Maximising the Potential Ecosystem Services in County Wicklow, Ireland

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Abstract

Ireland hopes to expand its woodlands in future years while trying to meet international targets for ecosystem services such as biodiversity. This study undertook an exploratory role in transferring a GIS method developed by Bailey et al. (2006) to Co. Wicklow to assess four woodland ecosystem services; biodiversity, carbon sequestration, recreation and landscape. This study predicted that areas providing high ecosystem service benefits are scattered and small throughout Co. Wicklow. However, issues with transferability of the method, such as differences in Public preferences and Irish legislation, mean that in future studies this method should be modified for an Irish context.
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1. Introduction

*Forests are the lungs of our land, purifying the air and giving fresh strength to our people*

*Franklin D. Roosevelt*

Humanity is a huge drain on the Earth’s resources. We have now created our own geological time frame, the Anthropocene, where humanity is shaping Earth’s very surface (Crutzen, 2006). Lynas, (2011b) refers to humans as the God Species, as we have influence and control over many of the Earth’s Ecosystems. Our increasing influence results in an ever increasing need to manage our natural capital effectively. Society receives many benefits from ecosystems; many of these are not accounted for in our economic markets. As the population grows accounting for what is deemed important in Society is prioritizing where natural resources can exist.

Recently, an awareness of the need to account for non-market benefits has increased which has led to a variety of methods for assessing ecosystems for future planning and policies. This study assesses the ecosystem services Society gains from woodland by applying a GIS method previously developed in the UK to an area in the Republic of Ireland.

It is hoped that this method will provide a cost effective way to assess many ecosystem services at once and compare Public preferences.
1.1 Brief background to woodland Ecosystem services in Ireland

Ireland is positioned on the western edge of Europe and enjoys a temperate climate, heavily influenced by the Atlantic Ocean. The resulting mild and wet conditions are extremely favourable for growing trees. Despite this advantage, Ireland is one of the least forested countries in the European Union. In 2012, the National forest covered 731,650 hectares (ha) or about 10.5% of the landscape (Forest Policy Review Group, 2013; O’Carroll, 2004; O’Halloran, 2012; Wade, 2012). The relatively small area is due to competition from the agri-food industry which currently contributes over €24 billion per year to the Irish economy and accounts for almost 10% of exports (Teagasc, 2010). Most agriculture is involved in raising livestock, with a huge reliance on cattle (over 6 million cattle) (CSO, 2012).

Natural/Ancient woodland is very rare in Ireland and most stands of trees have been modified or managed to some extent over past centuries (Department of Arts Heritage and the Gaeltacht, 2010). According to the National Woodland Survey, the total area of native woodland in 2004-2006 is estimated to be 132,990 ha (Perrin et al., 2008). The majority of woodlands in Ireland are conifer plantations originating from the 20th century when the Irish government began afforestation schemes for timber production (O’Carroll, 2004; O’Halloran, 2012; P. Bacon and Associates, 2003; Ryan, O’Donoghue, Upton, Phillips, & Farrelly, 2013; Wade, 2012). However, many of these schemes were initially poorly planned resulting in many forests being planted on marginal quality, isolated land (O’Carroll, 2004).

No attempt has been made to assess Irish woodlands non-market ecosystem services, with past focus resting on timber production, resulting in large stands of Sitka Spruce. Afforestation of private land was encouraged through grants such as Single Farm Payment, Common Agricultural Policy (CAP) or the Rural Environmental Protection Scheme (REPS) (DAFF, 2006; Forest Policy Review Group, 2013; O’Carroll, 2004; P. Bacon and Associates, 2003; Ryan et al., 2013). REPS put more focus on managing for improved biodiversity; however, this scheme has now closed.

The Irish state owned forests are managed through Coillte for a variety of services including non-market services such as biodiversity and recreation. This is a recent development in forest management with a move away from managing purely for timber production. Coillte’s current aim is to work towards managing forests to increase benefits to Society as a whole, both locally and nationally, through innovative and sustainable management (Coillte, 2014).
This has resulted in an increase in recreational paths and managing to boost biodiversity benefits.

