,486	492,400	2,455,886	2,177
2007/08	377	1,927,381	470,601	2,397,982	1,739
2008/09	731	1,440,026	458,627	1,898,653	1,562
2009/10	898	1,525,730	455,172	1,980,902	1,699
2010/11	917	2,786,005	435,710	3,221,715	1,613
2011/12	2,500	4,066,000	429,000	4,495,000	1,588
Total	38,105	49,852,076	9,081,709	58,933,785	
Average cost ($/ha)		**1,308.3 (84.6%)**	**238.3 (15.4%)**	**1,546.6 (100.0)**	

Source: (Bayfield & Meister, 2005; Statistics New Zealand, 2012b)

The costs for 1993/94 to 2004/05 were adjusted for GST as MPI's annual report for these years were reported on a GST inclusive basis. Table 7.1 shows that over the period 1993/94 to 2011/12, the project had spent $58.93 million for treating 38,105 hectares of land. The average cost of treating land under the project comes at $1,546.6/ha of which programme and administration expenses were $1,308.3/ha and $238.3/ha respectively. The nominal costs were inflated to 2012 dollars using a GDP deflator as shown in Appendix F.

The area of land treated by indigenous reversion is 2,795 hectares which is about 7 percent of the total area (Table 7.2). The areas under indigenous reversion for 1993/94 to 2005/06 and 2007/08 to 2010/11 are published, but for 2006/07 and 2011/12 data are not available. The area covered by indigenous reversion for those two years was derived by taking the average of areas in previous years as shown in Table 7.2. However, a cost breakdown for plantation forestry and indigenous reversion is not available and it is difficult to guess what those figures are. For this reason, the prevailing grant rate $1,512/ha in 2012 was considered as average per hectare cost of managing natural reversion in 2011/12. This assumption is reasonable as cost of treating target land by natural reversion will start after 2012 and continue until the scrubland is established. However, the majority of the expenditure will be in the first year on fencing, clearing weeds and managing natural regeneration process. Further, the grant rate is not reduced even if the proposed treatment area already has an existing fence as the project only makes sure that the grant is going to the correct person (J. Sinclair, personal communication, May 14, 2013). The administrative costs for the natural reversion programme should also be similar to the average administrative costs presented in Table 7.1, which stands at $238.3/ha in 2011/12 dollars. Hence, the total estimated costs for government of treating land by natural reversion stands at $1750.3/ha.

Table 7.2 Total area established by treatment option in the ECFP, 1993/94 to 2011/12

Year	**Area in hectares**			**Remarks**
	Plantation forestry	**Indigenous reversion**	**Total area**	
1993/94-2005/06	31100	962	32062	
2006/07	428	192[a]	620	[a]Average area (2000/01 - 2005/06)
2007/08	144	233	377	
2008/09	473	258	731	
2009/10	326	572	898	
2010/11	667	250	917	
2011/12	2172	328[b]	2500	[b] Average area (2007/08 - 2010/11)
Total	35310	2795	38105	

Source: (Bayfield & Meister, 2005; Ministry of Agriculture and Forestry, 2011c)

The researcher was not able to collect cost data from landowners who have treated their lands with assistance from ECFP. The landowners' extra costs of participating in ECFP were derived based on information provided by MPI staff and a forestry consultant. These costs are presented in Table 7.3. As Table 7.3 shows there are no costs involved in lodging a grant application because a policy shift in 2007 that reduced the application form from several pages to one page and eliminated costs involved in hiring consultants for filling and lodging application forms (Ministry of Agriculture and Forestry, 2011c). Another cost is for registering a covenant on the land title which proceeds after MPI staff visit the proposed treatment area and approve it for further processing. Land Information New Zealand (LINZ) charges $59 for registering a covenant. The other costs to landowners involve certifying their grant claims via a registered accountant which costs $500 per claim. For *Pinus radiata* treatment, the claim is right after the establishment of trees and at the time of one compulsory thinning around eight years. For natural reversion, the first claim is after the establishment of treatment and the second one at five years.

Table 7.3 Incremental costs to landowners of participating in ECFP in the Gisborne region (NZ$, GST exclusive)

Cost categories	Unit	Frequency	Year										
			1	2	3	4	5	6	7	8	9	…	56
Lodging grant application	Per application	Once	0	0	0	0	0	0	0	0	0		
Registering covenant on land title	Per covenant	Once	59.00	0	0	0	0	0	0	0	0		
Lodging grant claim	Per claim	Twice	50.00	0	0	0	0	0	0	50.00	0		
Registering covenant on land title	Per application	Once	500.00	0	0	0	0	0	0	0	0		
Total costs to landowners			609.00	0	0	0	0	0	0	50.00	0		

Source: MPI staff and a forestry consultant

Table 7.3 shows that landowners have to pay $609.0 in Year 1 and no other administrative costs until Year 8 when they pay $50.0 to certify their final claim by a registered accountant. The last row in table 6.3 represents cost flows for landowners. This information was used in the calculation for total costs for afforesting a land size of 8 hectares as shown in Appendix G. A land area of 8 hectares was chosen as it corresponds to the median covenant size for the Canterbury region registered with QEII. This will help to compare costs of natural reversion between these programmes. The only difference between plantation forestry and natural reversion treatments in ECFP is time of lodging the second claim which is at 5 years for natural reversion. The Net Present Value (NPV) of extra landowners' costs for afforesting a land size of 8 hectares by *Pinus radiata* is $609.4 or $76.2/ha (Appendix G).

Likewise, the NPV of extra costs of treating target land by natural reversion is $612.9 or $76.5/ha (Appendix G). There are additional costs of farm labour involvement in pest control measures and plot inspections. However, these were not included due to a lack of information.

7.2.2 QEII National Trust

The annual expenditure of the QEII National Trust is presented in Table 7.4. The main expenses for QEII Trust involve establishing new covenants and monitoring existing covenants every two years to make sure that fences are intact, pest control measures are in place, and features are protected. QEII representatives are involved in the preparation of new proposals including finding grants from other organisations such as ECan and DOC. ECan and DOC provide grants for controlling weeds and pests, and also for fencing to conserve biodiversity on private lands. The main activities are weeding, installing possum traps, and deer shooting in some cases. Farm labour are involved in monitoring and some pest control activities but these costs could not be collected. However, these costs are not thought to be significant (A. Shanks, personal communication, July 16, 2012). The most common pests in Banks Peninsula are Brushtailed possums (*Trichosurus vulpecula*) and Old Man's Beard (*Clematis vitalba*).

Table 7.4 Costs of establishing and monitoring QEII covenants in New Zealand (2011/12, NZ$, GST exclusive)

Year	Expenditure ($)			Registered area (ha)
	Programme costs	Administrative costs	Total costs	
2003/04	2219397	796674	3016071	3407
2004/05	2629822	950956	3580778	4766
2005/06	2647283	936762	3584046	5041
2006/07	2794056	782564	3576620	6063
2007/08	2552877	1110207	3663084	3389
2008/09	2394029	1170716	3564745	4320
2009/10	2726570	1191557	3918127	3322
2010/11	2648991	1191641	3840632	2387
2011/12	2381169	1242679	3623848	3436
Total	22994194	9373756	32367951	36131
Average cost ($/ha)	636.4 (71%)	259.4 (29%)	895.8 (100%)	

Source: QEII National Trust Annual Reports (2003/04-2011/12)

Some cost categories published in QEII Trust Annual Reports, such as public relations and depreciation costs were dropped from the analysis as they were not available for ETS and ECFP.

Further, costs shown under property operations were also dropped as these costs are incurred in the maintenance of QEII Trust properties, not on private lands. With these adjustments, the average cost of protecting a hectare of land under QEII Trust programmes in 2011/12dollar terms was $895.80. Although it is a not-for-profit organisation, the budget composition for QEII Trust over the last eight years shows that the government had been the major source of funding (73%), followed by interest on investments (12%), contestable funds (8%), and others (7%) which include donations, membership fees and property income respectively.

Table 7.5 presents landowners' costs of being involved in QEII National Trust programme. The major cost for landowners is fencing which is shared equally between the landowner and QEII Trust. QEII also pays $500 to each covenant and an equal amount is shared by a landowner for the pest control measures. Table 7.5 shows total extra costs (fencing plus weed control) for six covenantors in Banks Peninsula, which were provided by the QEII Trust regional representative in Christchurch. As the Table 7.5 shows total cost to covenantor E was 507.8 as a fence was already in place, whereas it was $14,279.8 for covenantor C. The costs presented in Table 7.5 were converted to real costs using a GDP deflator rebase to 2011/01. In 2011/12, the average extra cost to landowners of protecting special features on their land was $292.1 per hectare.

Table 7.5 Incremental costs to landowners' of participating in QEII National Trust programme in Banks Peninsula, Canterbury (2011/12, NZ$, GST exclusive)

Covenantor	Vegetation Protected	Year	Total Costs ($)	Registered area (ha)	Average costs ($/ha)
A	Two patches of Matai-rich hardwood forest	2000	9,506.3	9.7	980.0
B	Thin-barked Totara forest, regenerating hardwood forest and scrublands	2004	3,756.2	55.5	67.7
C	Matai-Totara hardwood Forest	2005	14,279.8	20.7	689.8
D	Thin-barked Totara forest, regenerating hardwood forest and scrublands	2005	1,186.5	10.5	113.0
E	Red beech and Kanuka Forest	2009	507.8	15.0	33.9
F	Podocarp-broadleaf lowland secondary forest	2011	4,911.6	5.52	889.8
	Total		34,148.3	116.9	292.1

Source: (A. Shanks, personal communication, 15 July, 2012)

7.2.3 Emissions trading scheme

The net cost to the Crown of implementing the ETS has not been published to date. Neither could this researcher collect landowners' costs of involvement in the ETS. Due to these reasons, ETS costs were derived based on MPI's Annual Reports and information provided by staff responsible for the ETS programme. The MPI's Annual Reports show combined expenditure incurred on 'implementation of the ETS and Indigenous Forestry (IF)', out of which 60 percent was assumed to be expenditure on ETS (P. Lough, personal communication, October 24, 2012). The derived ETS expenditures are presented in Table 7.6.

Table 7.6 Statement of departmental expenses and capital expenditure against appropriations for the year ended June 2011-2014 (NZ$, GST exclusive)

Activities	Year	Total Expenditure	ETS Expenditure (60% of total expenditure)	Cost recovered from ETS fees	Net costs to Crown	
					Nominal	($,2011/12)
Implementation of ETS and IF	2010/11	10,988,000	6,952,800	498,000	6,454,800	6,556,016
Implementation of ETS and IF	2011/12	13,048,000	7,828,800	681,000	7,147,800	7,147,800
Implementation of ETS and IF	2012/13	10,103,000	6,061,800	431,000	5,630,800	5,504,203
Implementation of ETS and IF	2013/14	12,648,000	7,588,800	325,000	7,263,800	7,100,489
Total						26,308,508

Source: MPI Annual Report 2010/11-2013/14

By the end of 2014, the ETS was successful in making allocation (NZUs) to 1,231,529 hectares of pre 1990 forests and registering 261,148 hectares of post 1989 forests (Ministry for the Environment, 2013a). In this research, both the pre-1990 and post-1989 forests were considered in cost analysis as these areas were registered into ETS after the forestry sector was brought into the programmes from 1 January 2008. So, with the investment of $26.30 million in four years, the ETS has been successful in registering 1.49 million hectares of Kyoto-eligible forests by 30 June 2014. Therefore, the cost to New Zealand government of bringing Kyoto-eligible forests into ETS was $17.65 per hectare in 2011/12 dollars. This cost figure does not include silvicultural costs, as they did not build-up because of the programme.

There are a number of costs for ETS participants as shown in Table 3.2 in Section 3.6.1 (Chapter 3). The ETS process starts with lodging an application for registering a Kyoto compliant forest area. The

MPI charges $489/application and the application requires a shapefile showing land boundaries and supporting documents. For this purpose, consultants charge landowners for site inspections, getting the shapefile from drafting services, and general paper work (filling in application forms and liaising with MPI). The other costs are for opening an account in NZEUR, adding CAAs, transmission of interests, filing emissions return including one mandatory return at the end of second commitment period (CP2) (1st Jan 2013 to 31st Dec 2017). For a forest size of less than 100 hectares, NZUs are assigned based on MPI's look-up table for carbon sequestration. However, for a forest size of 100 hectares or more, carbon is estimated by taking measurements from permanently established plots. For this, consultants charge in the range of $350-400/plot which is a significant cost for a 100 hectare area that requires measurements from 30 plots. Filing of emissions returns is another cost for landowners where they pay $89/filing to MPI and $120 to consultants. If a landowner does filing every year then the consultant would charge less as s/he has to do fewer calculations. Again there is a mandatory emissions return at the end of CP2. So, on an average within a CP, a landowner would have done at least one last mandatory filing by 31st March 2018 for CP2 or landowners can choose to file every year or after two, three, or four years or any combination of these (Ministry for the Environment, 2012c).

The landowners' costs of participating in the ETS are difficult to estimate as costs are specific to clients and vary considerably depending on forest size and location, number of times emissions returns are filed, number of CAAs added, and so on. The landowners' costs are derived from information provided by a forestry consultant and published fee structures for pre-1990 and post-1989 forests. Costs involved in transmission of interests were not included in the analysis as it seldom occurs (H. Vern, personal communication, May 15, 2013). Landowners' costs are calculated for a land size of 8 hectares to make similarity with other land-use programmes assessed in this research. For bigger landowners, it was assumed that they will register their land with ETS and then apply for adding CAAs at the end of each CPs to minimise operating costs. The incremental costs to landowners of participating in ETS for CP2 is presented in Tables 7.7 and 7.8. The costs are extended for two rotations and discounted using real interest rate to derive the Net Present Value (NPV) of costs. The NPV of total extra landowners' costs for planting 8 hectares is $2,326.8 which on a per hectare is $290.8 (Appendix H). This cost is $7,358.2/ha (or 73.6/ha) for a plantation block of 100-124 hectares (Appendix I). The landowners' cost is lower for a bigger forest block which comes from economies of scale.

Table 7.7 Incremental costs to landowners' in ETS for CP2 for a forest block 8 hectares (NZ$)

Cost categories	Unit	Frequency	Year				
			1	2	3	4	5
A. Total Costs payable to Government			**489**				**89**
Application fee	per application	Once	489				
Filing emissions return	per filing	1 per CP2					89
Adding CAA	per CAA	Variable					
FMA plotting		once per CP2					
B. Total Costs payable to consultant/firm			**1,820**				**200**
Site inspection	as required	Variable	550				80
General paperwork (application filling, liaise with MPI, etc.)	per application	Variable	450				
Making shapefile	per application	Variable	700				
Open NZEUR account	per account	Once	120				
Filing emissions return	per filing	1 per CP2					120
Adding CAA		Variable					
FMA plotting		once per CP2					
Total costs for landowners (A+B)			**2,309**				**289**

Table 7.8 Incremental costs to landowners' in ETS for CP2 for a forest block 100-124 hectares (NZ$)

Cost categories	Unit	Frequency	Year				
			1	2	3	4	5
A. Total Costs payable to Government			**489**				**178**
Application fee	per application	Once	489				
Filing emissions return	per filing	1 per CP2					89
Adding CAA	per CAA	Variable					
FMA plotting		once per CP2					89
B. Total Costs payable to consultant/firm			**6,120**				**12,000**
Site inspection	as required	Variable	1,000				1,000
General paperwork (application filling, liaise with MPI, etc.)	per application	Variable	1,500				
Making shapefile	per application	Variable	3,500				
Open NZEUR account	per account	Once	120				
Filing emissions return	per filing	1 per CP2					500
Adding CAA		Variable					
FMA plotting		once per CP2					10,500
Total costs for landowners (A+B)			**6,609**				**12,178**

7.3 Cost comparison among land-use programmes

Table 7.9 presents costs of treating land on a per hectare basis by different land-use programmes. As Table 7.9 shows the grant approach (ECFP) costs $1,623 to treat a hectare of land by plantation forestry whereas same would cost only $308 through market/price based approach (ETS). On the other hand, natural reversion would cost $1,827/ha through ECFP grants and $1,188/ha through QEII National Trust. The incremental cost to landowners is only $76.5/ha in ECFP as most of the costs are reimbursed by the government. It is $292/ha in QEII Trust which is because of 1:1 cost sharing for fencing between the Trust and landowners. In the ETS, landowners' have to bear an extra $291/ha for registering and certifying carbon claims.

Table 7.9 A comparison of costs among land-use programmes (2011/12, $/ha, GST exclusive)

Cost categories	Plantation forestry		Natural reversion	
	ETS	ECFP	ECFP	QE II
A. Total costs to government/agency	17.5	1546.6	1750.3	895.8
Programme cost	-	1308.3	1512.0	636.4
Administrative cost	17.5	238.3	238.3	259.4
B. Landowners' extra cost of participating in the programme	290.8	76.2	76.5	292.0
Total costs (A+B)	308.3	1622.8	1826.8	1187.8

Table 7.9 shows that programme cost for ECFP is $1,308.30/ha whereas there is no such cost for the ETS. In the case of the natural reversion scenario, the programme cost of ECFP is approximately 2.3 times more than that of the QEII Trust. The administrative costs on afforestation through natural regeneration did not differ much between ECFP and QEII, but differ significantly between ETS and ECFP for plantation forestry scenario ($17.50/ha for ETS vs $238.30/ha for ECFP). The results here show that a market based approach to paying for an ecosystem service like the ETS has the lowest average cost. The reason for this is because the costs of running the system are largely fixed (the market) and decrease on average as more area is added to the market. The incentive payment to the landowner is funded privately in the market as a repayable credit. For subsidy approaches like the ECFP and QEII Trust the overhead cost is a much smaller portion of the total cost and thus the average cost per hectare of these programmes remains relatively high. What this study did not determine was the amount of extra planting induced by any these programmes at the study site, which could then be compared to extra costs for deriving cost effectiveness per hectare.

7.4 Cost effectiveness of land-use programmes

Cost effectiveness analysis (CEA) involves comparing relative costs of two or more courses of action against their outcomes (Robinson, 1993). CEA has been widely used in the health sector for measuring effectiveness of programmes by comparing their costs to outcomes using Quality Adjusted Life Years, and also in measuring effectiveness of conservation programmes in New Zealand using Conservation Output Protection Years (Cullen *et al.*, 2005). In this research, cost effectiveness of land-use programmes are expressed in terms of ratios where the numerator is average extra cost per hectare of limited-focus land-use programmes and the denominator is average extra area planted/reverted by these land-use programmes.

For measuring cost effectiveness of land-use programmes it would be necessary to find out new planting areas these programmes would induce. This requires modelling landowners' behaviour for the uptake of afforestation or reforestation which was not done in this research. Neither has this research asked landowners what their future afforestation/reforestation will look like if they had access to either ETS or ECFP or QEII. This research has simply studied the cost of running subsidy type programmes like ECFP and QEII, and a market type programme like the ETS which is facilitated by the government but runs under a free market mechanism. The costs reported in this study are indicative only as they are based on very limited information provided by the responsible organisations and landowners participating in these programmes. Only the incremental costs that arise because of landowners' participation into either of these programmes were included in the cost effectiveness analysis. So, the research has calculated indicative extra costs of bringing a unit area under afforestation/reforestation by these programmes.

Afforestation decisions usually depend upon the yield potential of commercial species and anticipated market value of timber at harvest. In addition to these, landholding size, land suitability, period running property, perceived relative profitability of forestry, financial problems, current forest tax policy, off-farm self-employment and off-farm income determine the forestry investment and extent of forestry expansion by smallholders in New Zealand (Dhakal *et al.*, 2008). Under the ETS, forests have potential to make carbon returns. In order model the land area (both existing and new) that will be planted under ETS, it is necessary to integrate returns from carbon forestry in the analysis. However, capitalising on carbon returns can expose landowners to price risks at the time they sell their carbon credits or surrender their carbon liabilities due to highly fluctuating carbon prices (Anastasiadis & Kerr, 2013).

7.4.1 New plantings under the ETS

It is difficult to project how much area of new planting or replanting will take place as a result of carbon incentives from the ETS. In this regard, Horgan (2007) found a positive correlation between returns and new planting. He projected that there may be no planting below internal rate of return (IRR) 4.7 percent, but plantings can reach to 90,000 hectares per annum if the IRR for forestry reaches 10.0 percent (Horgan, 2007). Other studies have modelled relationship between carbon prices and forestry plantings. Maclaren *et al.* (2008) found that the land-price hurdle of \$3,000/ha (at 8% real rate of return) could be met if carbon price for Radiata clearwood regime is at least \$13.0/tCO_2e. At zero carbon price an average forest site can yield \$1,215/ha which increases to \$6,647/ha if the carbon price reaches \$30/tCO2e. Using the equation developed by Horgan (2007), the extra new planting area for the ETS was calculated.

$$\text{Area of new planting} = -151027 + 22922 * \text{IRR} \qquad (7.1)$$

Table 7.10 Projected extra new planting under the ETS for 2012/13 to 2019/20 (hectares)

IRR (%)	Carbon price (\$/tCO_2e)	Area of new planting (ha)
≈6.0	≤15	≈0
7.0	20	9,427
7.7	25	25,472
8.6	30	46,102

Source: (Horgan, 2007; Manley & Maclaren, 2009)

Table 7.10 shows that carbon forestry is capable of inducing 25,000 hectares of new planting at an IRR of 7.7 percent, corresponding to a carbon price of \$25.0/tCO_2e. New planting falls to nearly zero at around an IRR 6.59 percent. This finding is reasonable as one can doubt that the current low price for carbon will aid to (if any) extra planting. Figure 7.1 presents the actual planting and replanting for New Zealand. Planting rate in New Zealand has decreased after 2001, and became lowest between 2006 and 2010. Replanting rate improved during 2012 and 2013, but again fell after 2013. However, replanting rate was more stable compared to new planting rate over the years. Some of the replanting may have been attributed to the ETS, but it is difficult to determine what those areas are. ETS was thought to induce rapid plantings in marginal lands, but that has not happened in reality. This could be due to very low carbon prices in the international markets (Figure 7.1).

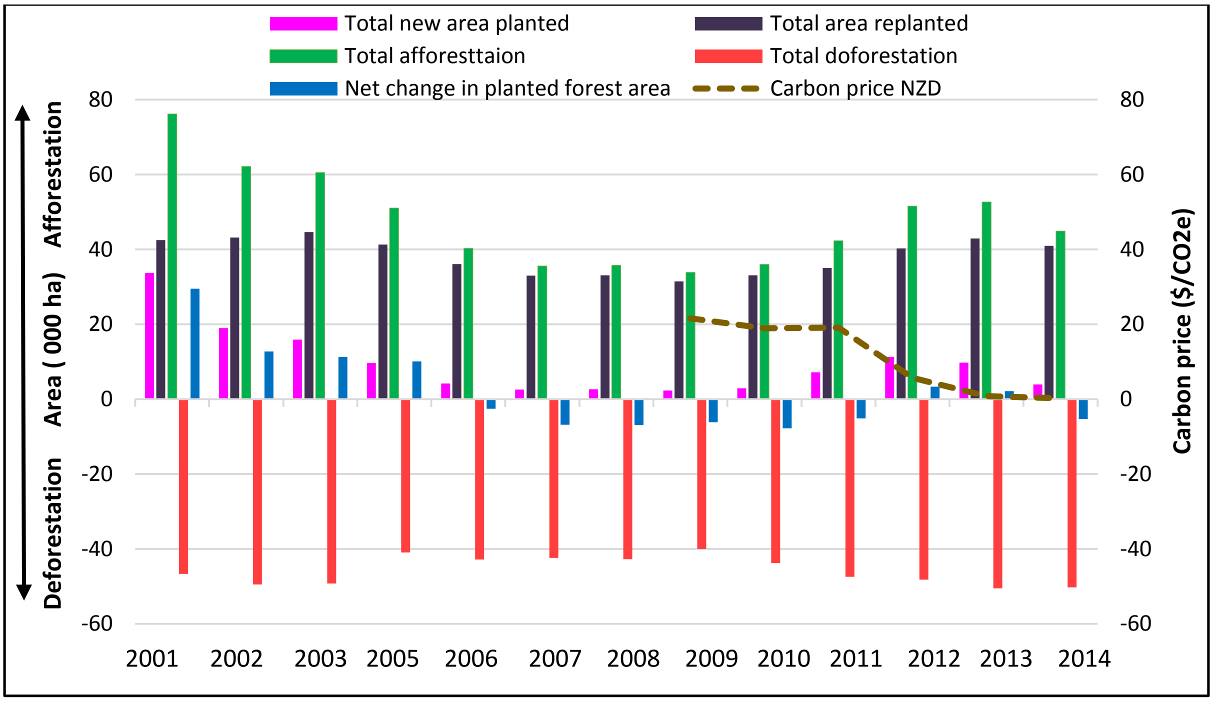

Figure 7.1 Net change in actual planted forest area in New Zealand

7.4.2 New planting/reversion under ECFP

From 1993 to 2012, about 25,500 hectares of target land and an additional 12,500 hectares non-target land (land adjacent to target land) were treated by ECFP. Still, about 34,500 hectares of target land remains to be afforested or reforested within eight years as budgets for new grants are available till 2020. Hence, on an average about 4,312 hectares of target land per year needs to be treated by the ECFP during that time. There was a spike in planting rate around 2011 and 2102, but again it declined in 2013 as the carbon price fell by that time (Ministry for the Environment, 2014). Given the current rate of progress of the programme (1,342 ha of target land or 2,000 ha of target and non-target land combined per year) it is unlikely that the ECFP will meet its objectives by 2020.

Table 7.11 presents the actual area treated by the ECFP which shows that after 2001/02, the programme could achieve approximately one fifth of its annual target rate. There are a number of issues associated with the slow uptake of the programme. The majority of the remaining target land is in the Waiapu catchment (44%) which is mostly Māori land. Issuing grants on Māori land with multiple owners is difficult, so are the financial barriers and compliance issues (administrative process, long duration covenants and restrictive forestry regimes) that prevent landowners from participating in the ECFP (Scion, 2012). However, a 15 year agreement, starting from 28 August 2014 to manage soil erosion on the target land instead of a 50 years covenant, is expected to improve the uptake of ECFP grants (Ministry for Primary Industries, 2014a). Also grantees can get an additional incentive (carbon credits) for managing erosion on their target land if they enter into the ETS or PFSI.

Table 7.11 Rate of planting for the ECFP

Year	Target (ha/year)	Achievement against target (%)	Plantation forestry		Indigenous reversion	
			Total area (ha)	Achievement (ha/year)	Total area (ha)	Achievement (ha/year)
1993/94-2000/01	7,000	46.5	26,062	3,258	-	-
2001/02-2011/12	4,608	18.25	9,248	841	-	-
2001/02-2011/12	1,392	18.25	-	-	2,795	254

7.4.3 Indigenous reversion under QEII

Conserving biodiversity on private land is important as it can benefit all segments of society. However, as biodiversity benefits have public good aspects, landowners need some incentives to motivate them in this task. In this regard, central and local governments as well as other organisations like QEII National Trust and Ngā Whenua Rāhui provide some subsidies to landowners for protecting native species on private land. Among the non-governmental organisations, QEII National Trust and Ngā Whenua Rāhui are the main organisations involved in the protection of biodiversity on private land through the mechanism of a covenant on land title (Ministry for the Environment, 2007b).

The progress of registering covenants was slower in the beginning as it took almost 20 years to register the first 1000th covenant, but then the speed of covenanting became faster as same number of covenants was registered in another 10 years (Ministry for the Environment, 2007a). After 2004/05, the average area brought under permanent protection was higher than the programme's yearly average target (Table 7.12). At the national level, the average and median size of a QEII covenant equal to 41.3 and 4.7 hectares respectively. The costs were calculated for a median covenant size (8.1 ha) for Canterbury. This is not the area that would be induced by the QEII programme or ECFP. It was selected to calculate the extra per hectare costs to landowners' for planting or managing indigenous reversion on their land. Based on the current progress of QEII, the future area under indigenous reversion is kept at 3,534 ha/year.

Table 7.12 Area protected under QEII

Year	Target (ha/year)	Achievement against Target (%)	Total area (ha)	Achievement (ha/year)
1977/78-2003/04	3,534	74.4	68,365	2,629.4
2004/05-2011/12	3,534	115.7	32,724	4,090.5

7.4.4 Comparison

Table 7.13 summarises the indicative extra plantings under these land-use programmes.

Table 7.13 Indicative new plantings under different options

Options/ programme	Baseline (2011/12, ha/year)		Target rate for 2012/13-2019/20 (ha/year)	Indicative planting/reversion (2012/13-2019/20) (ha/year)					
	Average target (ha/year)	*Progress as of 2011/12 (%/year)		Normal forestry	New ECFP**		Carbon forestry ($/tCO₂e)		
					50%	100%	≤15	20	25
ETS	25,000	0.0	25,000	0	-	-	0	25,000	46,000
ECFP (plantation)	4,608	18.25	4,608	841	1,261	1,682	-	-	-
ECFP (reversion)	1,392	18.25	1,392	254	381	508	-	-	-
QE II (reversion)	3,534	100.0	3,534	3,534	-	-	-	-	-

* Average proportion for 11 years (2001/02-2011/12)

** It was assumed that new planting rates may increase in the range of 50-100% over baseline due to new ECFP arrangements

The extra planting/reversion areas were compared to extra cost of each programme. For the ETS, there are only administrative costs. So, administrative costs were assumed to be more or less the average expenditure in the last four years (2009/10-2013/14). In case of ECFP, the administrative cost for baseline was fixed at $4,29,000 of which two third was assumed to be expenditure on planation forestry and remaining one third on the administration of indigenous reversion. For future scenarios, which is new ECFP grants from 28 August 2014 (Ministry for Primary Industries, 2014b), the administrative costs were set at the average administrative costs from 2003/04 to 2011/12. For the QEII, the average per hectare costs from Table 7.9 were applied as the future new area coverage under QEII would be equivalent to current target rate 3,534/ha. With these adjustments, the results of cost effectiveness analysis for the plantation and indigenous reversion are presented in Tables 7.15 and 7.16.

Table 7.14 Indicative cost effectiveness of the ETS and ECFP for afforestation ($/ha, 2011/12)

Options	Scenarios	Extra area (ha)	Administrative cost ($)	Program cost ($)	Landowners cost ($)	Total cost ($)	$/ha
East Coast forestry project							
Status quo	Baseline 2011/12	841	286,000	1,100,028	64,084	1,450,112	**1,724**
New ECFP	50% area increase	1,261	305,751	1,649,388	96088	2,051,227	**1,627**
New ECFP	100% area increase	1,682	305,751	2,200,056	128168	2,633,975	**1,566**
Emissions trading scheme							
Status quo	≤$15/tCO₂e	0	6,577,127	0	0	6,577,127	N/A
Increased carbon price	$20/tCO₂e	25,000	6,577,127	0	7,275,000	13,852,127	**554**
Increased carbon price	$25/tCO₂e	46,000	6,577,127	0	13,386,000	19,963,127	**434**

Table 7.15 Indicative cost effectiveness of ECFP and QEII for indigenous reversion ($/ha, 2011/12)

Options	Scenarios	Area (ha)	Administrative Cost	Program cost	Landowners' cost	Total cost	$/ha
East Coast forestry project							
Status quo	Baseline 2011/12	254	143,000	384,048	19,456.4	546,504	**2,152**
New ECFP	50% area increase	381	152,876	576,072	29,184.6	758,133	**1,990**
New ECFP	100% area increase	508	152,876	768,096	38,912.8	959,885	**1,889**
QEII National Trust							
Status quo	Baseline 2011/12	3,534	2,249,079	916,854	1,031,928	4,197,861	**1,188**

When future planting scenarios are considered, the ETS programme is currently the least cost effective as it cannot induce any extra plantings at the current carbon price. However, if future carbon price rises to at least $20/tCO_2e$, then ETS would require one third of the resources that are required for ECFP (Table 7.15). For the natural reversion scenario, QEII is desirable over ECFP as the former would require approximately half of the resources required for the latter. These tables clearly show that reductions in cost can be achieved by increasing area under future afforestation or reforestation. The results from cost effectiveness analysis indicate that ES benefits from scrub can be achieved at lower costs through QEII Trust programmes than through ECFP. In the case of benefits from plantation forestry, ETS would be far more cost effective than ECFP if future carbon prices rise to the level to induce landowners in afforestation activities. Otherwise, ETS is highly cost ineffective in terms of its contribution in generating extra plantings.

7.5 Chapter summary

This chapter has presented costs of single-focus land-use programmes that would lead to broad ecosystem service provision through either afforesting land or natural forest reversion. The costs were calculated for two rotations corresponding to time required for carbon to reach a steady state. The total cost of each land-use programmes was derived by adding agencies' costs, which include programme costs and administrative costs and landowner's extra costs of involvement in these programmes. In this research, extra costs to landowners' means incremental costs that are related to being involved in land-use programmes and exclude all costs that would have otherwise incurred as a part of a regular forestry operation. The cost analysis in this chapter showed that the average cost per hectare of a market based approach (ETS) is significantly less than the subsidy approach (ECFP and QEII Trust).

The cost effectiveness analysis in terms of programmes contribution in generating extra plantings/reversion showed that it makes sense to promote natural reversion through voluntary organisations such as QEII. For promoting exotic forests, the ETS would outweigh ECFP in terms of costs only when carbon price rises to at least \$20/tCO_2e. This is because ETS has potential to induce about 35,000 hectares new plantings with minimal administrative cost. At the current low carbon price, it is doubtful that the ETS has induced any extra new plantings. There is a similar case with the natural reversion programme, which if promoted through QEII Trust programme, would only require about half of the resources required for the ECFP.

Chapter 8
Discussion

8.1 Introduction

This research looked at the provision of broad ecosystem services through limited or single focus programmes. This was done to determine whether they could be viable alternative to complicated ecosystem services markets. It did this by using biophysical models and preference weight elicitation methods for the assessment of forestry schemes in the delivery of ecosystem services (ES). The ES outputs obtained in physical quantities were normalised and multiplied with preference weights so as to derive weighted indicator scores for the existing and potential afforestation scenarios. Cost analysis was performed to find out the least costly land-use programme in the provision of ES. This facilitated comparison among different land-uses in the provision of ES without monetising the benefits. The purpose of this chapter is to discuss the findings of the current research in the light of existing research and report on its significance for enhancing ES in New Zealand.

8.2 Preferences for ES

Two different methods, namely the Analytical Hierarchy Process (AHP) and Max100, were used to elicit people's preferences for ecosystem services provided by natural systems in Canterbury. Both the methods showed that water quality and quantity, production and erosion control services are more valued than are cultural and carbon sequestration services. A previous study which collected preferences from water resource managers and policy makers for assessing the sustainability and cost-effectiveness of water storage projects on the Ophi River in Canterbury (Hearnshaw & Cullen, 2010) is consistent with our finding that regulating ES are more preferred than are production and cultural ES. Hughey *et al.* (2008) found that water quality related issues and their impacts on recreational activities are the most pressing environmental concerns to New Zealanders. Surprisingly, we found that cultural ES, which includes recreational values and others (for example, educational and aesthetic values), are less preferred than are regulation and production services. A possible explanation for this is that preferences for cultural ecosystem services might have been captured by water quality services as recreational activities such as swimming and kayaking require clean water. This research did not explicitly assess public preferences for recreational services. Rather it assessed public preferences for cultural ecosystem services, which apart from natural habitat provision also include aesthetic, educational, recreational and heritage values.

Studies of ecosystem services weights, particularly in Canterbury and generally in New Zealand, are scanty. Tompkins *et al.* (2011) collected preferences of six local and fifteen regional stakeholder representatives and used AHP to calculate preference weights of 17 different ecosystem services provided by the Opihi River in Canterbury. In their study, stakeholders were found to have placed higher importance on regulating ecosystem services than on food, fibre and abiotic products (specifically, provisioning ecosystem services). Some other studies have also highlighted the importance of water in the Canterbury region due to its multitude of uses for irrigation, hydroelectricity generation and household consumption (McDonald *et al.*, 2008). According to Rodríguez *et al*. (2006), people tend to prefer, in this order, provisioning, regulating, and then cultural ecosystem services. However, in this study production was found as the second most preferred ecosystem service after water quality (a regulating ecosystem service). Hearnshaw (2009) concluded that people's preferences in Canterbury region focussed around food ecosystem services, reflecting the dominance of agricultural production in the region. This study has reiterated that point.

Although the emphasis of this research was not to compare methods of weight elicitation, some inferences can easily be drawn with respect to their suitability for collecting people's preferences. While the AHP has been employed before to find out preferential weights from experts and stakeholder representatives, the Max100 technique has not previously been used in a New Zealand context. Through this research it was found that the Max100 weight elicitation method is more straightforward and easy to use as compared to the AHP method. The AHP method is complex and often suffers from inconsistency and rank reversal problem (Belton & Gear, 1983; Dyer, 1990). Moreover, the AHP method is complex and tedious because respondents have to compare each ecosystem service with all other possible combinations of ecosystem services under investigation. In fact, it is sometimes hard for people to maintain transitivity while making comparisons of ecosystem services. This has been reflected in the inconsistency test where 48 out of 80 responses were dropped as they crossed the inconsistency ratio of 15 percent adopted for this study. This is higher than the usual 10 percent ratio found in research literature (Kangas, 1994; Saaty, 1994a). One potential way of improving consistency in the AHP survey is by using it in groups where members collectively revise their preferences before finally agreeing on them (Ishizaka & Labib, 2011; Wilson & Howarth, 2002). However, in the group approach of weight elicitation, the researcher should be vigilant that the voice of everyone is heard and no one is influencing or dominating the group.

With the Max100 survey, 54 respondents were able to assign relative scores to ecosystem services and only 26 responses were dropped because they lacked either a highest score of 100 for the most preferred ecosystem service or they had more than one ecosystem service assigned a full score of 100. The lower rates of acceptable responses in this study as compared to earlier studies on the subject could be due to the fact that people rushed to complete the survey as their primary aim was to visit the Agriculture and Pastoral show rather than to participate in the survey. Hence, avoiding surveying in such places and circumstances could improve the response rate.

The Max100 method has yielded internally consistent results in 91 percent of occasions as compared to the Direct Rating and Min10 methods which gave internally consistent results in 87 and 75 percent of occasions respectively (Bottomley & Doyle, 2001). The Direct rating method involves asking people to rate each attribute on a scale 0 to 99, whereas in the Min10 method people are asked first to assign 10 points to the least important attribute and then a scale value >10 with no specified upper limit to other attributes according to their importance compared to the least important attribute. It has been shown that people preferred Max100 method over DR and Min10 as the former was reported to be simpler and easier to use by respondents (Bottomley & Doyle, 2001).

According to Colombo *et al.* (2009), the preference weights obtained from interviewing citizens and experts can be similar. This has been restated by this research and by Tompkins *et al.* (2011) which were based on the survey of individual experts and stakeholder representatives. However, this does not imply that the expert's judgements should be viewed as substitutes for preferences derived from the public, as the findings of one place may not be applicable to another place or setting. This research has shown that preferences for certain ES can differ significantly between sexes and age groups. This highlights the importance of including people from different ethnic backgrounds, sex, age groups, dwellings and interest groups in land-use decisions so that their preferences are represented in the weight elicitation exercise and subsequently in policy decisions.

In these methods, when people are making pair-wise comparisons in the AHP survey or assigning 100 points to the most preferred ecosystem service and then using a relative scale (0-99) to the remaining ecosystem services in the Max100 method, they are essentially expressing their willingness to give up one ecosystem service for a gain in another ecosystem service. From a viewpoint of ecosystem services sustainability, these methods embrace the 'weak sustainability' concept as 'strong sustainability' posits that ecosystem services cannot be compensated or traded-off with each other (Farley, 2012; Prato, 2007). This is because there are thresholds for each ecosystem services below which they can be lost forever. However, identifying those threshold levels is challenging due to ES being a product of complex and dynamic ecosystems. Hence, in my opinion, applying a safe minimum principle can help to minimise irreversible consequence of ecosystem services loss. Given the definition of ecosystem services that was adopted for this study (Section 2), which applied to any goods or services from an ecosystem and which are valued by humans, the compensatory method chosen in this study is a valid method of determining people's preferences for ecosystem services, especially in situations where it is difficult to set those safe minimum thresholds. After all it is true that without beneficiaries there are no ecosystem services.

8.3 Impact of land-use on flows of ES

The impacts of land-use change on flows of ES have been quantified using biophysical models and equations for the Kaituna catchment. For this purpose, potential areas for afforestation, which is called target land in the research, were identified using Land Use Capability (LUC) classes. Then, ES flows were estimated for the existing and afforestation scenarios at the steady state and results were summarised for the catchment. A previous study by Ausseil & Dymond (2008) assessed benefits of afforestation on erosion prone land in the Manawatu catchment, New Zealand. Other studies that have assessed ecosystem services in New Zealand include trade-off assessments of soil, water and carbon associated with forestry (Dymond *et al.*, 2012; Rutledge *et al.*, 2010), prediction of annual water yields and low flows under different land-uses in the catchment (Fahey *et al.*, 2004), erosion assessment under different land-use scenarios (Bergin *et al.*, 1991; Dymond *et al.*, 2010; Hicks, 1985), carbon sequestration benefits of forests and scrub (Carswell *et al.*, 2012; Coomes *et al.*, 2002; Trotter *et al.*, 2005), and biodiversity and conservation values (Ausseil *et al.*, 2011; Dymond *et al.*, 2008). Most of these researches have focused on flows of one or few ES and have not assigned weights to ES flows according to the preferences of members of the public. This research has assessed six ES and weighted them according to the importance people attach to them. This was done because biophysical assessment only quantifies changes of flows of ES, but does not say anything about how important those changes are from social perspective. Hence, the following sub-sections present and discuss flows of ES from this research in comparison to previous research findings.

8.3.1 Timber yield

The quantities of timber and carbon were estimated by Radiata pine calculator version 3.0 which uses New Zealand based tree growth models and equations. It was assumed that the proposed land in the Kaituna catchment (the target land) is afforested by Pinus radiata grown on a standard silvicultural regime, that is, plant 1250 stems/ha with three pruning to 6.5m and one final thinning to

300 stems/ha on a 28 years rotation. The 300 index[3] of 26.2 m^3/ha/yr and site index of 24.5 m given in the calculator for an average Canterbury farm were used to estimate timber yield and carbon sequestration at the research site.