The Department of Agriculture, Food and Forestry (DAFF) plans to afforest 20,000ha per year from 2000 - 2030 (DAFF: Department of Agriculture Food and Forestry, 1996; Ryan et al., 2013). However, while this afforestation aims are to “develop an internationally competitive and sustainable forest sector that provides a full range of economic, environmental and social benefits to Society” (Forest Policy Review Group, 2013); there is no plan showing how maximising non-market services for the social benefits will be achieved. No knowledge exists as to where these services exist or where they could be enhanced through development of natural capital such as woodland. A lack of spatial knowledge exists in Ireland for these services despite their importance to Society’s well-being.

The Irish Public places high values on non-market benefits from woodland despite the lack of official identification techniques. This was made evident when, due to the 2008, recession the Irish government suggested selling Coillte’s forests. Public outcry forced the Irish Government to reconsider its stance in June 2013 and the plan was halted (Coveney, 2013). As funds are scarce, in Ireland, there is an increased need to streamline methods to produce the greatest benefit from woodland, not just timber production, but Society’s overall well-being too.
2. Literature Review

2.1 Ecosystem services are…?

Ecosystem services is a term which first appeared in the 1970s (Gómez-Baggethun, de Groot, Lomas, & Montes, 2010). The term links the functions performed by an ecosystem that directly or indirectly benefit humans (Campbell et al., 2008; Millennium Ecosystem Assessment, 2003). It was developed to help aid our understanding and management of processes that are produced from ecosystems (Daily, 1997; Gómez-Baggethun et al., 2010; Rudolf S De Groot, Wilson, & Boumans, 2002). Ecosystems provide a variety of goods and services that are necessary for human existence, and are often consisting of natural capital, an economic term used to describe ecosystems (Constanza et al., 1997; R. de Groot et al., 2012; Millennium Ecosystem Assessment, 2005c). It is extremely multi-disciplinary and involves aspects from all the traditional sciences, e.g. zoology and botany, as well as physics and mathematics (Daily & Ehrlich, 1999). This creates a very complex system.

Available literature on ecosystem services has increased in the last twenty years, especially with the formation of the Millennium Ecosystem Assessment (MA); which led to an exponential growth in literature produced (Fisher, Turner, & Morling, 2009; Millennium Ecosystem Assessment, 2003). This growth in awareness has led to ecosystem services being increasingly included in decision making policy and many market based methods have been put in place to help conserve ecosystems and maximise benefits to Society (Gómez-Baggethun et al., 2010). See Figure 1 for a conceptual view of how ecosystem services are linked to human well-being.
There is no agreed definition of an ecosystem service as the theory and use of ecosystem services has changed over time. Evolving from the original idea in the 1970s through to use in the scientific conservation areas and introduction to economic markets and use as a decision making tool (Gómez-Baggethun et al., 2010). The definition more commonly referred to is from the MA which defines ecosystem services as “the benefits people obtain from ecosystems” (Millennium Ecosystem Assessment, 2005a, p. 40). It classified ecosystem services into four areas: supporting, provisional, regulating and cultural services (Constanza et al., 1997; R.S. de Groot, Alkemade, Braat, Hein, & Willemen, 2010; Fisher et al., 2009; Millennium Ecosystem Assessment, 2005a). These four classifications play a fundamental role in how Society functions (Constanza et al., 1997). Figure 2 shows examples of how woodlands produce many ecosystem services in each of these four classifications.
Figure 2: Ecosystem services provided by woodlands under the four classifications defined by the Millennium Ecosystem Assessment 2005

In 2000, The MA was called for by the United Nations, to assess the consequences of ecosystem change on human health. It also assessed the scientific knowledge that could be used to aid conservation and sustainable use of these ecosystems for Society’s’ benefits (Millennium Ecosystem Assessment, 2005c). 1,360 experts worked on it, concluding that the World’s ecosystems are under threat due to human exploitation (Millennium Ecosystem Assessment, 2005b). One of the key findings of the report was that 15 of the 24 ecosystems investigated were in a state of decline (Fisher et al., 2009; Millennium Ecosystem Assessment, 2005b).