The research results show that afforesting target land in Kaituna catchment by Radiata pine (*Pinus radiata*) grown on a 28 years rotation would produce 57,792 m^3 of roundwood per year as only 84 hectares area is ready for harvesting each year after 28 years. When timber yields are considered at the catchment level, an estate level strategy would produce 13.1 m^3 of roundwood per hectare every year from 28 years onwards. This is because timber yields are averaged over the entire catchment area 4,684 hectares whereas timber yields are realised from an area of 84 hectares grown on a 28 years rotation. Goulding (2005) reported mean annual increment (MAI) for Radiata pine grown on a high productivity site under direct sawlog regime in New Zealand at between 25 and 30 m^3/ha/year. Kimberley *et al.* (2005) analysed data from permanent sample plots established in New Zealand and calculated mean 300 index value of 31.7, 22.8, 18.6, and 22.4 m^3/ha/yr for fertile ex-farm, East Coast dry, Coastal sand, and North Island forest sites respectively.

The timber yield depends on the lifespan of trees, number of trees grown to maturity, and the productivity of site. Site productivity is influenced by parameters such as temperature, rainfall, soil, and topography. Radiata pine grows best on sites that have well drained clay loam soils, receive at least 750 mm of annual rainfall and do not exceed 900 m altitude. The growth rate is sensitive to frost injury above that altitude (Department of Environment and Primary Industries, n.d.). As the proposed area of afforestation (target land) at the research site has good moisture availability (average annual rainfall 752 mm) and is free from severe frost (altitude of target land varies from 220 to 752 meters), the Radiata pine trees gave 24.4 m^3/ha/yr of roundwood from each plot on alternate years due to forest estate regime.

8.3.2 Carbon sequestration

Apart from timber, carbon sequestration is another ES that is produced when target land is afforested by *Pinus radiata* on a rotational basis. At the steady state, which is reached after two rotations (56 years), the stand-level strategy will stock 205 tCO_2e/ha. This will be the minimum amount of carbon stored by Radiata pine trees in live above and below ground biomass, deadwood, and litter excluding carbon changes in under storey or soil carbon pools. On the other hand, an estate level strategy would stock a minimum of 411 tCO_2e/ha which is almost twice the amount of

[3] Mean annual volume increment (m3/ha/yr) of a stand of Pinus radiata that is pruned to six metres, thinned at the completion of pruning, and grown to a final crop stocking of 300 stems/hectare to age 30 years.

carbon stock in the stand-level strategy. Earlier studies in New Zealand have calculated carbon sequestered by Radiata pine in various silvicultural regimes using different procedures. For example, Manley and Maclaren used Radiata pine calculator for estimating carbon stored in a clearwood regime (prune to 5.5 meters in two lifts and thin to 250 stems/ha) grown on a 30 years rotation and found that a stand-level strategy stocks a minimum of 250 tCO_2e/ha whereas estate-level strategy stocks approximately 550 tCO_2e/ha (Manley & Maclaren, 2012). They used an average New Zealand farm site index of 30.2m and 300 index of 29m^3/ha/year. This caused higher volume productivity and carbon stock than found in this research.

Ford-Robertson *et al.* (1999) estimated long term carbon stock in live Radiata pine trees using a stand modelling tool called STANDPAK and came up with figures 814 tCO_2e/ha and 550 tCO_2e/ha for high and low productivity sites respectively. They considered carbon in live biomass only and still got a higher amount of carbon stock which seems contradictory to the findings of this research and also with the findings by Manley and Maclaren (2012). This is because carbon stock is not equivalent to total amount of carbon stored by trees within its life cycle. The reason being that carbon stored in trees is released back into the atmosphere when trees are harvested. Further, carbon stored in deadwood pool of Radiata pine is also released back into the atmosphere due to stumps decaying in about ten years under New Zealand condition**.** Tate *et al.* (2002) calculated average carbon sequestration rate for plantation forests as 18 tCO_2e/ha/yr whereas Dymond *et al.* (2012) suggested that plantation forests could add up to 31 tCO_2e/ha/yr during its growth period. Using these rates and 28 years rotation cycle, plantation forests at our study site would sequester 504 tCO_2e/ha and 868 tCO_2e/ha respectively which is more than the carbon stock found in this research. This was mainly due to average farm productivity (300 index and SI) values used in this research.

This study also estimated amount of carbon sequestered by scrub in 56 years as the plantation forestry scenario was assessed for two rotations, each rotation of 28 years. The results show that the scrubland scenario would sequester 305.6 $tCo2_e$/ha in 56 years or at the rate 5.45 $tCo2_e$/ha/yr which is less than carbon sequestration values reported in other studies. For example, Trotter *et al.* (2005) found that Manuka/Kanuka scrubland, depending on site conditions, on average sequesters 6.9 to 9.1 $tCo2_e$/ha/yr during active growth period of 40 years. Using the minimum sequestration rate reported in their study, they found that Manuka/Kanuka scrubland could store 276 $tCo2_e$/ha/yr in 40 years. Funk (2009) estimated total carbon storage on naturally regenerating marginal pasture lands in Gisborne district between 191.2 and 347.6 $tCo2_e$/ha in 70 years. These research have illustrated that the mean carbon accumulation rate in scrub would depend mainly on soil fertility and the mean annual rainfall rather than on the mean annual temperature at those sites.

Some research has assessed carbon stored in all pools; that is above and below ground live biomass, coarse woody debris, fine litter and mineral soils. Coomes *et al.* (2002) assessed carbons in all pools of natural indigenous scrublands in South Island transact and found 598 tCO_2e/ha carbon stock in Manuka/Kanuka dominated scrubland. This is equivalent to 230 tCO_2e/ha after removing the carbon in mineral soils. The look-up tables prepared by MAF for forestry in the ETS showed that 50 year old Manuka/Kanuka in Canterbury would stock about 323.4 tCO_2e/ha which includes carbon in all components of the forest except soil (Ministry of Agriculture and Forestry, 2011b). This research found 56 year old Manuka/kanuka scrubland in Kaituna catchment would sequester 305.6 tCO_2e/ha which is close to the value given in the ETS look-up table. However, as the research assumed that each of the 28 plots will be fenced and destocked for facilitating natural regeneration process at 1 year interval, the average carbon stock present in 28 plots would be 255 tCO_2e/ha.

8.3.3 Regulation of water flow (water yield)

The land simulation results showed that afforestation of target land by Radiata pine reduced water flow in the catchment. This was evidenced by approximately 21 percent reduction in annual water yield when target land was converted from primarily sheep and beef hill to plantation forestry. Many New Zealand based studies have illustrated changes in streamflow due to land-use changes in catchments that are usually less than 1000 hectares (Bosch & Hewlett, 1982; Davie & Fahey, 2005; Fahey, 1994; Fahey *et al.*, 2004; Jowett & Duncan, 1990; Rowe, 2003a; Rowe *et al.*, 2002). Bosch & Hewlett (1982) reviewed altogether 94 catchment experiments around the world and concluded that for every 10 percent change in pine and eucalypt forest cover there is about 40 mm reduction in water yields. However, this conclusion, which simply assumes a linear relationship between rainfall and run-off, does not hold true as hydrologic response to rainfall at a given location is influenced by various parameters such as the intensity and duration of rainfall events, geology and soil type, the connection between surface water and groundwater, and the climatic variability (Rowe, 2003b). Further, in the case of commercial forestry, stand management practices such as method of planting (estate or stand level); spacing between trees; under-storey control; pruning and thinning practices; and timing of harvesting operations affect water yields to some extent (Fahey, 1994).

Rowe *et al.* (2002) reviewed research literature on the impact of vegetation on water yield and concluded that tall vegetation changes the amount of water in catchments. His review was mainly focused on the results of plot-based experiments around the world. Experiments conducted in New Zealand have shown 30 to 80 percent reductions in annual water yield following afforestation of pasture (Bosch & Hewlett, 1982; Davie & Fahey, 2005; Fahey, 1994; Fahey *et al.*, 2004; Jowett & Duncan, 1990; Rowe, 2003a; Rowe *et al.*, 2002). The results from these research exhibited 30 percent reduction in annual water yield for Mangatu and Porukohukohu catchment, and for Berwick and Moutere catchments (Duncan, 1995), the reductions in annual water yield stood at 38 percent and 80 percent, respectively. Other recent studies have further confirmed that plantation forests reduce water yields from catchments when replacing other land uses (R. B. Jackson *et al.*, 2005; Marcar *et al.*; Schrobback *et al.*, 2011; L. Zhang *et al.*, 2001). Some researchers have used biophysical models to simulate the impact of land-use change on water yields. WATYIELD is designed for this purpose by Landcare Research New Zealand which uses daily rainfall and evapotranspiration, together with other climatic parameters, in order to estimate the impacts of land-use change on annual water yields and low flows. Fahey *et al.* (2004) tested WATYIELD on the Rocky Gully catchment in South Canterbury and reported a 7 percent reduction in annual water yield when about half of the catchment area was changed from tussock and pasture to plantation forestry. In assessing trade-offs between soil, water and carbon associated with *Pinus radiata* forests at the national level in New Zealand, Dymond *et al.* (2012) concluded that water yield is primarily influenced by rainfall and secondarily by soils and land cover which are subject to human influence. At annual rainfalls of 600 mm, 1000 mm, and 2000 mm, the water yield from pasture was 100, 70, and 50 percent more than that from forest (Dymond *et al.*, 2012).

On the other hand, using WATYIELD model Ausseil and Dymond (2010) reported a 2.1 percent reduction in annual water yield when approximately 5.5 percent steep pastoral land in Manawatu catchment (585,000 ha) was converted to pine plantations. This finding suggests that small land-use changes in a bigger catchment may not markedly reduce water yields as much as in smaller catchments. However, some sub-catchments may show a greater reduction in water yield where land-use changes take place. Therefore, it is important to identify those sub-catchments and analyse them separately for their in-stream values and water usage for different activities. The only experimental study carried out in new Zealand to determine the impact of large scale afforestation on water flows was in Tarawera catchment (90,600 ha) in the central North island. It found a 13 percent reduction in river flows due to planting of *Pinus radiata* on 25,000 hectares (Dons, 1986). The Tarawera catchment showed a greater reduction in river flows as afforestation took place mainly in high rainfall areas and occupied approximately 28 percent of the catchment area.

The level of reduction in total water yield in smaller catchments due to afforestation cannot be scaled-up to larger catchments as reductions in total water yield in larger catchments may not be noticeable until 20 percent of a catchment is afforested (Bosch & Hewlett, 1982). This is because, apart from vegetation, variability in geology, soils, elevation, and rainfall affects water yields in catchments. However, one thing that is clear from research literature and from this research is that land-use change from grassland/pasture to tall vegetation (scrubs and trees) leads to reduction in stream flow, which is apparent in smaller as well as larger catchments like Tarawera in New Zealand although the magnitude of such reductions are usually larger in smaller catchments than in larger catchments.

The reductions in flows are likely to be greatest in high rainfall areas (Fahey, 1994) and may not be apparent until at least 20 percent of catchment area is changed from short vegetation to tall vegetation such as trees and scrub. Further, if estate level planting is followed as has been assumed in this research, the impact of afforestation on water yields will be smaller due to varying stages of tree growth in the catchment. However, the effects of trees on water yields are not noticeable for quite some time (5-8 years) after which reductions in water yields peak during the active growth period (8-15 years) and ceases as trees mature.

Water yields in catchments have been reported to increase following harvesting**.** However, for a measurable increase in stream flow, at least 20 percent of catchment area needs to be harvested (Bosch & Hewlett, 1982). This was seen in studies conducted in the Appalachian Mountain hydrologic region, USA and in Canada. However, other studies have shown that this is not the case. For example, the data from the Rocky Mountain region and the Central Plains in the USA showed a measurable increase in water yield when 15 and 50 percent forests in those catchments were harvested. This suggests that simple general rule of 20 percent may not be applicable across all catchments.

The increase in stream flow after deforestation (or harvesting) is greater during initial years (1-5 year) and in areas of high rainfall. However, the increase in stream flow is usually shorter lived in high rainfall areas due to rapid re-growth of vegetation than in low rainfall areas (Bosch & Hewlett, 1982). Streamflow response to deforestation or afforestation depends both on the region's mean annual precipitation and on the precipitation for the year under treatment (Rowe, 2003b). This means that the changes in streamflow are attributable to the type of vegetation present in the catchment and to the amount of rainfall in the area.

Summing up, New Zealand based studies carried out in smaller catchments have revealed that land-use change from pasture to plantation forestry reduces annual water yields due to interception of rainfall by trees' branches and leaves and loss of water by evapotranspiration above wet canopy. Harvesting of trees, on the other hand, increases annual water yields in catchments but for a shorter time period. Although geology, rainfall and climatic variability are the primary drivers of water yields in catchments, forest management practices (estate versus stand level), planting area and density, pruning and thinning, and time of harvesting (avoiding harvesting during summer time) can have significant influence on water yields. Thus, resource managers should utilise stand management practices to help augment water flows in catchments that have water shortages during summer.

8.3.4 Maintenance of water quality

Land-use in Kaituna catchment from sheep and beef hill to plantation forestry or scrubs showed improvement in water quality due to reduction in nitrogen, phosphorus and bacterial loads by 15.3, 10.0 and 31.4 percent respectively. It is widely accepted that forestry has a positive impact on water quality. Larned *et al.* (2004), in a nationwide review of water quality streams in New Zealand, reported that concentrations of dissolved reactive phosphorus, nitrate and nitrite, ammonium, and E. coli in pastoral and urban classes were 2-7 times higher than in native and plantation forest classes. Ausseil and Dymond (2010) studied the impact of afforesting erosion prone land in Manawatu catchment on flows of ecosystem services and reported slight improvement in water quality due to conversion of pasture to forested lands (1.5% reduction of N and P leached, and 3.5% reduction in E. coli). As the afforestation took place in steep land that is usually not grazed and the retirement of agricultural land on an average would reduce animal numbers by 10 percent, there was a slight improvement in water quality.

In a study of identifying trade-offs in ecosystem services of changing 75,000 hectares of sheep and beef and 5,000 hectares of dairy to carbon forestry in the Waikato region, Huser *et al.* (2012) found that by 2050 the nitrogen and phosphorus loads in Mokau River mouth on the west coast will be reduced by 6-7 percent. Quinn & Stroud studied the effects of land-use on water quality at Whata whata catchment farm near Hamilton from 1995 to 1999, and concluded that pasture stream had 3.70 and 1.90 times higher total nitrogen and 1.36 and 1.40 times higher total phosphorus concentrations than from the stream draining native and pine forests respectively (Quinn & Stroud, 2002).

Many studies in New Zealand, ranging from catchment to national levels, have shown that the concentrations of E. coli, and dissolved inorganic nitrogen and reactive phosphorus in low-elevation rivers and streams have exceeded recommended levels required for the protection of aquatic life and human health (Larned *et al.*, 2004; Ministry for the Environment, 2013b; Monaghan *et al.*, 2007). Maintaining water quality in streams and rivers is important for recreational use and maintaining suitable habitat for aquatic plants and animals.

8.3.5 Soil erosion control

Afforestation of target land by Radiata pine or scrubs showed beneficial results with regards to soil erosion control. This is because, as compared to sediment load in the existing land-use, which mainly consists grassland in 74 percent of the catchment area, sediment load at the outlet of the catchment would be reduced by 62.3 and 69.0 percent under plantation forestry and scrubland scenarios respectively. The reduction in sediment yield was higher for scrubs than for plantation forestry as there are soil losses during harvesting of pine trees. This is consistent with an earlier finding by Hicks (1985) who assessed the effect of vegetation on the amount of damage caused by Cyclone Bola that hit the East Coast in March 1988 and found that areas covered under pine or indigenous forest cover reduces mass movement relative to pastures or reverting scrubs.

The beneficial role of forestry for soil protection is well documented in literature (Dymond *et al.*, 2010; Fahey *et al.*, 2003; Hicks, 1985; Marsden, 2004; O'Loughlin, 2005). Tree roots provide good soil enforcement which helps to reduce soil loss by erosion, landslides, and mass movement. Fahey *et al.* (2003) compared sediment yield from the Tamingimingi catchment (in pasture) and Pakuratahi catchment which was in matured pines, and found that sediment yield from the pasture catchment was 3 times more than that from the pine catchment. In the study of landslide damage to fully stocked Manuka and/or Kanuka, Bergin *et al.* (1993; 1995) estimated 65 percent reduction in landslides by Manuka dominated 10 year old stands than pasture which reached to 90 percent at the stand age of 20 and near 100 percent as the stand becomes older and gets replaced by Kanuka trees. This shows that scrubs are more effective in controlling soil erosion as they grow older. It could take 10 to 15 years for indigenous scrubs to decrease soil erosion significantly on hill country.

Other studies have compared effectiveness of Pinus radiata and scrubs in reducing soil erosion caused by storm events (Hicks, 1985; Phillips *et al.*, 1990). These studies have concluded that pine trees and fully stocked stands of Manuka/Kanuka are effective in reducing landslides, but according to Philips *et al.* (1990) eight year old pine stands can reduce landslides by 90 percent, whereas for similar level of protection against erosion, scrubs would take 15 years. However, according to Ekanayake *et al.* (1997) fully stocked regenerating Kanuka provides better protection than by Pinus radiata in the first eight years, but as the stands grow older, the opposite is true. This research also finds that sediment yield from scrubland is slightly lower than that from Plantation forestry. In a report to the ECan Commissioners by Joint Forestry Submitters, O'Louglin argues that about 40 percent of water sensitive sub-catchments in Canterbury are vulnerable to soil erosion due to susceptible soils in headwaters and other parts of catchments. However, ECan controls (restricts or regulates) new forestry plantings in catchments thereby limiting soil protection and other ecosystem services benefits in the region.

8.3.6 Natural habitat provision

Using the national measure of natural habitat provision developed by Dymond *et al.* (2008), the research found that shifting from current land-use, which is primarily high and low producing grassland, to plantation forestry or scrubland improves the natural habitat provision index by 41.7 and 63.9 percent respectively. This showed that plantation forestry has an important role to play in New Zealand government's goal of protecting natural areas in landscapes and conserving biodiversity. Previous researches have shown that plantation forestry contributes to indigenous biodiversity by creating suitable habitat for some plants and animals. Examples include several species of birds including rare species like Falcon and long-tailed Cuckoo (Clout & Gaze, 1984; R. W. Jackson, 1971; Maunder *et al.*, 2005); long-tailed bats (Borkin & Parsons, 2010; R. W. Jackson, 1971); plants (Allen *et al.*, 1995; Brockerhoffa *et al.*, 2003; Ogden *et al.*, 1997); native forest beetles (Berndt *et al.*, 2008; Hutcheson & Jones, 1999); native Hochstetter's frog (*Leiopelma hochstetteri* and red colour fungus fly agaric (*Amanita muscaria*) (Maunder *et al.*, 2005).

Cullen *et al.* (1999) developed a method for estimating contribution of a conservation project by measuring Conservation Output Protection Year (COPY) and comparing COPY scores to costs of available projects to find out the least costly project. This method is found suitable for assessing productivity of a single species or multiples species (Cullen *et al.*, 2005), but required site specific information. However, in the absence of such information, which is the case in many countries including New Zealand, Dymond *et al.* (2008) developed a method that measures progress towards a conservation goal by calculating proportion of natural area remaining in a land environment. This method has been used for assessing impact on natural habitat of conversion from pasture to forests on erosion prone land in Manawatu catchment (Ausseil & Dymond, 2010) and for estimating habitat provision for indigenous forests and grasslands, and freshwater wetlands remaining in New Zealand (Ausseil *et al.*, 2011). In measuring natural habitat provision, it is important to find out which projects or programmes achieve that goal at minimum cost.

At present forestry is being penalised for its role in reducing streamflow without assessing other ecosystem services co-benefits. New forest planting in catchments is subject to resource consent which is a lengthy process and incurs a significant cost. This has discouraged investment in the forestry sector which provides a range of ES that benefits local people and society at large. At present forestry plantings in water sensitive catchments are allowed up to the extent where reduction in the seven day mean annual low flow or the mean flow is not more than 5 and 10 percent respectively. However, according to Dr. Tim Davie in the evidence submitted to the ECan Commissioners in relation to chapter 5 of Natural Resources Regional Plan, setting these limits are problematic as it is difficult to detect 5 percent change in low flows using available gauge meters (Davie, n.d.). Instead, allowing forestry in ≤20 percent of a catchment area and leaving aside low-flow producing areas in water sensitive catchments, could be a way forward to promote forestry and enhance ES without greatly reducing water yield. Another possible way to deal with the low flow issues could be to store winter run-off and later utilise it during the time of water shortages.

8.4 Cost effectiveness of forestry programmes

This research has compared the costs of the ETS, ECFP, and QE II National Trust schemes as they would provide different incentives to landowners for engaging themselves in the provision of ecosystem services. The results showed that afforestation by *Pinus radiata* in Kaituna catchment with incentives from ETS and ECFP would cost $308/ha and $1,623/ha in 2011/12 dollars respectively. On the other hand, managing natural reversion through ECFP and QEII Trust would cost $1,827/ha and $1,188/ha respectively. Studies that help assess the costs of forestry programmes in New Zealand have been rare. There was a review of ECFP in 2005 but it was mainly focused on the physical targets of the project. The latest review of MAF afforestation schemes showed that the project has been receiving about $4.5 million annually but the actual annual spending between 2007 to 2009 was only $1.7 to 2.2 million due to high drop-out of applicants. This shows that incentives may not necessarily lead to perfect uptake of programmes as ECFP provide highest cash reimbursement (grants) than other forestry programmes, yet has not been able to achieve its objectives. The ETS programme costs government comparatively less which means it can be targeted for controlling greenhouse gases as well as soil erosion throughout the country but government has to provide landowners some sort of assurance on carbon prices.