2.2 Why are Ecosystem services important?

The world population has been increasing rapidly in the last 50 years and is now over 7 billion, as of 2011, according to the United Nations Department of Economic and Social Affairs: Population Division (2014). This increases the demand for resources such as fresh water, food and timber etc. and when combined with the threat of climate change, the likelihood of degraded ecosystems in future will only increase (R. de Groot et al., 2012).
Functioning ecosystems and resulting ecosystem services are the fundamental life support system, without which, key elements of Society would cease. They purify the air and water, help regenerate soil fertility for agriculture, maintain biodiversity and dispose of waste. In the absence of these ecosystem services, there will be major effects on economic activity and human health; both of which contribute to societies well-being (Constanza et al., 1997; Crossman et al., 2013; Millennium Ecosystem Assessment, 2005b). Having access to natural sites has been shown to have beneficial effects on human levels of stress and mental health, and to decrease levels of depression, while levels of concentration and self-discipline increase (Lawton et al., 2010).

In future, the need to deliver effective management of land use will increase in order to provide ecosystem services to Society without incurring excessive costs or losses of market opportunities (Troy & Wilson, 2006). If effective ways of assessing and managing ecosystem services are not created, ecosystems will degrade and future generations’ well-being will suffer (Millennium Ecosystem Assessment, 2005b). Thus, an efficient, flexible method which can take into consideration changes in Public preferences and culture must be developed for improved decision-making and effective use of natural capital available. This project hopes to target areas where maximisation of these ecosystem services from woodlands can be prioritised by decision makers through the use of spatial analysis.

2.3 Why Ecosystem Services are under provided?

Ecosystems are a Public good. As a result, they are non-excludable (those who do not pay for a public good cannot be excluded from benefiting from it) and non-rival (consumption by one person does not diminish the ability of others to consume that good) (Perman, Ma, McGilvray, & Common, 2003). This makes providing and managing these resources extremely challenging for governments, if they wish to maintain them sustainably for future generations.

Some governments have attempted to introduce payments for ecosystem services, for example through water charges, which have recently been introduced to Ireland (Citizens Information, 2014). Another method of accounting for ecosystem services to a limited degree can be seen through the implementation of taxes on industry such as the fishing industry or industries that exceed air quality emissions. However, these are limited and the vast majority of ecosystem services are poorly accounted for in Society.
2.5 What benefits come from woodland?

Afforestation has been supported for many years internationally and through the European Agricultural Policy (Nijnik & Bizikova, 2008; Upton, Donoghue, & Ryan, 2014) as it’s considered an important ecosystem. In this study, four main benefits that come from woodlands as identified by Bailey, Lee, & Thompson (2006); biodiversity, recreation, carbon sequestration and landscape benefits are examined.

2.5.1 Biodiversity

Ireland’s biodiversity is extremely important, despite it having a lower biodiversity compared to the rest of Europe due to its isolated location and glacial history. It has some internationally important habitats and species’ communities, with over 31,000 species (Department of Arts Heritage and the Gaeltacht, 2010, 2011). It is estimated that of these, 7,000 species of fungi and algae have yet to be discovered; thus, the potential benefits from these species is still unknown (Department of Arts Heritage and the Gaeltacht, 2011). Within woodlands, species diversity increases as woodland complexity increases, with higher biodiversity found in the early successional years or in very mature woodland (Á. Ní Dhubháin, Bullock, Moloney, & Upton, 2011; Oliver & Larson, 1996; Quine & Humphrey, 2003).