8.5 Indicator units versus currency units for ecosystem services

In this thesis biophysical models and indicators were used for the assessment of ecosystem services in different land uses as guided by different forestry programmes. Use of indicators in ecosystem services assessments is promising as they help to measure and detect changes in ecosystem services. There has been some progress made in this area (de Groot *et al.*, 2010; MEA, 2005; Wang *et al.*, 2010), but there is still lacking a fully agreed set of indicators upon which monitoring of each ecosystem service could be performed (Layke, 2009; Tompkins *et al.*, 2011). This is because indicators for provisioning ecosystem services are well developed, but indicators for cultural and regulating ecosystem services are less developed due to some difficulty of quantifying and measuring these services which are often quasi-public goods. Due to a lack of data for cultural and regulating ecosystem services, it has become difficult to fully capture changes in these services. Nonetheless, programmes like The Economics of Ecosystems and Biodiversity (TEEB) and Rationalising Biodiversity Conservation in Dynamic Ecosystems (RUBICODE) are involved in developing indicators for ecosystem services which would help us to measure the impacts of human interventions on ecosystem services over time.

Ecosystem services assessments have been mostly limited to the use of few well established indicators (Ausseil & Dymond, 2010; X. Zhang & Lu, 2010), but some studies have developed and/or used a comprehensive set of indicators in ecosystem services assessments (Dobbs *et al.*, 2011; Hearnshaw *et al.*, 2011; Wang *et al.*, 2010). For example, Wang *et al.* (2010) identified 21 indicators for assessing the effects of hydropower project on watershed ecosystem services in Fujian province China, Hearnshaw *et al.* (2011) used a range of biophysical and socioeconomic indicators for assessing the impact of the Opuha Dam on ecosystem services provided in Opihi catchment in Canterbury, New Zealand. In these studies, indicators were estimated in dollars (Wang *et al.*, 2010; X. Zhang & Lu, 2010), physical quantities (Ausseil & Dymond, 2010), or in both (Hearnshaw *et al.*, 2011). Hearnshaw *et al.* (2011) have mentioned lack of both biophysical and socioeconomic indicators for ecosystem services that fall in regulating and cultural ecosystem services class. We have included three classes of ES in this research.

Posthumus *et al.* (2010) showed how ecosystem services indicators measured in different units, both monetary and non-monetary, can be normalised and then used for estimating changes in ecosystem services under different land-use scenarios in lowland flood plains in England. In the absence of preference weights, they assigned equal weights to all ecosystem services and calculated cumulative indicator scores, while highlighting potential synergy and conflicts among different management scenarios. In this research, ecosystem services outputs were normalised to a maximum ±1 following the procedure of Posthumus *et al.* (2010), but as opposed to assigning equal weights to ES as they did, this study weighted ES outputs by preference weights collected by interviewing members of the public.

The method used in this research is significant for several reasons. First, it avoids assigning dollar values to every ecosystem service. A number of researchers have highlighted the limitations of economic valuations, especially, for non-marketed goods and suggested alternative evaluation methods, such as, use of multi-criteria analysis, engaging multi-stakeholders in the assessment and valuation of ecosystem services (Howarth & Farber, 2002; Spangenberg & Settele, 2010). Further, with the development of both biophysical and socio-economic indicators for each ecosystem services, an ecosystem services index can be constructed which can then be used in the appraisal of environmental projects as it can capture long term trends in ecosystem services (Boyd & Banzhaf, 2007; Hearnshaw *et al.*, 2011). With the index comparison of implementation costs and identification of least costly options for maintaining or enhancing ecosystem services can be done. Second, it integrates peoples' preferences (social aspects) with flows of ecosystem services obtained from biophysical models (ecological aspects) and facilitates comparison of ES among land-uses. Further, comparing costs of each land-use programmes to weighted indicator scores will tell which programme to target for enhancing ES so as to maximise social benefits.

8.6 Summary

From the above discussions it is evident that afforestation of target land enhances a number of ecosystem services, except water yield which is undesirable in areas that have limited amount of water to allocate among competing land-uses. Harvesting of trees gives timber and increases water flows in catchments for some years, which are desirable, but makes water quality, soil erosion control, natural habitat provision, and climate regulation services worse-off. Following harvesting, sediment transport to water bodies increases thereby deteriorating water quality. Further, exposed soil surfaces are vulnerable to flooding if storms hit during the period between harvesting and soil stabilisation by new plantings, which for *Pinus radiata* in New Zealand takes about 8 years. However, if plantation forestry is practiced on an estate level, the ES loss over the catchment will be greatly reduced and closer to the ES values reported in this research.

The survey of members of public showed Canterburians higher preferences for regulating services than provisioning services or cultural services. Water quality is the most preferred ES followed by production ES. An earlier study by Hearnshaw (2009) has also found that people in Canterbury region have higher preferences for food ecosystem services. This research has found that it is important to integrate peoples' preferences in land-use decisions as the land-use ranking for 'target land into plantation forestry' scenario changed from third to second with regards to ES flows when preference weights were applied to ES flows. This implies that peoples' preferences should be integrated in land-use decisions. The next chapter draws summary of major findings, strengths and weaknesses of research, and possible areas for future research.

Chapter 9

Summary of Findings, Conclusions, and Policy Implications

This chapter presents a summary of the main results and draws conclusions based on discussion of those points. The summary of major findings is presented in the context of the research questions raised in the thesis, followed by conclusions and recommendations. At the end, the limitations of the research and the possible areas for future research are presented.

9.1 Research objectives and research design

The degradation of ecosystem services is of great concern to humanity as it reduces welfare of both the present and of future generations. However, as many ES are quasi-public goods, people do not have strong incentives to engage themselves in the production of ES unless they are compensated for their action. In this regard, markets have been created for some of the ES such as carbon and nutrients discharges (N), and payments for ecosystem services (PES) have been implemented in Central American countries for the hydrological functions of watershed (Wunder & Albán, 2008). In New Zealand, markets have been created through cap and trade programmes for the atmospheric sink function of CO_2 and nutrients in Lake Taupo (Waikato Regional Council, 2010). In the forestry sector, there are programmes like the ETS (price based) and the ECFP (grant based) that put a value (price) on the climate regulation service provided by trees. In these programmes, the main objective of the government is to increase forest area so that the country can meet its carbon liabilities. On the other hand, the main aim of the grant based programmes, like the ECFP, is to protect soil on severely eroding hills of Gisborne district. Although these forestry programmes have a targeted focus on ES like carbon sequestration in the ETS or soil conservation in the ECFP, they can also promote other ES (spill-over effects). Studying those spill-over effects may provide an alternative to broad ecosystem service markets that are either difficult to establish, and/or complex and costly to operate. With this motivation, the research focused on the following research questions:

- Do limited focus land-use programmes provide broad ES outcomes?
- Are there differences in ES outcomes between the ETS (market based), the ECFP (regulatory/grant based) and the QEII (voluntary local NGO) approaches?
- Which approach/programme is the most cost effective in the provision of ES?
- What are the public's preferences for the selected ES?

To address these research questions, the three land-use programmes were studied in the Kaituna catchment in Banks Peninsula, Canterbury. Although ECFP grants are confined to target land (classes VII and VIII) in the Gisborne district, for this study it was assumed that something similar to ECFP grants will be available to landowners for controlling soil erosion. Similarly it was assumed that support from QEII is available for facilitating indigenous reversion on land that are on LUC class≥V and which have plenty of seed source. To assess ecosystem services flows, bio-physical models developed in New Zealand were used for simulating impact of land-use change on the flows of six ecosystem services, namely, timber yield, carbon sequestration, water quality and quantity, soil erosion and natural habitat provision. The present research used mostly the secondary data except landowners' extra costs for participation in the land-use programmes and public preferences for ES were collected by surveys and personal contacts. The AHP and the Max100 methods were employed to estimate public preferences for these ES. Indicators were used for estimating changes in the flows of ES, which were normalised and multiplied by ES weights in order to derive weighted indicator scores for each land-use scenario. Finally, costs per hectare of extra planting were derived for the ETS, ECFP and QE II schemes. The findings of the research are presented with regards to the research questions posed in chapter one.

9.1.1 Whether limited focus land-use programmes provide broad ES outcomes?

A review of literature and research results has revealed that limited-focus land-use programmes can provide broad ES outcomes. This is due to spill-over effects of those land-use programmes, which generate targeted and non-targeted ES. In this research, afforestation of target land by *Pinus radiata* or scrub showed improvement in water quality, reduction in sediment load from the catchment, higher scores for natural habitat provision, and contribution towards climate regulation due to higher carbon sequestration than in the existing land use. Specifically, as compared to the existing land use, which is mostly sheep and beef hill, the 'target land into plantation forestry' scenario increased timber yield 18.7 times, carbon benefits 4.3 times, and the conservation score 1.4 times. Likewise, it led to a significant improvement in water quality due to a reduction in the nitrogen and phosphorus cumulative yields by 15.3 percent and 9.9 percent, and sediment load by 62.7 percent as compared to the existing land use. However, as compared to the existing land use, afforestation of target land would reduce annual water yield by approximately 21 percent. The latter outcome could be an issue in the Canterbury region, which has already added an extra 60,000 hectares of irrigated land between the years 2007 and 2012 which represents nearly three-fifths of the total irrigated land area increase in New Zealand during that period (Statistics New Zealand, 2013b). On the other hand when ES flows in the scrub scenario are compared to those in existing land use, there would be no difference in timber yield, but carbon benefits and conservation score would increase by 2.6 and 1.6

times, respectively. The reductions in nitrogen and phosphorus cumulative yield are similar to those obtained in the plantation forestry scenario, but scrub would reduce sediment load and annual water yield by 69.1 percent and 9.6 percent, respectively. Although the flows of ES obtained in these scenarios are different as the present study has indicated, it is clear that limited or single focus land-use programmes provide broad ecosystem services outcomes.

9.1.2 Are there differences in ES outcomes between the ETS (market based), ECFP (regulatory/grant based) and QEII (voluntary local NGO) approaches?

The results of the research showed no significant differences in ES outcomes between the ETS and ECFP when the plantation forestry scenario was considered. Likewise, no significant difference was observed between ECFP and QEII when a natural reversion scenario was considered. This is because landowners can plant exotic species (*Pinus radiata*) on target land and register in the ETS if they wish to apply for carbon benefits or apply for grants for planting *Pinus radiata* on land that needed an effective tree cover for soil protection. The ECFP also allows clearfell of trees as with the ETS but the only difference is that it has to be immediately replanted due to a 50 years covenant on the land title. For these reasons, the flows of ES obtained under these two approaches are similar. Similarly, managing natural reversion through ECFP or QEII Trust has also yielded similar ES outcomes.

One of the reasons for getting similar ES outcomes between these approaches is because of modelling assumptions made in the research. This research assumed that estate level planting will be practiced for both the Pinus radiata and scrub. If all of the catchment area were planted and harvested once then the flows of ES under plantation forestry scenario would have been different from those obtained in this research as felling all the trees in the catchment would lead to greater amount of disservices than in estate level harvesting. This research selected ECFP under regulatory/grant approach which allows harvesting of timber provided that replanting is immediately followed after harvesting due to a 50 years covenant on the land title. However, if Afforestation Grant Scheme (AGS) was considered in place of ECFP and compared to ETS or QEII, the flows of ES between these approaches might have been different as first 10 years of carbon credit in AGS goes to the government (Ministry of Agriculture and Forestry, 2011c).

9.1.3 Which approach/programme is most cost effective in the provision of ES?

Cost-effectiveness analysis showed that plantation forestry can be promoted through ETS when carbon prices are high enough to induce landowners in afforestation activities. At the current low carbon price, ETS is not effective at all in inducing extra plantings. For increasing scrub cover in marginal lands and in lands that are prone to soil erosion (LUC≥ V), the QEII Trust programme requires nearly half of the costs required by the ECFP scheme. Thus, the research indicates that it is more economical for the New Zealand government to increase new forest area through the ETS rather than something like the ECFP, but government might have to provide a minimum support price for carbon in situations when international market prices are below \$15/tCO_2e. Similarly, natural regeneration process can be promoted through voluntary based not-for-profit NGOs like QEII Trust so as to save costs. Thus, from the results of this study, the ECFP appears to be costly. Further, high dropout rates (Ministry of Agriculture and Forestry, 2011c) and slow uptake of the programme (Bayfield & Meister, 2005) can raise serious concerns as to the effectiveness of ECFP. This suggests that the ECFP may need to be revised and implemented in a new way addressing the issues of Maori land. In this regard, the new ECFP grant arrangements may speed-up the uptake of the programme due to removal of covenant and shortening of grant to 15 years (Ministry for Primary Industries, 2014a).

9.1.4 What are publics' preferences on selected ES?

Analytical Hierarchy Process (AHP) and Max100 surveys were carried out to determine public preferences for ES provided by natural systems in Canterbury. The results showed differences in ranking of preference weights by these two methods. For example, according to AHP weights, production, soil erosion control and cultural ES ranked second, fourth, and fifth most preferred ES, whereas they ranked fourth, second, and sixth by Max100 weights. However, both the methods showed water quality and water quantity as the most preferred and the third most preferred ES, respectively. The ranking of ES weights reflected higher preferences of Canterburians for regulating ES than for production or cultural ES. When ES weights were analysed by socio-demographic factors, the average weights for male versus female as well as for people living in rural versus urban areas did not differ significantly. Nevertheless, the average ES weights for the age group 18 to 44 years differed significantly from those in the age group >44 years. More specifically, those in the 18-44 year old age group ranked erosion control and cultural ES as the 5th and 4th most preferred ES, whereas those in the >44 years old age group ranked erosion control and cultural as the 3rd most preferred and least preferred ES, respectively. Based on this result it can be concluded that it is important to include people from different ethnic background, sex, age groups, and so on in the research design phase (sample selection), specifically, while collecting peoples' preferences for ES.

9.2 Summary of findings

Although the studied land-use programmes have limited focus, for example, ECFP focuses on soil conservation, ETS focuses on carbon sequestration for reducing greenhouse gas CO_2, and QEII Trust focuses on conserving biodiversity and unique features on land, they could provide broader ecosystem services outcomes (co-benefits). For example, increasing Kyoto compliant forest area and sequestering more CO_2 will boost the climate regulation service, but would also enhance other ES, namely, air quality, water quality, soil erosion control, provisioning ES (timber, fuel-wood, fodder, etc.), flood control benefits, scenic beauty, recreational services, and conservation values. This is also the case with ECFP which while targeting soil conservation through exotic or indigenous forestry, enhances other ES. However, converting land from short grassland to tall vegetation (trees or scrubs) also leads to reduction in annual water yields and low flows in catchments, destruction of natural habitat provision and loss of biodiversity, greater amount of sediment loss and risk of landslides, if a storm like Cyclone Bola hit during the window period (time between harvesting of trees and slope stabilisation by new trees).

However, when plantation forestry is practiced on an estate level, the disservices mentioned above, especially, increased sediments and biodiversity losses are greatly reduced. This is mainly because only a proportion of the area in the catchment is required to be cleared each year. Thus, it can be concluded that the sum of ES benefits generated from afforestation outweighs the loss from reduced water yields. When indicator scores for ecosystem services were normalised, weighted, and averaged over the catchment, it showed that plantation forestry is more beneficial than scrubland mainly because timber yield is foregone in scrubland and also that carbon benefits are lower than in plantation forestry. With regards to ES flows, it does not matter whether afforestation is promoted through ETS or ECFP, but it matters on the ground of costs. ES benefits from indigenous reversion can be achieved at lower cost through QEII Trust program than through ECFP grants. The ETS has potential to induce large area of new plantings but only when carbon prices rise to \$20/tCO_2e or above. The cost effectiveness analysis indicates which programme is economical to promote for enhancing ES on private lands. Government should target these least costly programmes in a way that more landowners' get engaged in these land-use programmes which ultimately enhance multiple ES on private land.

9.3 Contribution of the research

The method used in this research is useful for ES assessment in some significant ways. It used an ecosystem services approach put forward by Millennium Ecosystem Assessment for analysing impact of land-use change on flows of ES. Further, by normalising ES and integrating them with preference weights, this research has clearly demonstrated how one could assess the contribution of different land-use programmes in the provision of ES without monetising them. Hence, district and regional councils can follow recommendations for a quick assessment of ES flows or outputs when required to weigh different land use options in the provision of ES.

The main contribution of the research is that it has explored an alternative to complex ES markets for enhancing ES on private lands at minimum costs. For this purpose it studied limited or single focus land-use programmes as they provide broad ecosystem services outcomes (spill-over effects). By assessing ES flows across different policy approaches or land-use programmes, weighting ES flows by publics' preferences and comparing weighted ES flows to costs of land-use programmes, this research has suggested the most cost effective programmes that could be implemented with existing institutions. This method is simple, yet provides a holistic approach of combining biophysical assessments with peoples' preferences for assessing different policies, programmes, or projects for their contribution in the provision of ES.

9.4 Strengths, weaknesses and directions for future research

The main output of the research is that it shows how one can use readily available GIS data (climate, vegetation, soils, etc.) together with biophysical models to evaluate flows of ES from different land uses. This approach can be used by regional and district councils to quantify flows of ES in alternative land uses. By adopting a method of normalising ES flows and then integrating them with public's preferences (ES weights), the research has illustrated how a non-monetised method can be used to assess the contributions of different land-use programmes in the provision of ES. This method is useful for the evaluation of regulating and cultural ES which are difficult to quantify in monetary terms. Further, unlike in the past when Regional and District Councils had few if any estimates of ES impacts when deciding whether or not to allow plantation forestry in catchments for example, these organisations can now obtain estimates not just of provisioning ES but also regulating and cultural ES. The increasing number of concerns amongst the public in land and water related forums and meetings in Canterbury points towards a need to adopt a holistic approach that integrates not only biophysical dimension but also social and cultural dimension of ES. The method adopted and outcomes found in this research might also help in the sustainable management and utilisation of ES which are crucial for the country's economy and wellbeing.

This research has used AHP as well as Max100 methods to determine the publics' preferences for ES provided by natural systems in Canterbury. The Max100 method was not previously used to calculate peoples' preferences for ES in New Zealand context and the use of AHP was found in calculating preferences of experts and stakeholder representatives in the Ophi river case in Canterbury. The results showed that Max 100 method in particular, is straightforward and easy to use as compared to the AHP. The latter approach (or method) is complex and often suffers from inconsistencies as it is difficult for people to maintain transitivity while making comparisons of each ES with all ES under consideration. In future work one may explore the use of hybrid methods, such as, combining AHP with participatory methods or a more advanced form of AHP, called Analytical Network Process (ANP), which involves interactions and dependencies between the clusters and between the elements within clusters (Saaty, 2008). It is useful in scenarios where decision problems cannot be structured hierarchically because they involve interactions and dependence of higher-level elements on lower-level elements (Saaty, 2008). Other methods to consider include outranking methods, namely, Elimination and Choice Expressing Reality (ELECTRE) and preference ranking organization method for enrichment of evaluations PROMETHE for estimating peoples' preferences for ES.

The main limitations of the research is it has assessed flows of six ES, leaving behind other important ES, such as, aesthetic values, heritage values, recreational values, air quality regulation and disease and pest regulation. This was due to non-availability of methods for quantifying changes in flows of cultural ES. A previous researcher has already assessed values of all ES from plantation forests in New Zealand (RivasPalma, 2008). Future research can explore using multi-criteria analysis with economic and/or non-economic methods or both so that strengths of these methods can be broaden up.

Public preferences for ES were collected in the Agriculture and Pastoral show and the researcher's personal experience suggests that though it offers an advantage to directly communicate with respondents, the flapping of tents and people in a hurry at the show may have contributed to the high level of inconsistent responses (48 out of 80 in the AHP survey) and invalid responses (26 out of 80 in Max100 survey). The aforementioned scenario or limitation suggested that shows may not be ideal for collecting public preferences. By asking people to complete internet based surveys at their convenience one would increase the number of valid responses as this approach would provide more time for participants to understand the questions and complete the survey appropriately.

As the landowners' costs of involvement in the ETS, ECFP, and QE II Trust schemes were based on information provided by landowners and few forestry consultants, it is possible that the costs figure derived in the research are not accurate. Further, the costs for government of running these programmes were also collected from personal communications which could have been a source of small errors.

It is worthwhile to note that this research used biophysical models developed in New Zealand for estimating flows of ES in different land-use and they required running separate tools, such as, WATYIELD, NZeem®, CLUES, and benefit function. Future research can explore the research problem in a greater depth by using more advanced decision making tools, such as, InVest (developed by Stanford University, US) for mapping or valuing ES in New Zealand context. It usually involves a suite of software models which produce results in either biophysical terms or economic terms. However, before this tool can be applied in New Zealand context, it needs to be calibrated to suit the country's biophysical, socio-economic, and cultural conditions. This research has assessed some of co-benefits of afforestation, without monetising them all. Future research should consider including all ES using monetary or non-monetary measures or a combination of these methods. Use of land optimisation models together with multi-criteria analysis can help resource managers to decide which type of land use to promote in the catchment, and where, so that ES benefits are maximised.