Ireland is part of the Convention on Biological Diversity (CBD) which in 2010 found that biodiversity loss, fragmentation and degradation has not been halted, pushing ecosystems to tipping points (Lynas, 2011a; Secretariat of the Convention on Biological Diversity, 2010). The Irish government made commitments at the United National Conference on the Environment and Development and at the second Ministerial Conference on the Protection of Forests (MCPFE) to maintain and enhance biodiversity in Irish forests (Á. Ní Dhubháin et al., 2011). While improvements in Ireland have been made in the last decade; the loss of biodiversity has not been halted (Department of Arts Heritage and the Gaeltacht, 2010, 2011). Efforts need to be made to conserve and expand native woodlands in Ireland, if Ireland is to meet its CBD targets (Department of Arts Heritage and the Gaeltacht, 2010; Secretariat of the Convention on Biological Diversity, 2010).

The Irish National Forestry Standard (Forest Service, 2000b) and its associated Guidelines on Biodiversity (Forest Service, 2000a) recommend that where possible, broadleaf trees are planted and that on areas larger than 10ha, 15% of the area is put aside for enhancing biodiversity of the site (Á. Ní Dhubháin et al., 2011). This would increase the attractiveness
of the site, benefiting recreation as well as biodiversity. Passive users could gain benefit from the knowledge that this was present without ever visiting the site (Perman et al., 2003).

The Irish economy has been struggling since the economic downturn in 2008. Forestry in Ireland is valued at €55 million per year and this could increase to €80 million if native woodland increases (C. Bullock, Kretch, & Candon, 2008; Department of Arts Heritage and the Gaeltacht, 2011). Increasing the data and knowledge of the current location of non-market ecosystem services and areas where they could provide maximum benefits to Society, could vastly increase the economic and social value of woodlands. Bacon and Associates, (2004) estimated annual welfare associated with biodiversity to be €23.3 million while Á. Ní Dhubháin et al., (2011) estimated the value of woodland including non-market ecosystem services, to the Irish economy at €673 million.

Bailey et al., (2006) identified four aspects for assessing where to find areas providing maximum biodiversity benefits from woodlands. These aspects were:

a) The area of the woodlands

The area should not be too small otherwise it won’t support a large enough biodiversity to remain viable. If the woodland was found to be less than 3ha, the area needed to be expanded, and planted more densely, whilst retaining some open spaces as open spaces in woodlands can host large numbers of species. If woodlands were found to be over 20ha, open spaces should be established.

b) Yield class

Yield class is a means to account for the maximum growth a tree species can achieve on a given site. This can be calculated through aspect, slope, elevation and soil type.

c) The coverage of the woodland

The percentage area of the woodland is very important for social preferences and for reducing patch isolation. Bailey et al., (2006) found that 30% coverage was ideal; below this the woodland was too sparse and above this the landscape became too densely wooded.

d) Proximity to existing ancient woodland

For the development of new woodlands with good colonisation prospects, new woods shouldn’t be developed over 20m away from any existing ancient woodlands, as larger distances could prevent or slow the colonisation of fauna and flora to the new woodland from the old.
2.5.2 Recreation

Forests provide areas to participate in many kinds of outdoor activities such as walking, horse riding, mountain biking, fishing, hunting and bird watching. Access to these activities is directly related to well-being and human health. This is becoming increasingly more important due to Ireland’s rising obesity problem (Fitzpatrick and Associates, 2005). Through the creation or expansion of forests close to areas of high potential use i.e. close to high populations, the benefits from recreation can be increased.

Ireland’s rising urban population has recently seen a rise in outdoor recreation. Eight million people were estimated to have visited Coillte’s forests in 1999 (Clinch (1999) as referenced in Á. Ní Dhubháin et al., 2011). Since then numbers have risen to approximately 18 million visitors annually in the early 2000s resulting in approximately €97 million on non-market value to forests and trails, with a single visit estimated as €5.42 increase (Fitzpatrick and Associates, 2005; Hynes & Cahill, 2007). Hynes & Cahill, (2007) estimated the non-market values of recreational activities in two forests in Galway, (Barna Woods and Renville Forest Park) at €7.69 per trip. According to the Forest Policy Review Group (2013) the total economic activity from recreation use of forests is estimated to be €268 million generated by domestic forest users, while overseas visitors, account for €138 million per annum (Forest Policy Review Group, 2013).

With increased investment in woodland and development of methods to locate areas which maximise recreational benefits, user numbers, financial and social well-being could be increased. Already Coillte operates an open forest policy where the public are permitted access, unless major harvesting is taking place (Coillte, 2014). However, these woods were not designed or planted in areas that could maximise recreational benefits. If recreational numbers are to increase in future, woods must be planted in areas where demand is highest and they are easily accessed by recreational users. While Coillte has open woodlands, the Irish Public, unlike those in other European countries, have no right to avail of privately owned forests (Á. Ní Dhubháin et al., 2011). Careful policies need to be put in place if Society is to benefit from future afforestation.

When assessing recreation benefits Bailey et al., (2006) created two layers, potential demand and woodland accessibility. Potential demand was created by assessing the populations of settlements within a 5 mile radius and calculating the woodland per capita. The woodland accessibility layer was calculated by assessing the distance of areas within 20 metres of a road or public right of way. These layers were combined resulting in identifying 3% of the study area suitable for high recreation benefits.
2.5.3 Carbon sequestration

Ireland has agreed to reduce its greenhouse gas emissions as part of the global effort to reduce climate change (Byrne & Black, 2003). Scientific evidence on climate change indicates carbon dioxide is an extremely important greenhouse gas influencing earth’s climate (Hendrick & Black, 2009; IPCC, 2007, 2013). Forests are seen as one of the best stores of carbon, as the world’s forests contain more carbon than the entire atmosphere (CBD, 2014). The importance of woodlands’ ability to sequester and store atmospheric carbon will only increase in coming years as efforts to curb CO\textsubscript{2} in the atmosphere are increased. The rate of sequestration in woodlands will vary depending on soil type, tree species, yield class as well as human actives such as harvesting, fertilisation or land use (I. J. Bateman & Lovett, 2005; Byrne & Black, 2003). Conifers sequester much more than broadleaf tree species in the same timeframe; however, as broadleaf species have a longer life span, it is thought that over time they sequester about the same (Hendrick & Black, 2009).

Irish forests remove approximately 6 million tonnes of CO\textsubscript{2} per year, this is almost 6% of Ireland’s greenhouse emissions (Hendrick & Black, 2009). Irish Kyoto forests (those planted after 1990) are estimated to have sequestered 11 million tonnes of CO\textsubscript{2} from 2008-2012 (Forest Policy Review Group, 2013; Hendrick & Black, 2009). With average prices of €20 per tonne of CO\textsubscript{2}, the value of the forests’ carbon sequestration is estimated to be equivalent to €220 million (Forest Policy Review Group, 2013; Hendrick & Black, 2009).

There are huge incentives to increase woodlands ability to sequester carbon. However, due to the large area of land in Ireland dominated with peat, careful planning and placement of future woodlands is needed. Peat is a huge store for carbon and afforesting in areas of peat could have detrimental effects not only to the amount of long term carbon stored, but also to drainage and biodiversity (Black, O’Brien, Redmond, Barrett, & Twomey, 2008; C. H. Bullock, Collier, & Convery, 2012). According to the National Forest Inventory, 263,000 ha of former blanket bog have already been planted (Forest Service, 2007). While this may serve as a rehabilitation method after peat harvesting, if not properly assessed it could have negative impacts on carbon sequestration. Through spatial analysis, the identification of other land uses that currently have very poor carbon storage abilities could be targeted instead for future afforestation schemes (C. H. Bullock et al., 2012), thus increasing the net rate of carbon sequestration in Ireland.