9.5 Conclusions

The field of ecosystem services research is growing due to two reasons. One, about two thirds of world's ES have been severely degraded (MEA, 2005) and if this trend is unchecked, it will have serious repercussions on the livelihood of majority of people who directly or indirectly depend on flows of ES. Second, due to public good characteristics of many ES, there is need to find alternative ways of protecting, conserving or enhancing ES at minimum social costs. This is because establishing ES markets are complex and difficult. In this regard, this research studied limited or single focus land-use programmes as these programmes provide broad ecosystem services outcomes. The results of the study show that it makes sense to implement limited focus land-use programmes as they provide broad ES outcomes and are easy to implement with the existing institutions. However, it is economical to implement market based approaches such as the ETS than grant based approaches such as ECFP as grants are very costly and not so effective in treating target land as seen in the case of ECFP. Thus, it is important that all the alternate land-use programmes be assessed for their contribution in the provision of ES and compared to costs of running those programmes. This will show which programme can deliver greatest ES benefits at minimum costs. The costs calculated in this research are indicative only and there is an urgent need of a detailed cost effectiveness analysis of all the land-use programmes available in the country. The government can, then implement the most cost effective land-use programme for enhancing ES that ultimately benefits all.

References

Alho, J. M., Kangas, J., & Kolehmainen, O. (1996). Uncertainty in Expert Predictions of the Ecological Consequences of Forest Plans. *Applied Statistics, 45*(1), 1-14

Allen, R. B., Platt, K. H., & Coker, R. E. J. (1995). Understorey species composition patterns in a Pinus radiata plantation on the central North Island volcanic plateau, New Zealand. *25*(3), 301-317.

Ananda, J., & Herath, G. (2003). The use of Analytic Hierarchy Process to incorporate stakeholder preferences into regional forest planning. *Forest Policy and Economics, 5*(1), 13-26.

Ananda, J., & Herath, G. (2005). Evaluating public risk preferences in forest land-use choices using multi-attribute utility theory. *Ecological Economics, 55*(3), 408-419. doi:http://dx.doi.org/10.1016/j.ecolecon.2004.12.015

Ananda, J., & Herath, G. (2006). Analysis of forest policy using multi-attribute value theory. In G. Herath & T. Prato (Eds.), *Using multi-criteria decision analysis in natural resource management* (pp. 13): Ashgate Publishing Limited, England.

Ananda, J., & Herath, G. (2009). A critical review of multi-criteria decision making methods with special reference to forest management and planning. *Ecological Economics, 68*(10), 2535-2548.

Anastasiadis, S., & Kerr, S. (2013). *Land use and farming intensity: For 1996, 2008 and 2020.* Retrieved from http://www.motu.org.nz/assets/Documents/our-work/environment-and-resources/lurnz/Land-Use-and-Farming-Intensity-For-1996-2008-and-2020.pdf

Arrow, K. J. (1950). A Difficulty in the Concept of Social Welfare. *Journal of Political Economy, 58*(4), 328-346. doi:10.2307/1828886

Ash, N., Blanco, H., Brown, C., Garcia, K., Henrichs, T., Lucas, N., . . . Zurek, M. (2010). *Ecosystems and Human Well-Being: A Manual for Assessment Practitioners*. Retrieved from http://www.unep-wcmc.org/C87C3B76-06D2-4AAA-BF7E-952132DE6ACD/FinalDownload/DownloadId-263E63B2BA7F2937C1054648D6FBD62E/C87C3B76-06D2-4AAA-BF7E-952132DE6ACD/medialibrary/2010/10/31/90af3045/EcosystemsHumanWellbeing.pdf

Asquith, N. M., Vargas, M. T., & Wunder, S. (2008). Selling two environmental services: In-kind payments for bird habitat and watershed protection in Los Negros, Bolivia. *Ecological Economics, 65*(4), 675-684. doi:http://dx.doi.org/10.1016/j.ecolecon.2007.12.014

Auckland Council. (2014). *The Auckland Plan*. Retrieved from http://theplan.theaucklandplan.govt.nz/aucklands-environment/

Ausseil, A.-G. E., & Dymond, J. R. (2010). *Evaluating ecosystem services of afforestration on erosion-prone land: A case study in the Manawatu Catchmanet, New Zealand*. Paper presented at the meeting of the International Congress on Environmental Modelling and Software, Ottawa, Canada.

Ausseil, A.-G. E., Dymond, J. R., & Weeks, E. S. (2011). Provision of Natural Habitat for Biodiversity: Quantifying Recent Trends in New Zealand. In O. Grillo & G. Venora (Eds.), *Biodiversity Loss in a Changing Planet*. Rijeka, Croatia: InTech. Retrieved from http://www.intechopen.com/books/biodiversity-loss-in-a-changing-planet/provision-of-natural-habitat-for-biodiversity-quantifying-recent-trends-in-new-zealand

Barbier, E. B., & Heal, G. M. (2006). Valuing ecosystem services. *The Economists's Voice, 3*(3). Retrieved from http://www.bepress.com/cgi/viewcontent.cgi?context=http%3A%2F%2Fwww.bepress.com%2Fev&article=1118&date=&mt=MTI5OTU0NDU2Nw%3D%3D%0D%0A&access_ok_form=Continue

Barkmann, J., Glenk, K., Keil, A., Leemhuis, C., Dietrich, N., Gerold, G., & Marggraf, R. (2008). Confronting unfamiliarity with ecosystem functions: The case for an ecosystem service approach to environmental valuation with stated preference methods. *Ecological Economics, 65*(1), 48-62.

Baskaran, R., Cullen, R., & Colombo, S. (2009). Estimating values of environmental impacts of dairy farming in New Zealand. *New Zealand Journal of Agricultural Research, 52*(4), 377-389.

Bateman, I. J., Carson, R. T., Day, B., Hanemann, M., Hanley, N., Hett, T., . . . Swanson, J. (2002). *Economic valuation with stated preference techniques: a manual*. Cheltenham, UK: Edward Elgar.

Bateman, I. J., Harwood, A. R., Mace, G. M., Watson, R. T., Abson, D. J., Andrews, B., . . . Termansen, M. (2013). Bringing Ecosystem Services into Economic Decision-Making: Land Use in the United Kingdom. *Science, 341*(6141), 45-50. doi:10.1126/science.1234379

Bayfield, M. A., & Meister, A. D. (2005). *East Coast Forestry Project Review*. Retrieved from http://www.mpi.govt.nz/news-resources/publications

Belton, V., & Gear, T. (1983). On a short-coming of Saaty's method of analytic hierarchies. *Omega, 11*(3), 228-230.

Belton, V., & Stewart, T. J. (2002). *Multiple Criteria Decision Analysis: An Integrated Approach*. London: Kluwer Academic Publishers.

Bennett, J., Morrison, M. D., Blamey , R. K., & Louviere, J. J. (1996). *A comparison of stated preference techniques for estimating environmental values* (1). Canberra: School of Economics and Management, The University of New South Wales. Retrieved from http://www.crawford.anu.edu.au/pdf/staff//jeff_bennett/chmdrr01.pdf

Bergin, D. O., & Kimberley, M. O. (1995). Protective value of regenerating tea tree stands on erosion-prone hill country, East Coast, North Island, New Zealand. *New Zealand Journal of Forestry Science, 25*(1), 3-19.

Bergin, D. O., Kimberley, M. O., & Marden, M. (1991). How soon does regenerating scrub control erosion. *New Zealand Journal of Forestry, 36*(3), 21-22.

Berndt, L. A., Brockerhoff, E. G., & Jactel, H. (2008). Relevance of exotic pine plantations as a surrogate habitat for ground beetles (Carabidae) where native forest is rare. *Biodiversity Conservation, 17*(5), 1171–1185.

Bishop, R. C. (1993). Economic Efficiency, Sustainability, and Biodiversity. *Ambio, 22*(2/3), 69-73. doi:10.2307/4314049

Borkin, K. M., & Parsons, S. (2010). The importance of exotic plantation forest for the New Zealand long-tailed bat (Chalinolobus tuberculatus). *New Zealand Journal of Zoology 37*(1), 35-51.

Bosch, J. M., & Hewlett, J. D. (1982). A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. *Journal of Hydrology, 55*(1-4), 3-23.

Bottomley, P. A., & Doyle, J. R. (2001). A comparison of three weight elicitation methods: good, better, and best. *Omega, 29*(6), 553-560.

Boyd, J., & Banzhaf, S. (2007). What are ecosystem services? The need for standardized environmental accounting units. *Ecological Economics, 63*(2-3), 616-626. doi:10.1016/j.ecolecon.2007.01.002

Braat, L. C., & de Groot, R. (2012). The ecosystem services agenda:bridging the worlds of natural science and economics, conservation and development, and public and private policy. *Ecosystem Services, 1*(1), 4-15. doi:http://dx.doi.org/10.1016/j.ecoser.2012.07.011

Brockerhoffa, E. G., Ecroydb, C. E., Leckiea, A. C., & Kimberley, M. O. (2003). Diversity and succession of adventive and indigenous vascular understorey plants in Pinus radiata plantation forests in New Zealand. *Forest Ecology and Management, 185*(3), 307-326.

Buchanan, A. (2007). Energy and CO2 Advantages of Wood for Sustainable Buildings. *New Zealand Timber Design Journal, 15*(1), 11-21.

Canterbury Mayoral Forum. (2009). *Canterbury water management strategy: Strategic framework*. Retrieved 01/08/2011, from http://ecan.govt.nz/publications/Plans/cw-canterbury-water-wanagement-strategy-05-11-09.pdf

Carpenter, S. R., Mooney, H. A., Agard, J., Capistrano, D., DeFries, R. S., Díaz, S., . . . Whyte, A. (2009). Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. *Proceedings of the National Academy of Sciences, 106*(5), 1305-1312. doi:10.1073/pnas.0808772106

Carswell, F. E., Burrows, L. E., Hall, G. M. J., Mason, N. W. H., & Allen, R. B. (2012). Carbon and plant diversity gain during 200 years of woody succession in lowland New Zealand. *New Zealand Journal of Ecology, 36*(2), 191-202.

Cawsey, E. M., & Freudenberger, D. (2008). Assessing the biodiversity benefits of plantations: The plantation biodiversity benefits score. *Ecological Management and Restoration, 9*(1), 42-55.

Chan, K. M. A., Shaw, M. R., Cameron, D. R., Underwood, E. C., & Daily, G. C. (2006). Conservation planning for ecosystem services. *PLoS Biology, 4*(11), e379.

Chand, N. B. (2011). *Production Efficiency of Community Forestry in Nepal : A Stochastic Frontier Analysis*. Lincoln University, Lincoln, Canterbury. Retrieved from http://researcharchive.lincoln.ac.nz/dspace/bitstream/10182/3770/3/Chand_PhD.pdf

Chee, Y. E. (2004). An ecological perspective on the valuation of ecosystem services. *Biological Conservation, 120*(4), 549-565.

Christchurch City Council. (2007). *Banks Peninsula Landscape Study: Final Report*. Retrieved from http://resources.ccc.govt.nz/files/BanksPeninsulaLandscapeStudyFinalReport-9May2007.pdf

Christie, M., Fazey, I., Cooper, R., Hyde, T., Deri, A., Hughes, L., . . . Reyers6., B. (2008). *An Evaluation of Economic and Non-economic Techniques for Assessing the Importance of Biodiversity to People in Developing Countries*. Retrieved25/10/2010, from http://randd.defra.gov.uk/Document.aspx?Document=WC0709_7562_FRP.pdf

Clark, D. A., Caradus, J. R., Monaghan, R. M., Sharp, P., & Thorrold, B. S. (2007). Issues and options for future dairy farming in New Zealand. *New Zealand Journal of Agricultural Research, 50*(2), 203-221.

Clout, M. N., & Gaze, P. D. (1984). Effects of Plantation Forestry on Birds in New Zealand. *Journal of Applied Ecology, 21*(3), 795-815.

Coleman, D. (2009). *Whangarei District Ecosystem Services Background Report*. Retrieved from http://www.wdc.govt.nz/PlansPoliciesandBylaws/Plans/SustainableFutures/Documents/Sustainable%20Environment/30-50-ecosystem-service-final-report-background.pdf

Colombo, S., Angus, A., Morris, J., Parsons, D. J., Brawn, M., Stacey, K., & Hanley, N. (2009). A comparison of citizen and "expert" preferences using an attribute-based approach to choice. *Ecological Economics, 68*(11), 2834-2841. doi:10.1016/j.ecolecon.2009.06.001

Connor, E. F., & McCoy, E. D., &. (2001). *Species–area Relationships* [Encyclopaedia of Biodiversity]. San Diego: Academic Press.

Cook, A. (2008). *Public opinion on freshwater issues and management in Canterbury* (309). Lincoln: AERU, Lincoln University.

Coomes, D. A., Allen, R. B., Scott, N. A., Goulding, C., & Beets, P. (2002). Designing systems to monitor carbon stocks in forests and shrublands. *Forest Ecology and Management, 164*(1–3), 89-108. doi:http://dx.doi.org/10.1016/S0378-1127(01)00592-8

Cullen, R., Fairburn, G. A., & Hughey, K. F. D. (1999). COPY: A new technique for evaluation of biodiversity protection projects. *Pacific Conservation Biology, 5*(2).

Cullen, R., Moran, E., & Hughey, K. F. D. (2005). Measuring the success and cost effectiveness of New Zealand multiple-species projects to the conservation of threatened species. *Ecological Economics, 53*(3), 311-323. doi:http://dx.doi.org/10.1016/j.ecolecon.2004.09.014

Daily, G. C. (1997). Introduction: what are ecosystem services. In G. C. Daily (Ed.), *Nature's Services: Societal Dependence on Natural Ecosystems* (pp. 1-10): Island Press, Washington.

Daily, G. C., Polasky, S., Goldstein, J., Kareiva, P. M., Mooney, H. A., Pejchar, L., . . . Shallenberger, R. (2009). Ecosystem services in decision making: time to deliver. *Frontiers in Ecology and the Environment, 7*(1), 21-28.

DairyNZ. (2012). *New Zealand Dairy Statistics 2011/12*. Retrieved 2013/01/12, from http://www.dairynz.co.nz/file/fileid/45159

Daly, H. E., & Farley, J. (2004). *Ecological economics: principles and applications* (1st ed.): Washington DC, Island Press.

Dasgupta, P. (2002). Economic development, environmental degradation, and the persistence of deprivation in poor countries Symposium conducted at the meeting of the World summit on sustainable development, Johannesburg.

Davie, T. (n.d.). *Submissions relating to Chapter 5 : Water Quantity in the proposed Canterbury Natural Resources Regional Plan (NRRP)*.

Davie, T., & Fahey, B. (2005). Forestry and water yield - current knowledge and further work. *New Zealand Journal of Forestry, 49*(4), 3-8.

de Groot, R., Alkemade, R., Braat, L., Hein, L., & Willemen, L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity, 7*(3), 260-272.

de Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., . . . van Beukering, P. (2012). Global estimates of the value of ecosystems and their services in monetary units. *Ecosystem Services, 1*(1), 50-61. doi:http://dx.doi.org/10.1016/j.ecoser.2012.07.005

de Groot, R., Wilson, M. A., & Boumans, R. M. J. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics, 41*(3), 393-408.

Department of Environment and Primary Industries. (n.d., 2011-04-27). *Radiata pine: Planning and establishment*. Retrieved 2013-11-08, from http://www.dpi.vic.gov.au/forestry/private-land-forestry/planning-and-design/radiata-pine-planning-and-establishment

Dhakal, B., Bigsby, H., & Cullen, R. (2008). Determinants of Forestry Investment and Extent of Forestry Expansion by Smallholders in New Zealand. *Review of Applied Economics 4*(1-2), 65-76.

Diamond, J. M. (2005). *Collapse: How Societies Choose to Fail or Succeed*: New York: Viking.

Dobbs, C., Escobedo, F. J., & Zipperer, W. C. (2011). A framework for developing urban forest ecosystem services and goods indicators. *Landscape and Urban Planning, 99*(3-4), 196-206. doi:10.1016/j.landurbplan.2010.11.004

Dons, A. (1986). The effect of large-scale afforestation on Tarawera river flows. *Journal of Hydrology (New Zealand), 25*(2), 61-73.

Duke, J. M., & Aull-Hyde, R. (2002). Identifying public preferences for land preservation using the analytic hierarchy process. *Ecological Economics, 42*(1–2), 131-145. doi:http://dx.doi.org/10.1016/S0921-8009(02)00053-8

Duke, J. M., Ilvento, T. W., & Hyde, R. A. (2002). *Public Support for Land Preservation: Measuring Relative Preferences in Delaware*. Newark: Department of Food and Resource Economics, University of Delaware. Retrieved from http://www.udel.edu/FREC/PUBS/RR02-01.pdf

Duncan, M. J. (1995). Hydrological impacts of converting pasture and gorse to pine plantation, and forest harvesting. *Journal of hydrology (NZ), 34*, 15-41.

Dyer, J. S. (1990). Remarks on the Analytic Hierarchy Process. *Management Science, 36*(3), 249-258.

Dymond, J. R., Ausseil, A.-G. E., Ekanayake, J. C., & Kirschbaum, M. U. F. (2012). Tradeoffs between soil, water, and carbon – A national scale analysis from New Zealand. *Journal of Environmental Management, 95*(1), 124-131.

Dymond, J. R., Ausseil, A.-G. E., & Overton, J. M. (2008). A landscape approach for estimating the conservation value of sites and site-based projects, with examples from New Zealand. *Ecological Economics, 66*(2-3), 275-281.

Dymond, J. R., Ausseil, A.-G. E., Shepherd, J. D., & Buettner, L. (2006). Validation of a regionwide model of landslide susceptibility in the Manawatu-Wanganui region of New Zealand. *Geomorphology, 74*, 70-79.

Dymond, J. R., Betts, H. D., & Schierlitz, C. S. (2010). An erosion model for evaluating regional land-use scenarios. *Environmental Modelling & Software, 25*(3), 289-298.

Ekanayake, J. C., Marden, M., Watson, A. J., & Rowan, D. (1997). Tree roots and slope stability: A comparison between Pinus radiata and Kanuka. *New Zealand Journal of Forestry Science, 27*(2), 216-233

Fahey, B. (1994). The effect of plantation forestry on water yield in New Zealand. *New Zealand Journal of Forestry, 39*(3), 18-25.

Fahey, B., Ekanayake, J., Jackson, R., Fenemor, A., Davie, T., & Rowe, L. (2010). Using the WATYIELD water balance model to predict catchment water yields and low flows. *Journal of Hydrology (NZ), 49*(1), 35-58.

Fahey, B., Jackson, R., & Davie, T. (2004). *User's guide for the land use change water balance model (WATYIELD)* (LC0203/185). Retrieved from http://icm.landcareresearch.co.nz/knowledgebase/publications/public/Watyield_Users_guide.pdf

Fahey, B., Marden, M., & Phillips, C. J. (2003). Sediment yields from a plantation forestry and pastoral farming, coastal Hawke's Bay. *New Zealand Journal of Hydrology, 42*(1), 27-38.

FAO. (2010). *Global forest resources assessment 2010: Key findings*. Retrieved 16/05/2011, from http://foris.fao.org/static/data/fra2010/KeyFindings-en.pdf

FAO. (2012). FAOSTAT. from Food and Agriculture Organization of the United Nations http://faostat3.fao.org/home/index.html#DOWNLOAD

Farley, J. (2012). Ecosystem services: The economics debate. *Ecosystem Services, 1*(1), 40-49. doi:http://dx.doi.org/10.1016/j.ecoser.2012.07.002

Fernandes, L., Ridgley, M. A., & van't Hof, T. (1999). Multiple criteria analysis integrates economic, ecological and social objectives for coral reef managers. *Coral Reefs, 18*(4), 393-402.

Fisher, B., Turner, R. K., & Morling, P. (2009). Defining and classifying ecosystem services for decision making. *Ecological Economics, 68*(3), 643-653.

Ford-Robertson, J., Robertson, K., & Maclaren, P. (1999). Modelling the effect of land-use practices on greenhouse gas emissions and sinks in New Zealand. *Environmental Science & Policy, 2*(2), 135-144. doi:http://dx.doi.org/10.1016/S1462-9011(99)00009-X

Funk, J. (2009). *The Practice of Carbon Farming in New Zealand*. Stanford University, Palo Alto, California. Retrieved from http://www.motu.org.nz/files/docs/MEL0499_Funk_thesis_Ch1.pdf

Gómez-Baggethun, E., Groot, R. d., Lomas, P. L., & Montes, C. (2010). The history of ecosystem services in economic theory and practice: From early notions to markets and payment schemes. *Ecological Economics, 69*(6), 1209-1218.

Gordon, L. J., Finlayson, C. M., & Falkenmark, M. (2010). Managing water in agriculture for food production and other ecosystem services. *Agricultural Water Management, 97*(4), 512-519.

Goulding, C. J. (2005). Measurement of trees. In M. Colley (Ed.), *Forestry Handbook* (4th ed., pp. 318). Christchurch, New Zealand: New Zealand Institute of Forestry.