Bailey et al., (2006) estimated the potential for carbon sequestration by calculating the total carbon biomass from the yield class. The carbon storage per hectare of each species assessed, oak, ash and beech, was calculated by converting standing timber volume
(m3/ha) into tonnes of carbon biomass per hectares (tC/ha). Beech, ash and oak were predicted to have values of 132tC/ha, 81tC/ha and 82tC/ha respectively. Bailey et al., (2006) also calculated the net change in long term soil carbon under various land uses as this could have a very strong influence on the quantity of carbon that could be stored. This result showed that if woodlands were developed on grassland it would result in a varying change in net carbon from a carbon reduction of 25tC/ha from grassland to woodlands on brown soils to an increase of 64tC/ha from grassland to woodlands on surface gleys.

There have been various ways to estimate soil organic carbon (SOC) in Ireland; Tomlinson, (2005) concentrated on looking at different soil types ability to store carbon while Eaton, McGoff, Byrne, Leahy, & Kiely, (2008) assessed carbon stocks under different land uses. Both soil type and land-use have a strong influence on a forest’s ability to sequester carbon. A 2013 study looking at SOC in agricultural soils in Ireland showed that within grassland the long term change in SOC changes from 246.9 to 1079.3 Tg (Khalil, Kiely, Brien, & Müller, 2013).

2.5.4 Landscape

Fáilte Ireland promotes Ireland’s natural heritage as a key experience for tourists, resulting in the majority of tourists indicating that natural beauty and culture are key reasons for visiting Ireland (Department of Arts Heritage and the Gaeltacht., 2011). Ecosystems play a key role in promoting this image of Ireland such as those found in national parks and nationally protected sites (Department of Arts Heritage and the Gaeltacht, 2011).

Woodlands can provide both positive and negative impacts on landscape services. However, the subjectivity of landscape services makes them very difficult to assess. As a result, there have been few attempts to assess the Irish Public’s preferences for landscape. Irish Public in some areas are adverse to woodlands either through their preference for an agricultural landscape or experience of badly planned afforestation such as schemes in the 20th century which lead to monocultures of high density Sitka spruce or lodge pole pine plantations, which encroached on the landscape. (Carroll, M.S., Ní Dhubháin, Á., Flint, 2011; Á. Ní Dhubháin et al., 2011; O’Leary & McCormack, A.G., Peter Clinch, 2000; Upton et al., 2014). Studies have found that preferences for woodland tend to be in areas that are more accustomed to woodland, while communities where agricultural land dominates are adverse to the idea (Collier, Dorgan, & Bell, 2002; Áine Ní Dhubháin, Fléchard, Moloney, Connor, & Crowley, 2006; O’Leary & McCormack, A.G., Peter Clinch, 2000). Due to the complicated
nature, differences in areas and the subjectivity of landscape benefits, spatial assessment is difficult to assess and hasn’t been carried out in Ireland. To date, no identification of landscape has been carried out in Ireland which makes assessment and identification of important areas of landscape very difficult. Bacon and Associates, (2004) concluded that it was impossible to place any value on the impact of woodland on the landscape in the absence of precise data. Therefore, they assigned a zero value to the impact in the absence of precise data and information. However, by following the method outlined in Bailey et al., (2006) it is hoped that a rough estimate of areas suitable for woodland within a landscape can be found without creating severe adverse effects.

Bailey et al., (2006) identified areas of landscape character or of cultural importance by carrying out a literature review of the study site in collaboration with a previous study by English Nature. They were able to identify areas such as a beech outcrop that is very important for the overall landscape of the area. Landscape character is important and highly valued in England as a tool for planning and landscape conservation. Creating new habitats can thus be informed and targeted towards landscape areas that could benefit from its creation.

2.6 What is GIS?

GIS stands for Geographical Information System, which is computer software used for assessing, storing, analysing, managing and displaying any geographical referenced information (Chang, 2010; Heywood, Cornelius, & Carver, 2011b). GIS is widely used to present spatial data in a clear easily understood format. Its applications are widespread in research, planning, managing and modelling. It can be easily used to assess locations, patterns, trends such as deforestation, conditions such as woods within a certain distance of a town or implications such as travel time (Heywood et al., 2011b). The ability of GIS to present information to decision makers in a visual and spatial setting makes it very useful. Multi-criteria analysis (MCA) is very easily carried out with GIS, with information originating from various sources and a variety of scales so it can be displayed visually and spatially allowing selection of sites which can maximise ecosystem benefits (Bailey et al., 2006; Chang, 2010; Heywood et al., 2011b).

The software used here is ArcGIS 10.1, which is the most up to date available for this study. It is commonly used and is suitable for a wide array of spatial analysis.
2.7 Past research

Ireland has very little research assessing the spatial extent of ecosystem services or where they can be found to provide most benefit to Society. The majority of past research has looked at the value of ecosystem services such as a consumer’s willingness to pay for the use of these services and what the service’s value is in monetary terms (Bacon and Associates, 2004; Fitzpatrick and Associates, 2005).

Maps can illustrate a range of options, such as where supply or demand is greatest, and hence provides a useful tool for decision or policy makers (Crossman et al., 2013; Fisher et al., 2009). Mapping use is growing as spatial information is easily displayed and understood (Troy & Wilson, 2006). Spatial analysis of ecosystem services, while limited in application in Ireland, has been applied using a variety of approaches elsewhere.

Since the MA, there have been extensive studies undertaken globally on ecosystem services at a variety of scales; locally, regionally, nationally and globally (Ian J. Bateman, Mace, Fezzi, Atkinson, & Turner, 2011; James Boyd, 2007; Constanza et al., 1997; Crossman et al., 2013; Egoh et al., 2008; Naidoo et al., 2008; Nelson et al., 2009; Schröter et al., 2005; Schulp, Alkemade, Klein Goldewijk, & Petz, 2012). These have resulted in a variety of tools and methods for analysing, mapping and valuing ecosystem services. Some tools involve development of software packages while others are more ad hoc (Bagstad, Semmens, Waage, & Winthrop, 2013). No consensus on which methods should be used has been made. This is possibly due to ecosystem services being Public goods and elusively defined, with definitions changing with interpretations resulting in a common method being very difficult to produce (Bagstad et al., 2013; J. Boyd & Banzhaf, 2007; James Boyd, 2007; Kareiva, Tallis, Ricketts, Daily, & Polasky, 2011).

However, there is a growing need to make ecosystem service assessment more credible, cost effective, quick, replicable and flexible, especially in the present economic downturn since 2008 (Bagstad et al., 2013). Counting undefinable ecosystem services is an improvement yet remains imprecise and uncertain. The move towards spatial analysis of ecosystem services serves as a better representation of their services in a spatial framework context (Troy & Wilson, 2006).
There are inconsistencies in the spatial methods currently used, which reduces the robustness and transferability of mapping ecosystem services for inclusion in policy and decision making (Crossman et al., 2013).

Attempts have been made to create a common method for mapping ecosystem services, such as the blueprint developed by Crossman et al., (2013), from which future mapping could be carried out. However, it is too soon to assess if this method will gain the peer support needed to become the accepted common method. The scientific community is working towards making mapping a useful and effective method through the use of workshops such as “Mapping, Visualization and Data access tools of Ecosystem Services” and production of special issue publications such as “Best Practices for Mapping of Ecosystem Services”, which is due to be complied in 2015 (Willemen, Burkhard, Crossman, Palomo, & Drakou, 2013). This may improve mapping of services in the future.

Ireland currently has very limited studies involving the mapping of ecosystem services for use in decision making, it is estimated that Ireland’s ecosystem services could be valued at approximately €2.6 billion, so accounting for them in future plans and policies is important (C. Bullock et al., 2008).