Guria, J., Leung, J., Jones-Lee, M., & Loomes, G. (2005). The Willingness to Accept Value of Statistical Life Relative to the Willingness to Pay Value: Evidence and Policy Implications. *Environmental and Resource Economics, 32*(1), 113-127. doi:10.1007/s10640-005-6030-6

Gürlük, S., & Rehber, E. (2008). A travel cost study to estimate recreational value for a bird refuge at Lake Manyas, Turkey. *Journal of Environmental Management, 88*(4), 1350-1360. doi:10.1016/j.jenvman.2007.07.017

Harrington, K. C., Beskow, W. B., & Hodgson, J. (2011). Recovery and viability of seeds ingested by goats. *New Zealand Plant Protection, 64*, 75-80.

Hart, G., Rutledge, D., & Greenhalgh, S. (2012). *'Ecosystem services' in the proposed Waikato Regional Policy Statement* (TR 2012/41). Retrieved from http://www.waikatoregion.govt.nz/PageFiles/23961/TR201241.pdf

Heal, G., & Barbier, E. B. (2006). Valuing ecosystem services. *Economist's Voice, 3*(3), 1-5.

Hearnshaw, E. J. S. (2009). *A Post-Classical Economics Approach to Ecosystem Management*. Lincoln University. Retrieved from http://researcharchive.lincoln.ac.nz/dspace/bitstream/10182/1425/3/Hearnshaw_PhD.pdf

Hearnshaw, E. J. S., & Cullen, R. (2010, 26-27 August, 2010). *The sustainability and cost-effectiveness of water storage projects on Canterbury rivers: the Ophi river case*. Paper presented at the meeting of the New Zealand Agricultural and Resource Economics Society (Inc.), Nelson, New Zealand. Retrieved from http://ageconsearch.umn.edu/bitstream/97265/2/2010_25_water%20stroage%20projects_Hearnshaw_and_Cullen_NZARES_paper.pdf

Hearnshaw, E. J. S., Cullen, R., & Hughey, K. F. D. (2011). *Ecosystem Services Review of Water Storage Projects in Canterbury: The Opihi River Case*. Christchurch: Environment Canterbury. Retrieved from http://ecan.govt.nz/publications/Plans/cw-ecosystem-services-review-the-opihi-river-case.pdf

Hein, L., van Koppen, K., de Groot, R., & van Ierland, E. C. (2006). Spatial scales, stakeholders and the valuation of ecosystem services. *Ecological Economics, 57*(2), 209-228.

Henkens, R. J. H. G., Tassone, V. C., Grafakos, S., de Groot, R., & Luttik, J. (2007). *A participatory decision support tool to access costs and benefits or tourism development scenarios : application of the ADAPTIVE model to Greater Giyani, South Africa*. Retrieved from http://edepot.wur.nl/23348

Herath, G. (2004). Incorporating community objectives in improved wetland management: the use of the analytic hierarchy process. *Journal of Environmental Management, 70*(3), 263-273.

Hewlett, J. D., & Hibbert, A. R., &. (1967). *Factors affecting the response of small watersheds to precipitation in humid areas*: Cornell University.

Hicks, D. L. (1985). Erosion under pasture, pine plantaions, scrub and indigenous forest: a comparison from Cyclone Bola. *New Zealand Journal of Forestry, 30*(1), 144-158.

Horgan, G. (2007). *Financial returns and forestry planting rates*. Retrieved from www.maf.govt.nz/climatechange/forestry/ets/returns/returns-and-new-planting-rates.pdf

Hostmann, M., Bernauer, T., Mosler, H.-J., Reichert, P., & Truffer, B. (2005). Multi-attribute value theory as a framework for conflict resolution in river rehabilitation. *Journal of Multi-Criteria Decision Analysis, 13*(2-3), 91-102.

Hougner, C., Colding, J., & Söderqvist, T. (2006). Economic valuation of a seed dispersal service in the Stockholm National Urban Park, Sweden. *Ecological Economics, 59*(3), 364-374.

Howard, A. F., & Nelson, J. D. (1993). Area-based harvest scheduling and allocation of forest land using methods for multiple-criteria decision making *Canadian Journal of Forest Research, 23*(2), 151-158.

Howarth, R. B., & Farber, S. (2002). Accounting for the value of ecosystem services. *Ecological Economics, 41*(3), 421-429.

Hughey, K. F. D., Kerr, G. N., & Cullen, R. (2008). *Public perceptions of New Zealand's environment: 2008*: Lincoln University.

Huser, B., McDonald, G., Phyn, D., Hurkens, J., Delden, H. v., Rutledge, D. T., & Simmons, J. (2012). Land use change from pastoral farming to carbon forestry: Identifying trade-offs between ecosystem services using economic-ecological spatial modelling. In R. Seppelt, A. A. Voinov, S. Lange & D. Bankamp (Chair), Symposium conducted at the meeting of the Managing Resources of a Limited Planet: Pathways and Visions under Uncertainty, Leipzig, Germany. Retrieved from http://www.iemss.org/sites/iemss2012//proceedings/iEMSs2012_proceedings

Hutcheson, J., & Jones, D. (1999). Spatial variability of insect communities in a homogenous system: Measuring biodiversity using Malaise trapped beetles in a Pinus radiata plantation in New Zealand. *Forest Ecology and Management, 118*(1-3), 93-105.

IPCC. (2003). *Good Practice Guidance for Land Use, Land-Use Change and Forestry*. Retrieved from http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/GPG_LULUCF_FULL.pdf

Ishizaka, A., & Labib, A. (2009). Analytic Hierarchy Process and Expert Choice: Benefits and limitations. *Insight, 22*(4), 201-220. doi:doi:10.1057/ori.2009.10

Ishizaka, A., & Labib, A. (2011). Review of the main developments in the analytic hierarchy process. *Expert Systems with Applications, 38*(11), 14336-14345.

Jack, B. K., Kousky, C., & Sims, K. R. E. (2008). Designing payments for ecosystem services: Lessons from previous experience with incentive-based mechanisms. *Proceedings of the National Academy of Sciences, 105*(28), 9465-9470.

Jackson, R. B., Jobbagy, E. G., Avissar, R., Roy, S. B., Barrett, D. J., Cook, C. W., . . . Murray, B. C. (2005). Trading Water for Carbon with Biological Carbon Sequestration. *Science, 310*(5756), 1944-1947.

Jackson, R. W. (1971). Birds in Exotic Forests in New Zealand. *New Zealand Journal of Forestry, 16*(1), 61–68.

Jim, C. Y., & Chen, W. Y. (2009). Value of scenic views: Hedonic assessment of private housing in Hong Kong. *Landscape and Urban Planning, 91*(4), 226-234. doi:10.1016/j.landurbplan.2009.01.009

Johnson, P., & Gereaux, P. (2004). *Wetland types of New Zealand*. Retrieved 04/08/2010, from http://www.doc.govt.nz/upload/documents/science-and-technical/WetlandsBW.pdf

Jowett, I. G., & Duncan, M. J. (1990). Flow variability in New Zealand rivers and its relationship to in-stream habitat and biota. *New Zealand Journal of Marine and Freshwater Research, 24*(3), 305-317.

Kahneman, D., Knetsch, J. L., & Thaler, R. H. (1990). Experimental Tests of the Endowment Effect and the Coase Theorem. *Journal of Political Economy, 98*(6), 1325-1348. doi:10.2307/2937761

Kaiser, B., & Roumasset, J. (2002). Valuing indirect ecosystem services: the case of tropical watersheds. *Environment and Development Economics, 7*(04), 701-714.

Kangas, J. (1993). A multi-attribute preference model for evaluating the reforestation chain alternatives of a forest stand. *Forest Ecology and Management, 59*(3–4), 271-288. doi:http://dx.doi.org/10.1016/0378-1127(93)90007-A

Kangas, J. (1994). An approach to public participation in strategic forest management planning. *Forest Ecology and Management, 70*(1-3), 75-88. doi:10.1016/0378-1127(94)90076-0

Kangas, J., & Kangas, A. (2005). Multiple criteria decision support in forest management--the approach, methods applied, and experiences gained. *Forest Ecology and Management, 207*(1-2), 133-143. doi:10.1016/j.foreco.2004.10.023

Kangas, J., & Kuusipalo, J. (1993). Integrating biodiversity into forest management planning and decision-making. *Forest Ecology and Management, 61*(1-2), 1-15.

Kangas, J., & Pukkala, T. (1996). Operationalization of biological diversity as a decision objective in tactical forest planning. *Canadian Journal of Forest Research, 26*(1), 103-111

Kangas, J., Store, R., Leskinen, P., & Mehtätalo, L. (2000). Improving the quality of landscape ecological forest planning by utilising advanced decision-support tools. *Forest Ecology and Management, 132*(2-3), 157-171.

Kemkes, R. J., Farley, J., & Koliba, C. J. (2010). Determining when payments are an effective policy approach to ecosystem service provision. *Ecological Economics, 69*(11), 2069-2074. doi:http://dx.doi.org/10.1016/j.ecolecon.2009.11.032

Kimmberly, M., West, G., Dean, M., & Knowles, L. (2005). The 300 Index - a volume productivity index for radiata pine. *New Zealand Journal of Forestry, 50*(2), 13-18.

Kremen, C., Williams, N. M., & Thorp, R. W. (2002). Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences of the United States of America, 99*(26), 16812-16816.

Kroeger, T., & Casey, F. (2007). An assessment of market-based approaches to providing ecosystem services on agricultural lands. *Ecological Economics, 64*(2), 321-332.

Kumar, M., & Kumar, P. (2008). Valuation of the ecosystem services: A psycho-cultural perspective. *Ecological Economics, 64*(4), 808-819.

Kuusipalo, J., Kangas, J., & Vesa, L. (1997). Sustainable Forest Management in Tropical Rain Forests. *Journal of Sustainable Forestry, 5*(3), 93-118.

Lara, A., Little, C., Urrutia, R., McPhee, J., Álvarez-Garretón, C., Oyarzún, C., . . . Arismendi, I. (2009). Assessment of ecosystem services as an opportunity for the conservation and management of native forests in Chile. *Forest Ecology and Management, 258*(4), 415-424.

Larned, S. T., Scarsbrook, M. R., Snelder, T. H., Norton, N. J., & c, B. J. F. B. (2004). Water quality in low-elevation streams and rivers of New Zealand: Recent state and trends in contrasting land-cover classes. *New Zealand Journal of Marine and Freshwater Research 38*(2), 347-366

Layke, C. (2009). Measuring nature's benefits: A prelliminary roadmap for improving ecosystem service indicators. . Retrieved 05-10-2010, from World Resources Institute http://pdf.wri.org/measuring_natures_benefits.pdf

Leathwick, J. R., Overton, J. M., & McLeod, M. (2003). An Environmental Domain Classification of New Zealand and Its Use as a Tool for Biodiversity Management. *Conservation Biology, 17*(6), 1612-1623.

Leung, P., Muraoka, J., Nakamoto, S. T., & Pooley, S. (1998). Evaluating fisheries management options in Hawaii using analytic hierarchy process (AHP). *Fisheries Research, 36*(2–3), 171-183. doi:http://dx.doi.org/10.1016/S0165-7836(98)00097-6

Liu, S., Costanza, R., Farber, S., & Troy, A. (2010). Valuing ecosystem services. *Annals of the New York Academy of Sciences, 1185*(1), 54-78. doi:10.1111/j.1749-6632.2009.05167.x

Lloyd, R. C. (1960). Growth Study of Regenerated Kauri and Podocarps in Russel Forest. *New Zealand Journal of Forestry, 8*(2), 355-361.

Løken, E. (2007). Use of multicriteria decision analysis methods for energy planning problems. *Renewable and Sustainable Energy Reviews, 11*(7), 1584-1595.

Loomis, J., Kent, P., Strange, L., Fausch, K., & Covich, A. (2000). Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. *Ecological Economics, 33*(1), 103-117.

Lynn, I., Manderson, A., Page, M., Harmsworth, G., Eyles, G., Douglas, G., . . . Newsome, P. (2009). *Land use capability survey hand book - a New Zealand handbook for the classification of land* (3rd ed.): AgResearch Ltd, Landcare Research and Institute of Geological and Nuclear Sciences Ltd.

Maclaren, P., Knowles, L., Hansen, L., & Kimberley, M. (2005). *Operating Manual for the Green Solution Radiata Pine Calculator Version 2.1*. Rotorua, New Zealand: Ensis.

Maclaren, P., Manley, B., Andrews, C., Branch, C., Coles, R., Cooper, B., . . . Yang, C. (2008). Impact of the New Zealand Emissions Trading Scheme on forest management. *New Zealand Journal of Forestry, 53*(33-39).

Manley, B., & Maclaren, P. (2009). Modelling the impact of carbon trading legislation on New Zealand's plantation estate. *New Zealand Journal of Forestry, 54*(1), 39-44.

Manley, B., & Maclaren, P. (2012). Potential impact of carbon trading on forest management in New Zealand. *Forest Policy and Economics, 24*(0), 35-40. doi:http://dx.doi.org/10.1016/j.forpol.2010.01.001

Marcar, N., Theiveyanathan, T., Roxburgh, S., Gilfedder, M., Littleboy, M., Almeida, A., . . . Benyon, R. (22-07-2014). *Methodology to assess site-specific impacts of plantations on catchment water yields*. Retrieved from http://www.clw.csiro.au/publications/waterforahealthycountry/2010/wfhc-plantations-site-impacts.pdf

Marsden, M. (2004). Future-proofing erosion-prone hill country against soil degradation and loss during large storm events: have past lessons been heeded? *New Zealand Journal of Forestry, 49*(3), 11-16.

Martin, G. N. (1973). Characterization of simple exponential baseflow recessions *Journal of Hydrology (New Zealand), 12*(1), 57-62.

Mau-Crimmins, T., de Steiguer, J. E., & Dennis, D. (2005). AHP as a means for improving public participation: a pre–post experiment with university students. *Forest Policy and Economics, 7*(4), 501-514. doi:http://dx.doi.org/10.1016/j.forpol.2003.08.001
Maunder, C., Shaw, W., & Pierce, R. (2005). Indigenous biodiversity and land use-what do exotic plantation forests contribute? *New Zealand Journal of Forestry, 49*(4), 20-26.
Maw, R. K. (2007). *Planning report on the review of the environmental minimum flow and water allocation for Knights Creek, the Halswell River, the LII River, the Kaituna River and Prices Stream.* (U07/61).
McDaniels, T. L. (1996). A Multiattribute Index for Evaluating Environmental Impacts of Electric Utilities. *Journal of Environmental Management, 46*(1), 57-66.
McDaniels, T. L., & Roessler, C. (1998). Multiattribute elicitation of wilderness preservation benefits: a constructive approach. *Ecological Economics, 27*(3), 299-312.
McDaniels, T. L., & Trousdale, W. (2005). Resource compensation and negotiation support in an aboriginal context: Using community-based multi-attribute analysis to evaluate non-market losses. *Ecological Economics, 55*(2), 173-186. doi:10.1016/j.ecolecon.2005.07.027
McDonald, G., Patterson, G., & Economics, N. Z. C. f. E. (2008). *Canterbury Region's "hidden" Economy: Assessing the Value of the Region's Ecosystem Services and Biodiversity*: New Zealand Centre for Ecological Economics. Retrieved from http://books.google.co.nz/books?id=IZ-3tgAACAAJ
MEA. (2003). *Ecosystems and human well-being: A framework for assessment*. Washington, D.C.: Island Press. Retrieved from http://www.maweb.org/en/Framework.aspx
MEA. (2005). *Ecosystems and Human Wellbeing: Synthesis*. Washington DC: Island Press.
Ministry for Primary Industries. (2011). *A Guide to Forestry in the Emissions Trading Scheme* Retrieved from http://www.mpi.govt.nz/news-resources/publications
Ministry for Primary Industries. (2012). *National Exotic Forest Description as at 1 April 2012*. Wellington: Ministry for Primary Industries.
Ministry for Primary Industries. (2014a). *East Coast Forestry Project: Changes to Administration* Retrieved from http://www.treasury.govt.nz/publications/informationreleases/ris/pdfs/ris-mpi-ecfp-jul14.pdf
Ministry for Primary Industries. (2014b). *Erosion Control Funding Programme - Questions and Answers July 2014*. Retrieved from https://www.mpi.govt.nz/funding-and-programmes/forestry/erosion-control-funding-programme/
Ministry for the Environment. (2003). New Zealand Land Cover Database Version 2: Illustrated Guide to Target Classes. from Ministry for the Environment http://www.mfe.govt.nz/issues/land/land-cover-dbase/illustrated-classes-lcdb2-part1.pdf
Ministry for the Environment. (2007a). *Protecting our Places - Information about the national priorities for protecting rare and threatened native biodiversity on private land*. Retrieved from https://www.biodiversity.govt.nz/pdfs/protecting-our-places-brochure.pdf
Ministry for the Environment. (2007b). *Protecting our Places: Information about the Statement of National Priorities for Protecting Rare and Threatened Biodiversity on Private Land*. Retrieved 2015-08-09, from http://www.doc.govt.nz/Documents/getting-involved/volunteer-or-start-project/funding/biodiversity-funds/protecting-our-places-priorities-detail.pdf
Ministry for the Environment. (2009). *Water Quality in Selected Dairy Farming Catchments: A baseline to support future water-quality trend assessments*. Wellington: Ministry for the Environment (MfE). Retrieved from http://www.mfe.govt.nz/publications/land/water-quality-selected-dairying-farming-catchments/water-quality-selected-dairying-farming-catchments.pdf
Ministry for the Environment. (2010). *New Zealand's Greenhouse Gas Inventory 1990–2008*. Retrieved from http://www.mfe.govt.nz/publications/climate/greenhouse-gas-inventory-2010/greenhouse-gas-inventory-2010.pdf

Ministry for the Environment. (2012a). *Land Use and Carbon Analysis System Satellite Imagery Iinterpretation Guide for Land-use classes (2nd edition)*. Wellington: Ministry for the Environment (MfE). Retrieved from http://koordinates.com/file/283-lucas-satellite-imagery-interpretation-guide-2nd-edition/download/

Ministry for the Environment. (2012b). *Report of the Ministry for the Environment for the Year Ended 30 June 2012*. Retrieved from http://www.mfe.govt.nz/publications/about/annual-report/2011-2012/annual-report.pdf

Ministry for the Environment. (2012c). *Report on the New Zealand Emissions Trading Scheme: NZ ETS 2011–Facts and figures*. Wellington: Ministry for the Environment (MfE). Retrieved from http://www.climatechange.govt.nz/emissions-trading-scheme/building/reports/ets-report/nzets-2011-facts-and-figures-2012.pdf

Ministry for the Environment. (2013a, 2013, September 17). *ETS 2012 – Facts and figures*. Retrieved from http://www.climatechange.govt.nz/emissions-trading-scheme/building/reports/ets-report/ets-2012-facts-and-figures.pdf

Ministry for the Environment. (2013b). *Freshwater reform 2013 and beyond*. Retrieved from http://www.mfe.govt.nz/publications/water/freshwater-reform-2013/freshwater-reform-2013.pdf

Ministry for the Environment. (2014). *Report of the Ministry for the Environment for the year ended 30 June 2014*. Retrieved from http://www.mfe.govt.nz/publications/about-us/report-ministry-environment-year-ended-30-june-2014

Ministry for the Environment. (n.d., 2014-05-20). *Forestry in the Emissions Trading Scheme*. Retrieved from https://www.climatechange.govt.nz/emissions-trading-scheme/participating/forestry/

Ministry of Agriculture and Forestry. (2007). *East Coast Forestry Project Grant Guidelines*. Retrieved 21/08/2010, from http://www.maf.govt.nz/forestry/east-coast-forestry/guidelines/page.htm

Ministry of Agriculture and Forestry. (2008). *Poplar and Willow Planting on Land Overlay 3A Gisborne, East Coast Region*. Retrieved from http://www.mpi.govt.nz/news-resources/publications.aspx?title=Poplar

Ministry of Agriculture and Forestry. (2009a, 22/11/2010). *Grant rates and payment schedule for 2009* Retrieved 10/12/2011, from http://www.mpi.govt.nz/forestry/funding-programmes/east-coast-forestry-project/grant-rates-and-payment-schedule.aspx

Ministry of Agriculture and Forestry. (2009b). *Situation and outlook for New Zealand agriculture and forestry*. Retrieved 10/07/2010, from http://www.maf.govt.nz/mafnet/rural-nz/statistics-and-forecasts/sonzaf/2009/sonzaf-2009.pdf

Ministry of Agriculture and Forestry. (2011a). *Funding programmes*. Retrieved from http://www.maf.govt.nz/forestry/funding-programmes

Ministry of Agriculture and Forestry. (2011b). *A guide to look-up tables for forestry in the emissions trading scheme*. Retrieved 12/04/2011, from http://www.maf.govt.nz/news-resources/publications.aspx?title=A%20guide%20to%20Look-up%20Tables%20for%20the%20Emissions%20Trading%20Scheme

Ministry of Agriculture and Forestry. (2011c). *Review of MAF Afforestation Schemes*. Retrieved from http://www.mpi.govt.nz/news-resources/publications

Moller, H., Macleod, C. J., Haggerty, J., Rosin, C., Blackwell, G., Perley, C., . . . Gradwohl, M. (2008). Intensification of New Zealand agriculture: implications for biodiversity (forum article) *New Zealand Journal of Agricultural Research, 5*(3), 253-263.

Monaghan, R. M., Wilcock, R. J., Smith, L. C., Tikkisetty, B., Thorrold, B. S., & Costall, D. (2007). Linkages between land management activities and water quality in an intensively farmed catchment in southern New Zealand. *Agriculture, Ecosystems & Environment, 118*(1-4), 211-222. doi:10.1016/j.agee.2006.05.016

Montis, A. D., Toro, P. D., DROSTE-FRANKE, B., OMANN, I., & STAGL, S. (2005). Assessing the quality of different MCDA methods. In M. Getzner, C. Spash & S. Stagl (Eds.), *Alternatives for Environmental Valuation* (pp. 298): Routledge UK.

Morgan, M., Bidwell, V., Bright, J., McIndoe, I., & Robb, C. (2002). *Canterbury Strategic Water Study*. Retrieved from http://ecan.govt.nz/publications/Reports/cwms-tech-rpt-stage-1-report.pdf

Munda, G., Nijkamp, P., & Rietveld, P. (1994). Qualitative multicriteria evaluation for environmental management. *Ecological Economics, 10*(2), 97-112.

Muñoz-Piña, C., Guevara, A., Torres, J. M., & Braña, J. (2008). Paying for the hydrological services of Mexico's forests: Analysis, negotiations and results. *Ecological Economics, 65*(4), 725-736. doi:http://dx.doi.org/10.1016/j.ecolecon.2007.07.031

Murlis, J., Fitter, A., Elmqvist, T., Haines-Young, R., Potschin, M., Rinaldo, A., . . . Zobel, M. (2010). *An Assessment of Ecosystem Services and Biodiversity in Europe*. Retrieved from http://www.rsc.org/ebooks/archive/free/BK9781849730181/BK9781849730181-00001.pdf

Mustajoki, J., Hämäläinen, R. P., & Salo, A. (2005). Decision Support by Interval SMART/SWING—Incorporating Imprecision in the SMART and SWING Methods. *Decision Sciences, 36*(2), 317-339.

Myers, N. (1997). The world's forests and their ecosystem services. In G. C. Daily (Ed.), *Nature's Services: Societal Dependence on Natural Ecosystems*: Island Press, Washington.

Naidoo, R., & Ricketts, T. H. (2006). Mapping the economic costs and benefits of conservation. *PLoS Biology, 4*(11), e360.

Namjou, P. (1988). *Hydrogeological and geophysical investigation of the groundwater system in the Kaituna valley, Banks Peninsula*. University of Canterbury, Christchurch. Retrieved from http://ir.canterbury.ac.nz/handle/10092/5554

National Research Council. (2005). *Valuing ecosystem services: toward better environmental decision making*: National academies press: Washington.

Nelson, E., Mendoza, G. A., Regetz, J., Polasky, S., Tallis, H., Cameron, D., . . . Shaw, M. (2009). Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment, 7*(1), 4-11. doi:10.1890/080023

New Zealand Dairy Board, &. (1983). *An Economic survey of factory supply dairy farms in New Zealand*: New Zealand Dairy Board

Newsome, P. F. J., Wilde, R. H., & Willoughby, E. J. (2010). Land Resource Information System Spatial Data Layers. from Landcare Research New Zealand http://lris.scinfo.org.nz/layer/76-nzlri-land-use-capability/#/layer/135-nzlri-south-island-edition-2-all-attributes/

Nijkamp, P., Vindigni, G., & Nunes, P. A. L. D. (2008). Economic valuation of biodiversity: A comparative study. *Ecological Economics, 67*(2), 217-231.

NZ Forest Owners Association. (2013). *Carbon sequestration and emissions trading* Retrieved 04/04/2013, 2013, from http://www.nzfoa.org.nz/plantation-forestry/carbon-sequestration

O'Loughlin, C. (2005). Environmental services provided by plantations. *New Zealand Journal of Forestry, 49*(4), 2.

Ogden, J., Braggins, J., Stretton, K., & Anderson, S. (1997). Plant species richness under Pinus radiata stands on the central North Island Volcanic Plateau, New Zealand. *New Zealand Journal of Ecology, 21*(1), 17-29.

Pagiola, S. (2008). Payments for environmental services in Costa Rica. *Ecological Economics, 65*(4), 712-724. doi:10.1016/j.ecolecon.2007.07.033

Pagiola, S., Ritter, K. v., & Bishop, J. (2004). *Assessing the Economic Value of Ecosystem Conservation*. Retrieved 12/12/2010, from https://www.cbd.int/doc/case-studies/inc/cs-inc-iucn-nc-wb-en.pdf

Parliamentary Counsel Office. (1991, 27 June 2014). *Resource Management Act 1991*. Retrieved from http://www.legislation.govt.nz/act/public/1991/0069/latest/DLM230265.html

Pawson, S. M., Ecroyd, C. E., Seaton, R., Shaw, W. B., & Brockerhoff, E. G. (2010). New Zealand's Exotic Plantation Forests as Habitats for Threatened Indigenous Species. *New Zealand Journal of Ecology, 34*(3), 342-355.

Pearce, D. W., & Turner, R. K. (1990). *Economics of Natural Resources and the Environment*: Harvester Wheatsheaf: Hertfordshire.

Perrings, C. (2009). The economics of ecosystem services. In S. A. Levin (Ed.), *The Princeton guide to Ecology* (pp. 1-809). Princeton: Princeton University Press.

Phillips, C. J., Marden, M., & Pearce, A. (1990). Effectiveness of reforestation in prevention and control of landsliding during large cyclonic storms Symposium conducted at the meeting of the XIX World IUFRO Congress, Montreal, Canada.

Posthumus, H., Rouquette, J. R., Morris, J., Gowing, D. J. G., & Hess, T. M. (2010). A framework for the assessment of ecosystem goods and services; a case study on lowland floodplains in England. *Ecological Economics, 69*(7), 1510-1523.

Prato, T. (2007). Selection and evaluation of projects to conserve ecosystem services. *Ecological Modelling, 203*(3–4), 290-296.

Pukkala, T., & Miina, J. (1997). A method for stochastic multiobjective optimization of stand management. *Forest Ecology and Management, 98*(2), 189-203.

QEII National Trust. (2010). *QEII National Trust: For open space in New Zealand*. Retrieved from http://www.openspace.org.nz/Site/About_QEII/default.aspx

Quinn, J. M., & Stroud, M. J. (2002). Water quality and sediment and nutrient export from New Zealand hill-land catchments of contrasting land use. *New Zealand Journal of Marine and Freshwater Research, 36*(2), 409-429.

Qureshi, M. E., & Harrison, S. R. (2001). A decision support process to compare Riparian revegetation options in Scheu Creek catchment in North Queensland. *Journal of Environmental Management, 62*(1), 101-112. doi:http://dx.doi.org/10.1006/jema.2001.0422

Rehman, T., & Romero, C. (1993). The application of the MCDM paradigm to the management of agricultural systems: Some basic considerations. *Agricultural Systems, 41*(3), 239-255.

Ricketts, T. H., Daily, G. C., Ehrlich, P. R., & Michener, C. D. (2004). Economic value of tropical forest to coffee production. *Proceedings of the National Academy of Sciences of the United States of America, 101*(34), 12579-12582.

RivasPalma, R. M. (2008). *Environmental and Social Values from Plantation Forests: A Study in New Zealand with Focus on the Hawke's Bay Region*. University of Canterbury, Christchurch.

Robinson, R. (1993). Cost-effectiveness analysis. *BMJ, 307*(6907), 793-795. Retrieved from http://www.bmj.com/content/307/6907/793.pdf%2Bhtml

Rodríguez, J. P., Beard, J. T. D., Bennett, E. M., Cumming, G. S., Cork, S. J., Agard, J., . . . Peterson, G. D. (2006). Trade-offs across Space, Time, and Ecosystem Services. *Ecology and Society, 11*(1 C7 - 28).

Rolfe, J. (2006). A simple guide to choice modelling and benefit transfer. In J. Rolfe & J. Bennett (Eds.), *Choice modelling and the transfer of environmental values* (pp. 260). UK: Edward Elgar Publishing, Inc.

Rossiter, D. G. (2003). Biophysical Models in Land Evaluation. In W. H. Verheye (Ed.), *Encyclopedia of Life Support Systems (EOLSS)* (Vol. II): EOLSS Publishers Co. Ltd. (UK). Retrieved from http://www.itc.nl/~rossiter/Docs/EOLSS_1527_Preprint.pdf

Rowe, L. (2003a). *A comparison of streamflow from New Zealand catchments with different vegetation covers* (6). Retrieved from http://icm.landcareresearch.co.nz/knowledgebase/publications/public/report6.pdf

Rowe, L. (2003b). *Land use and water resources: a comparison of streamflow from New Zealand catchments with different vegetation covers* (LC02032/188). Retrieved from http://icm.landcareresearch.co.nz/knowledgebase/publications/public/report6.pdf

Rowe, L., Jackson, R., & Fahey, B. (2002). *Land Use and Water Resources: Hydrological Effects of Different Vegetation Covers* (LC0203/027): Landcare Research New Zealand Ltd.

Russell, C., Dale, V., Lee, J., Jensen, M. H., Kane, M., & Gregory, R. (2001). Experimenting with multi-attribute utility survey methods in a multi-dimensional valuation problem. *Ecological Economics, 36*(1), 87-108.

Rutledge, D. T., Dymond, J. R., Greenhalgh, S., Ausseil, A.-G. E., Sinclair, R., Herzig, A., . . . Collins, A. (2010, July 5-8, 2010). *Mapping, Modelling and Managing Ecosystems Services in New Zealand*. Paper presented at the meeting of the International Congress on Environmental Modelling and Software, Ottawa, Ontario, Canada

Saaty, T. L. (1990a). An Exposition on the AHP in Reply to the Paper "Remarks on the Analytic Hierarchy Process". *Management Science, 36*(3), 259-268.

Saaty, T. L. (1990b). How to make a decision: The analytic hierarchy process. *European Journal of Operational Research, 48*(1), 9-26. doi:http://dx.doi.org/10.1016/0377-2217(90)90057-I

Saaty, T. L. (1994a). How to make a decision: The analytic hierarchy process. *Interfaces, 24*(6), 19-43.

Saaty, T. L. (1994b). A ratio scale metric and the compatibility of ratio scales: The possibility of arrow's impossibility theorem. *Applied Mathematics Letters, 7*(6), 51-57. doi:http://dx.doi.org/10.1016/0893-9659(94)90093-0

Saaty, T. L. (2001). *Creative thinking, problem solving and decision making* Pittsburgh: RWS Publications.

Saaty, T. L. (2008). The Analytic Hierarchy and Analytic Network Measurement Processes: Applications to Decisions under Risk. *EUROPEAN JOURNAL OF PURE AND APPLIED MATHEMATICS 1*(1), 122-196.

Sage, E. (2008, 11–12 June). *Water management challenges in Canterbury* Paper presented at the meeting of the Conflict in paradise-the transformation of rural New Zealand, Auckland, New Zealand. Retrieved from http://www.edsconference.com/content/docs/papers/Sage%2C%20E.pdf

Salzman, J. (2005). The promise and perils of payments for ecosystem services *International Journal of Innovation and Sustainable Development 1*(1/2), 5-20.

Salzman, J., & Ruhl, J. B. (2000). *Currencies and the Commodification of Environmental Law* Retrieved from http://scholarship.law.duke.edu/cgi/viewcontent.cgi?article=1884&context=faculty_scholarship

Schrobback, P., Adamson, D., & Quiggin, J. (2011). Turning Water into Carbon: Carbon Sequestration and Water Flow in the Murray–Darling Basin. *Environmental and Resource Economics, 49*(1), 23-45. doi:10.1007/s10640-010-9422-1

Scion. (2012). *Waiapu River Catchment Study–Final Report* (15201). Rotorua, New Zealand.

Semadeni-Davies, A., Elliot, S., & Shankar, U. (2011). *The CLUES project: Tutorial manual for CLUES 3.1* (HAM2011-003). Retrieved from ftp://ftp.niwa.co.nz/clues/CLUES%20Manual%20v3.1_21%20March%202011.pdf

Spangenberg, J. H., & Settele, J. (2010). Precisely incorrect? Monetising the value of ecosystem services. *Ecological Complexity, 7*(3), 327-337.

Spash, C. L., Stagl, S., & Getzner, M. (2005). Exploring Alternatives for Environmental Valuation. In M. Getzner, C. L. Spash & S. Stagl (Eds.), *Alternatives for Environmental Valuation* (pp. 1-20). London: Routledge.

Statistics New Zealand. (2012a). *Agricultural Production Statistics: June 2011 (final)*. Retrieved 2012/12/20, from http://www.stats.govt.nz/browse_for_stats/industry_sectors/agriculture-horticulture-forestry/AgriculturalProduction_final_HOTPJun11final.aspx

Statistics New Zealand. (2012b, 2013-04-17). *CPI All Groups for New Zealand (Qrtly-Mar/Jun/Sep/Dec)* Retrieved 12/05/2013, from http://www.stats.govt.nz/infoshare/ViewTable.aspx?pxID=47f12848-a13f-4d3b-b259-fe92c75ffcf6

Statistics New Zealand. (2013a). Age by sex, for the census usually resident population count, 1996, 2001, 2006, and 2013 Censuses (RC, TA, AU). Retrieved 10-08-2015 http://nzdotstat.stats.govt.nz/wbos/Index.aspx

Statistics New Zealand. (2013b). *Agricultural Production Statistics: June 2012 (final) – Media Release*. Retrieved from http://www.stats.govt.nz/browse_for_stats/industry_sectors/agriculture-horticulture-forestry/AgriculturalProduction_final_MRJun12final.aspx

Stavins, R. N. (1995). *Lessons learned from SO2 allowance trading*. Retrieved 12/05/2011, from http://www.choicesmagazine.org/2005-1/environment/2005-1-11.htm

Stephens, S. S., & Wagner, M. R. (2007). Forest plantations and biodiversity: A fresh perspective. *Journal of Forestry, 105*(6), 307-313.

Stone, E., & Wu, J. (2010). Targeting payments for ecosystem services. In S. Lockie & D. Carpenter (Eds.), *Agriculture, biodiversity and markets: livelihoods and agroecology in comparative perspective* (pp. 253-268): Earthscan, London.

Straton, A. (2006). A complex systems approach to the value of ecological resources. *Ecological Economics, 56*(3), 402-411.

Sullivan, J. J., Williams, P. A., & Timmins, S. M. (2007). Secondary forest succession differs through naturalised gorse and native kānuka near Wellington and Nelson. *New Zealand Journal of Ecology, 31*(1), 22-38.

Tate, K. R., Barton, J. P., Trustrum, N. A., Baisden, W. T., Saggar, S., Wilde, R. H., . . . Scott, N. A. (2002). *Monitoring and modelling soil organic carbon stocks and flows: a New Zealand perspective*. Retrieved from http://www.academia.edu/2579009/Monitoring_and_modelling_soil_organic_carbon_stocks_and_flows_a_New_Zealand_perspective

Taylor, M., & Good, M. (2006). *Brown trout spawning in the Lake Ellesmere (Te Waihora) tributaries, and some surrounding catchments*. Retrieved from http://ecan.govt.nz/publications/Reports/brown-trout-spawning-lake-ellesmere-tributaries-surrounding-catchments.pdf

Tietenberg, T. H. (2006). *Environmental and natural resource economics* (7th ed.): Pearson/Addison-Wesley, Boston.

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., & Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature, 418*(6898), 671-677.

Todd, M., & Kerr, S. (2009). *How does changing land cover and land use in New Zealand relate to land use capability and slope?*

Tompkins, J. M., Hearnshaw, E. J. S., & Cullen, R. (2011, 8-11 February). *Evaluating the sustainability of impounded river systems and the cost-effectiveness of dam projects: An ecosystem services approach.* Paper presented at the meeting of the 55th Annual AARES National Conference, Melbourne, Victoria.

Trotter, C., Tate, K., Scott, N., Townsend, J., Wilde, H., Lambie, S., . . . Pinkney, T. (2005). Afforestation/reforestation of New Zealand marginal pasture lands by indigenous shrublands: the potential for Kyoto forest sinks. *Ann. For. Sci., 62*(8), 865-871.

Turner, R. K., & Daily, G. C. (2008). The ecosystem services framework and natural capital conservation. *Environmental and Resource Economics, 39*(1), 25-35.

Turner, R. K., Georgiou, S., & Fisher, B. (2008). *Valuing ecosystem services: the case of multi-functional wetlands*: Earthscan, UK.

Turpie, J. K., Marais, C., & Blignaut, J. N. (2008). The working for water programme: Evolution of a payments for ecosystem services mechanism that addresses both poverty and ecosystem service delivery in South Africa. *Ecological Economics, 65*(4), 788-798. doi:http://dx.doi.org/10.1016/j.ecolecon.2007.12.024

Waikato Regional Council. (2010). *Nitrogen sourcing and trading in the Lake Taupo catchment*. Retrieved from http://www.ew.govt.nz/Projects/Lake-Taupo/Nitrogen-trading-in-the-Lake-Taupo-catchment/

Wang, G., Fang, Q., Zhang, L., Chen, W., Chen, Z., & Hong, H. (2010). Valuing the effects of hydropower development on watershed ecosystem services: Case studies in the Jiulong River Watershed, Fujian Province, China. *Estuarine, Coastal and Shelf Science, 86*(3), 363-368. doi:http://dx.doi.org/10.1016/j.ecss.2009.03.022

Ward, C. (2010). Kanuka and Manuka [ ]. *Bush Telegraph*(22). Retrieved from http://www.gbict.co.nz/Newsletters/Issue22/Kanuka%20Manuka.htm

Wardle, P. (2002). *Vegetation of New Zealand* Caldwell, New Jersy: Blackburn Press.

Whitten, S., van Bueren, M., & Collins, D. (2004). An Overview of Market-Based Instruments and Environmental Policy in Australia Symposium conducted at the meeting of the Market-based Tools for Environmental Management. Proceedings of 6th Annual AARES Symposium, RIRDC, Canberra, Australia. Retrieved from http://www.ecosystemservicesproject.org/html/publications/docs/MBIs_overview.pdf

Wilmshurst, J., &. (n.d.). *Story: Human effects on the environment* [Te Ara-the Encyclopedia of New Zealand].

Wilson, M. A., & Howarth, R. B. (2002). Discourse-based valuation of ecosystem services: establishing fair outcomes through group deliberation. *Ecological Economics, 41*(3), 431-443.

Wind, Y., & Saaty, T. L. (1980). Marketing Applications of the Analytic Hierarchy Process. *Management Science, 26*(7), 641-658. doi:10.1287/mnsc.26.7.641

Woods, R., Bidwell, V., Clothier, B., Green, S., Elliott, S., Harris, S., . . . Wheeler, D. (2006). *Predicting the effects of land-use on water quality-stage II* (CHC2006-096): Ministry of Agriculture and Forestry. Retrieved from http://www.mpi.govt.nz/news-resources/publications

Wunder, S., & Albán, M. (2008). Decentralized payments for environmental services: The cases of Pimampiro and PROFAFOR in Ecuador. *Ecological Economics, 65*(4), 685-698. doi:http://dx.doi.org/10.1016/j.ecolecon.2007.11.004

Yao, R. (2012). *The Non-Market Value of Biodiversity Enhancement in New Zealand's Planted Forests*. University of Waikato. Retrieved from http://researchcommons.waikato.ac.nz/bitstream/handle/10289/6399/thesis.pdf?sequence=3&isAllowed=y

Zhang, L., Dawes, W. R., & Walker, G. R. (2001). Response of mean annual evapotranspiration to vegetation changes at catchment scale. *Water Resources Research, 37*(3), 701-708. doi:10.1029/2000WR900325

Zhang, X., & Lu, X. (2010). Multiple criteria evaluation of ecosystem services for the Ruoergai Plateau Marshes in southwest China. *Ecological Economics, 69*(7), 1463-1470. doi:http://dx.doi.org/10.1016/j.ecolecon.2009.05.017

Appendix A

Lincoln University Human Ethics Committee's Approval Letter

Research and Commercialisation Office
T 64 3 325 3838
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PO Box 84, Lincoln University
Lincoln 7647, Christchurch
New Zealand
www.lincoln.ac.nz

Application No: HEC 2011-32 4 November 2011

Title: Contribution of forest related programmes in the provision of ecosystem services (ES in New Zealand

Applicant: Arun Prakash Bhatta

The Lincoln University Human Ethics Committee has reviewed the above noted application.

Thank you for your detailed response to the questions which were forwarded to you on the Committee's behalf.

I am satisfied on the Committee's behalf that the issues of concern have been satisfactorily addressed.

I am pleased to give final approval to your project. Please advise Julie Ward when you have completed your research and confirming that you have complied with the terms of the ethical approval.

May I, on behalf of the Committee, wish you success in your research.

Yours sincerely

Professor Grant Cushman
Chair, Human Ethics Committee

cc H Bigsby, R Cullen

PLEASE NOTE: The Human Ethics Committee has an audit process in place for applications. Please see 7.3 of the Human Ethics Committee Operating Procedures (ACHE) in the Lincoln University Policies and Procedures Manual for more information.

Appendix B

Questionnaire for Collecting Preferences for Ecosystem Services

Introduction

Ecosystem services refer to a range of benefits provided by our natural environment, including things like food, timber and water, and services like air and water purification, or simply pleasure we derive from natural views. Ecosystem services are vital to our wellbeing and survival. However, in many cases ecosystem services are being degraded through misuse, over-use or disregard for the benefits they provide. Hence, it is important to find ways by which ecosystem services can be restored or enhanced. This survey is part of a larger study of methods for restoring ecosystem services.

The purpose of this survey is to seek your preferences for a number of ecosystem services that are generated as a result of land use decisions. Your opinion is valuable as it will help in making decisions about how best to manage our land to fulfill the interests of individuals and society at large.

Your survey responses are anonymous.

Participation in the survey is completely voluntary and you can stop anytime you want. However, your opinion is valuable and it would be great if you finish the entire survey.

Once you complete the survey, it will not be possible to withdraw from it and you consent to publication of results for academic purposes.

It is expected to take 5 to 10 minutes to complete the survey.

You have to be 18 years or older to complete this survey.

If you are 18 years or older and willing to take part in this survey, please press the CONTINUE button. Otherwise press EXIT to stop the survey.

❍ CONTINUE
❍ EXIT

If EXIT Is Selected, Then Skip To ....End of Survey

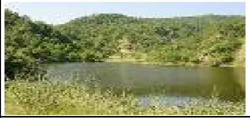
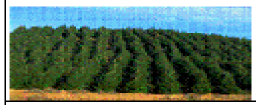
The survey covers a number of specific ecosystem services provided by land-based resources, including agriculture, forestry or natural areas. These ecosystem services are explained below. When completing the survey, please use these definitions and explanations to make your responses.

Ecosystem Services	Explanation	
Production	Outputs such as food, timber and wool.	
Carbon sequestration	Removal of carbon from atmosphere (carbon sequestration) and thus a reduction in the rate of temperature change through growth of vegetation.	
Water yield	Regulates timing and volume of river and ground water flows.	
Water quality	Filters nutrients and bacteria and makes water clean.	
Erosion control	Stabilised soils control or prevent soil erosion and sediment in rivers.	
Cultural	Services such as habitat for species, biodiversity, and aesthetic and recreational opportunities.	

Q1 Each row in the table contains a pair of ecosystem services. In each row please choose a number that best reflects your opinion about the relative importance of the two ecosystem services. If you think that the ecosystem service listed on the left hand side is more important than the ecosystem service on the right hand side, choose a number on the left hand side that reflects how much more important the left hand ecosystem service is. Do the same thing on the right hand side if you think the ecosystem service listed on the right is more important than the one on the left. The scale is from 1 to 9 where '1' means 'equally important' and '9' means 'absolutely more important' or 'critical'.

Ecosystem services	**Increasing importance** ←								**Equal**	**Increasing importance** →								**Ecosystem services**
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Carbon sequestration	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	Water quality
Water yield	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	Water quality
Water quality	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	Production
Production	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	Water yield
Cultural	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	Water quality
Production	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	Cultural
Carbon sequestration	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	Erosion control
Cultural	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	Carbon sequestration
Cultural	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	Water yield
Erosion control	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	Water quality
Production	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	Erosion control
Carbon sequestration	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	Production
Water yield	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	Erosion control
Erosion control	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	Cultural
Carbon sequestration	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	Water yield

Q2 For each of the ecosystem service listed below use the slider bar to indicate its relative importance based on services it provides. The scale is from 0 to 100, where 0 indicates 'not important' and 100 indicates 'absolutely more important' or 'critical'. **First choose the 'absolutely more important' or 'critical' ecosystem service from the options given below and slide the scale for that ecosystem service to 100**. Then, for each of the other ecosystem services, slide the scale to a point that indicates what you believe is its importance relative to the first ecosystem service you selected.

Scale	0	10	20	30	40	50	60	70	80	90	100
Production 											
Carbon sequestration 											
Water yield 											
Water quality 											
Erosion control 											
Cultural 											

Q3 Your gender
- ❍ Male
- ❍ Female

Q4 Your age
- ❍ 18 - 30 years
- ❍ 31 - 44 years
- ❍ 45 - 64 years
- ❍ > 64 years

Q5 Where do you live?
- ❍ Urban area
- ❍ Rural area

.... Thank you very much for your time on this survey. It is very much appreciated ....

Appendix C

Questionnaire for Landowners' Costs of Participating in Forestry Programmes

Introduction

This survey is part of a Ph. D. study at Lincoln University evaluating the effect of different programmes that involve forests and the provision of ecosystem services on private lands. The programmes being evaluated are the East Coast Forestry Project (ECFP), the Emissions Trading Scheme (ETS), and the QEII National Trust. We are seeking input from landowners/consultants who have participated/worked in at least one of these programmes.

The purpose of the survey is to determine the costs to landowners of participating in any of these programmes. In the following questions, the information you provide should only include the additional costs incurred due to participation in a programmes. Costs that would have been incurred even if you had not participated in a programme should not be included.

Your survey responses are anonymous and it will be used for academic purposes only.

The questions require ticking or writing in boxes for recording your responses.

Click >> to advance to the next page or << to visit the previous page.

Q1) Have you participated in the East Coast Forestry Programmes (ECFP) as a landowner or as a consultant?

- ❍ Yes
- ❍ No

If No Is Selected, Then Skip to **Q8)** Have you participated in the Emissions Trading Scheme...

Q2) How have you been involved in the ECFP?

- ❍ As a landowner
- ❍ As a consultant

If As a consultant Is Selected, Then Skip To **Q6)** Please provide landowner costs of ...

Q3) What is the total area of forest under ECFP, in hectares?

Q4) Please indicate external financial support received (District Council, environmental organizations), state the purpose of the support (e.g. planting, fencing, site preparation, weed control) and how much you have received.

	Source of funding	Purpose	Amount (NZ$)
1			
2			
3			
4			

Q5) Additional comments about external funding.

Q6) Please indicate landowner costs of being involved in the ECFP. These costs should only include incremental costs that are related to being involved in the ECFP and should exclude all costs that would have otherwise been incurred as a part of regular activity.

Please specify the type of costs (e.g. application fees, surveying, site visit/inspection, consultant, fencing) in the first column.

Enter the amount of the cost in the second column. This can be from actual receipts or an estimate.

Specify the unit of the cost (e.g. $/ha, $/yr, man-days/ha) in the third column.

If the amount of the cost is from actual receipts, indicate the year of the expenditure.

If the cost is incurred more than once, indicate the frequency (e.g. once, twice, every 5 years, and so on).

Activities	Amount	Unit	Year	Frequency of cost

Q7) Please provide any extra information about the costs of participating in the ECFP.

Q8) Have you participated in the Emissions Trading Scheme (ETS) as a landowner or as a consultant?

- ❍ Yes
- ❍ No

If No Is Selected, Then Skip To Have you participated in the QEII programme

Q9) How have you been involved in the ETS?

- ❍ As a landowner
- ❍ As a consultant

If As a consultant Is Selected, Then Skip to **Q12)** Please provide landowner costs of...

Q10) What is the total area of forest in ETS in hectares?

Q11) Please indicate external financial support received, the purpose of the support (e.g. planting, fencing, site preparation, weed control) and how much you have received.

	Source/s of funding	Purpose	Amount (NZ$)
1			
2			
3			
4			

Q12) Please provide landowner costs of being involved in the ETS. These costs should only include incremental costs that are related to being involved in the ETS and should exclude all costs that would have otherwise been incurred as a part of regular activity.

Please specify the type of costs (e.g. application fees, filing emissions returns, surveying, site visit/inspection, consultant, fencing costs) in the first column.

Enter the amount of the cost in the second column. This can be from actual receipts or an estimate.

Specify the unit of the cost (e.g. $/ha, $/yr, man-days/ha) in the third column.

If the amount of the cost is from actual receipts, indicate the year of the expenditure.

If the cost is incurred more than once, indicate the frequency (e.g. once, twice, every 5 years, and so on).

Activities	Unit	Year	Cost	Frequency of cost

Q13 Please provide any extra information about costs of participating in the ETS programmes.

Q14 Have you participated in the QEII National Trust's 'Protecting Native Forest Remnants' as a landowner or as a consultant?

- ❍ Yes
- ❍ No

If No Is Selected, Then Skip to End of Survey

Q15 How have you been involved in the QEII's programmes?

- ❍ As a landowner (1)
- ❍ As a consultant (2)

If As a consultant Is Selected, Then Skip to **Q18)** Please provide landowner costs of...

Q16 What is the total area in the programmes, in hectares?

Q17) Please indicate external financial support received (QEII National Trust, District Council, environmental organizations), the purpose of the support (e.g. planting, fencing, site preparation, weed control) and how much you received.

	Source of funding	Purpose	Amount (NZ$)
1			
2			
3			
4			

Q18) Please indicate landowners' costs of being involved in the QEII programmes. These costs should only include incremental costs that are related to being involved in the programmes and should exclude all costs that would have otherwise been incurred as a part of regular activity.

Please specify the type of costs (e.g. application fees, surveying, site visit/inspection, consultant, fencing costs) in the first column.

Enter the amount of the cost in the second column. This can be from actual receipts or an estimate.

Specify the unit of the cost (e.g. $/ha, $/yr, man-days/ha) in the third column.

If the amount of the cost is from actual receipts, indicate the year of the expenditure.

If the cost is incurred more than once, indicate the frequency (e.g. once, twice, every 5 years, and so on).

Activities	Unit	Year	Cost	Frequency of cost

Q19 Please provide any extra information about the costs of participating in the QEII National Trust's Protecting Native Forest Remnants programmes.

Thank you very much for completing this survey. Please **click >>** to record your responses.

Appendix D

Average Annual Rainfall for Sub-areas in Kaituna Catchment (mm)

SUB_AREA	COUNT	AREA	MIN	MAX	RANGE	**MEAN**	STD
1	24	6000000	1151	1244	93	**1197**	26
2	49	12250000	1039	1203	164	**1147**	38
3	38	9500000	1108	1170	62	**1137**	14
4	38	9500000	987	1119	133	**1055**	37
5	33	8250000	701	989	289	**869**	86

Appendix E

RMSE and MEF Values for the Existing Land-use

$$RMSE = \left[\sum_{i=1}^{i=n} \frac{(Pi - Oi)^2}{n}\right]^{0.5} \frac{100}{\bar{O}}$$

$$MEF = \frac{\sum_{i=1}^{i=n} (Oi - \bar{O})^2 - \sum_{i=1}^{i=n} (Pi - Oi)^2}{\sum_{i=1}^{i=n} (Oi - \bar{O})^2}$$

Year	Measured (Oi)	Modelled (Pi)	Pi-Oi	(Pi-Oi)²		**Oi-Ō**	**(Oi-Ō)2**	
1991	409.6	435.5	25.8	666.3		16.3	267.0	
1992	681.8	591.7	-90.2	8129.0		288.5	83255.3	
1993	474.4	382.1	-92.3	8517.8		81.1	6575.6	
1994	404.0	419.6	15.5	241.6	**RMSE = 20.3**	10.7	114.9	**MEF = 0.7**
1995	372.1	382.6	10.5	109.6		-21.2	447.7	
1996	395.6	512.7	117.2	13730.2		2.3	5.2	
1997	275.9	205.1	-70.9	5022.9		-117.4	13773.4	
1998	155.7	196.2	40.6	1645.2		-237.6	56472.8	
1999	384.5	441.5	57.0	3249.1		-8.8	76.7	
2000	470.8	489.4	18.7	348.3		77.5	6000.1	
2001	253.8	237.6	-16.2	261.5		-139.5	19460.3	
2002	382.9	453.3	70.4	4951.7		-10.4	108.2	
2003	242.1	424.2	182.1	33148.8		-151.2	22849.3	
2004	381.2	549.5	168.3	28339.7		-12.1	147.4	
2005	193.9	238.7	44.7	1999.7		-199.4	39744.4	
2006	571.5	661.8	90.3	8153.9		178.2	31765.9	
2007	200.7	262.7	62.0	3838.9		-192.6	37090.9	
2008	574.8	568.8	-6.0	36.6		181.5	32942.3	
2009	368.2	338.2	-30.0	899.2		-25.1	631.0	
2010	671.7	732.0	60.3	3636.1		278.4	77506.6	
AVG	393.3	426.2	∑(Pi-Oi)²	126926.1		∑(Oi-Ō)²	429234.9	
STDEV	150.3	151.4						
Max	681.8	732.0				Ō = 393.3		
Min	155.7	196.0						

Appendix F

ECFP Expenditure in 2011/12 dollars

GDP expenditure measure Base: 1995/96=1000		Rebase ($, 2011/12)	Nominal costs $		Costs $, 2011/12			Nominal $	Costs $, 2011/12
			Grants	Administration	Grants	Administration	Total costs	Approved grant rate	Approved grant rate
1994	958	0.6723	830506	147885	1235320	219969	1455289	1670	2484
1995	977	0.6856	1192645	294133	1739564	429015	2168579	1029	1501
1996	1000	0.7018	886272	296493	1262856	422475	1685331	1066	1519
1997	1016	0.7130	2169940	280985	3043394	394088	3437482	1513	2122
1998	1023	0.7179	2057134	307541	2865488	428390	3293878	1198	1669
1999	1027	0.7207	2738543	234017	3799838	324708	4124546	1412	1959
2000	1035	0.7263	2823180	368381	3887072	507202	4394274	1292	1779
2001	1068	0.7495	2070250	481671	2762175	642656	3404831	1497	1997
2002	1107	0.7768	1576172	463574	2029058	596774	2625832	877	1129
2003	1109	0.7782	2929597	498514	3764581	640599	4405180	994	1277
2004	1139	0.7993	2995111	504940	3747167	631728	4378895	1452	1817
2005	1176	0.8253	2950090	484879	3574567	587518	4162085	1701	2061
2006	1201	0.8428	2050000	434107	2432368	515077	2947445	1703	2021
2007	1241	0.8709	1710000	428831	1963486	492400	2455886	1896	2177
2008	1299	0.9116	1757000	429000	1927381	470601	2397982	1585	1739
2009	1333	0.9354	1347000	429000	1440026	458627	1898653	1461	1562
2010	1343	0.9425	1438000	429000	1525730	455172	1980902	1601	1699
2011	1403	0.9846	2743101	429000	2786005	435710	3221715	1588	1613
2012	1425	1	4066000	429000	4066000	429000	4495000	1588	1588

Appendix G

Landowners' costs in ECFP for treating land (8 ha) by *Pinus radiata* (2011/12, NZ$, GST exclusive)

	Year										
Plot	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**....**	**56**
1	609							50			
Costs	**609**							**50**			
NPV	**609.4**										
$/ha	**76.2**										

Landowners' costs in ECFP for managing indigenous reversion (8 ha) (2011/12, NZ$, GST exclusive)

	Year										
Plot	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**....**	**56**
1	609				50						
Costs	**609**				**50**						
NPV	**612.0**										
$/ha	**76.5**										

Appendix H

Landowners' costs in ETS (2011/12, NZ$, GST exclusive) (Area 8 ha)

Cost categories	Unit	Frequency	Year																											
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
A. Costs payable to Government			489				89					89					89					89					89			89
Application fee	per application	once	489																											
Filing emissions return	per filing	1 per CP					89					89					89					89					89			89
Adding CAA	per CAA	variable																												
FMA plotting		once per CP																												
B. Costs payable to consultant/firm			2020				200					200					200					200					200			200
Site inspection	as required	variable	550				80					80					80					80					80			80
General paperwork (application filling, liaise with MPI, etc.)	per application	variable	450																											
Making shape file	per application	variable	700																											
Open NZEUR account	per account	once	120																											
Filing emissions return	per filing	1 per CP					120					120					120					120					120			120
Adding CAA		variable																												
FMA plotting		once per CP																												
Total costs for landowners (A+B)			2309				289					289					289					289					289			289
NPV of total costs ($/ha)			2326.8																											
Average cost ($/ha)			290.8																											

Note: For the NPV calculation, costs in year 2 to 56 were discounted using real interest rate 2.3% and added to costs in year 1.

Appendix H

Landowners' costs in ETS (2011/12, NZ$, GST exclusive) (Area 8 ha)

Cost categories	Unit	Frequency	Year																												
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
A. Costs payable to Government			489				89					89					89					89					89			89
Application fee	per application	once	489																											
Filing emissions return	per filing	1 per CP					89					89					89					89					89			89
Adding CAA	per CAA	variable																												
FMA plotting		once per CP																												
B. Costs payable to consultant/firm			2020				200					200					200					200					200			200
Site inspection	as required	variable	550				80					80					80					80					80			80
General paperwork (application filling, liaise with MPI, etc.)	per application	variable	450																											
Making shape file	per application	variable	700																											
Open NZEUR account	per account	once	120																											
Filing emissions return	per filing	1 per CP					120					120					120					120					120			120
Adding CAA		variable																												
FMA plotting		once per CP																												
Total costs for landowners (A+B)			2309				289					289					289					289					289			289
NPV of total costs ($/ha)			2326.8																											
Average cost ($/ha)			290.8																											

Note: For the NPV calculation, costs in year 2 to 56 were discounted using real interest rate 2.3% and added to costs in year 1.

Cost categories	Unit	Frequency	Year																											
			29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
A. Costs payable to Government							89					89					89					89					89			89
Application fee	per application	once																												
Filing emissions return	per filing	1 per CP					89					89					89					89					89			89
Adding CAA	per CAA	variable																												
FMA plotting		once per CP																												
B. Costs payable to consultant/firm							200					200					200					200					200			200
Site inspection	as required	variable					80					80					80					80					80			80
General paperwork (application filling, liaise with MPI, etc.)	per application	variable																												
Making shape file	per application	variable																												
Open NZEUR account	per account	once																												
Filing emissions return	per filing	1 per CP					120					120					120					120					120			120
Adding CAA		variable																												
FMA plotting		once per CP																												
Total costs for landowners (A+B)							**289**					**289**					**289**					**289**					**289**			**289**

Appendix I

Landowners' costs in ETS (2011/12, NZ$, GST exclusive) (Forest block 100-124 ha)

Cost categories	**Unit**	**Frequency**	**Year**																											
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
A. Costs payable to Government			489				178					178					178					178					178			178
Application fee	per application	once	489																											
Filing emissions return	per filing	1 per CP					89					89					89					89					89			89
Adding CAA	per CAA	variable																												
FMA plotting		once per CP					89					89					89					89					89			
B. Costs payable to consultant/firm			6120				12000					12000					12000					12000					12000			12000
Site inspection	as required	variable	1000				1000					1000					1000					1000					1000			1000
General paperwork (application filling, liaise with MPI, etc.)	per application	variable	1500																											
Making shape file	per application	variable	3500																											
Open NZEUR account	per account	once	120																											
Filing emissions return	per filing	1 per CP					500					500					500					500					500			500
Adding CAA		variable																												
FMA plotting		once per CP					10500					10500					10500					10500					10500			10500
Total costs for landowners (A+B)			6609				12178					12178					12178					12178					12178			12178
NPV of total costs ($/ha)			7358.2																											
Average cost ($/ha)			73.6																											

Note: For the NPV calculation, costs in year 2 to 56 were discounted using real interest rate 2.3% and added to costs in year 1.

Cost categories	Unit	Frequency	Year																											
			29	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**
A. Costs payable to Government							178					178					178					178					178			178
Application fee	per application	once																												
Filing emissions return	per filing	1 per CP					89					89					89					89					89			89
Adding CAA	per CAA	variable																												
FMA plotting		once per CP					89					89					89					89					89			89
B. Costs payable to consultant/firm							12000					12000					12000					12000					12000			12000
Site inspection	as required	variable					1000					1000					1000					1000					1000			1000
General paperwork (application filling, liaise with MPI, etc.)	per application	variable																												
Making shape file	per application	variable																												
Open NZEUR account	per account	once																												
Filing emissions return	per filing	1 per CP					500					500					500					500					500			500
Adding CAA		variable																												
FMA plotting		once per CP					10500					10500					10500					10500					10500			10500
Total costs for landowners (A+B)							**12178**					**12178**					**12178**					**12178**					**12178**			**12178**

Appendix I

Landowners' costs in ETS (2011/12, NZ$, GST exclusive) (Forest block 100-124 ha)

Cost categories	**Unit**	**Frequency**	**Year**																											
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
A. Costs payable to Government			489				178					178					178					178					178			178
Application fee	per application	once	489																											
Filing emissions return	per filing	1 per CP					89					89					89					89					89			89
Adding CAA	per CAA	variable																												
FMA plotting		once per CP					89					89					89					89					89			
B. Costs payable to consultant/firm			6120				12000					12000					12000					12000					12000			12000
Site inspection	as required	variable	1000				1000					1000					1000					1000					1000			1000
General paperwork (application filling, liaise with MPI, etc.)	per application	variable	1500																											
Making shape file	per application	variable	3500																											
Open NZEUR account	per account	once	120																											
Filing emissions return	per filing	1 per CP					500					500					500					500					500			500
Adding CAA		variable																												
FMA plotting		once per CP					10500					10500					10500					10500					10500			10500
Total costs for landowners (A+B)			6609				12178					12178					12178					12178					12178			12178
NPV of total costs ($/ha)			7358.2																											
Average cost ($/ha)			73.6																											

Note: For the NPV calculation, costs in year 2 to 56 were discounted using real interest rate 2.3% and added to costs in year 1.