Some mapping has been carried out in Ireland for the assessment of how ecosystem services affect timber production, but a precise study mapping several ecosystem services directly has not been carried out. Forestry productivity maps have been created in Ireland through the mapping of elevation, soil and habitat. These have created yield class areas (Farrelly, Bulfin, & Radford, 2010). This indication of where Ireland’s ecosystem services provide good forestry productivity falls short of providing spatial information on where in Ireland a variety of ecosystem services can be found and to what extent these can benefit Society’s well-being. The productivity map was used as a GIS layer in the Forest Inventory and Planning System (FIPS) by the Forest Service, Department of Agriculture, Fisheries and Food, in the development of an Indicative Forest Strategy (IFS) for forestry in Ireland. If this GIS layer could be extended to include other ecosystem services then the non-market, benefits of woodland would be increased and Society would benefit.

Some methods use scenarios to predict how changes in future ecosystem services can benefit planning. Analysis carried out in the Swiss Alps does this to assess ecosystem changes under human development and climate change. Ecosystem services assessed include scenic beauty, habitat and avalanche protection (Grêt-Regamey, Bebi, Bishop, & Schmid, 2008). This MCA GIS analysis was able to predict how changes in ecosystem services could change suitability of areas for development of infrastructure.
South Africa has had a detailed assessment of many of its ecosystem (Egoh et al., 2008), showing how possible it is to apply these GIS methods to large areas. From the use of spatial data Egoh et al. (2008) could make suggestions for a more focused, less intensive future management plan for these services.

While areas exist that provide high ecosystem services, studies have found that some trade-offs need to be made for all of them to exist in the same location. This is due to underlying incompatibilities (Chan, Shaw, Cameron, Underwood, & Daily, 2006; Naidoo et al., 2008). In California, a study assessing ecosystem services for compatibility with biodiversity conservation goals found that, on the whole, working towards biodiversity aims can help maintain and benefit other ecosystem services, but some trade-offs are needed in some cases (Chan et al., 2006).

Another study by Lant et al., (2005) used models in GIS to map ecosystem services benefits to farm productivity on the production of agricultural goods. However, these models remain complex and full understanding of human behaviour is needed to make full use of them.

Bailey et al., (2006) present a similar method for mapping of several ecosystem services from woodland using ArcGIS. They assessed four ecosystem services; biodiversity, carbon sequestration, recreation and landscape benefits, to the area of the Chilteens, in the UK. They were able to clearly identify areas that provided maximum benefits from all four services, according to Public preferences.
2.8 Uncertainty in GIS

Despite the usefulness and intuitiveness of GIS, there can be a lot of error associated with the development of a final map for ecosystem services (Longley, Goodchild, Maguire, & Rhind, 2011). These can come from a variety of sources such as user error, incorrect selection of analysis operations, inappropriate presentation of results and computational errors (Heywood, Cornelius, & Carver, 2011a).

The quality of inputted data will also affect the quality, precision and accuracy of the output. This is especially important to remember when carrying out MCA, where data sources come from a variety of places with varying scales, reliability of source and date.

Classification and conversion of formats can result in loss of detail, resulting in vagueness (Heywood et al., 2011a).

These errors can result in misleading information, which will affect decision makers which could have long lasting effects. These uncertainties and errors in GIS can cause further problems when transferring methods across countries. This is due to differences in conceptualisation of the study site across countries with differences in political, cultural or changes in definitions (Longley et al., 2011).

MCA for ecosystem services is an amalgamation of many indicators representing the natural world and the benefits it is viewed as supplying. However, this amalgamation can lead to ambiguity and over generalisation of these services. Transferring methods used in one area to another can create problems as different countries will have differing views on what is important and what should be amalgamated.

Geographical representation of countries will vary as scale and quality of available datasets changes. There will also be differences in how this data is classified from discrete or conceptual (Longley et al., 2011). These differences could affect the method usability. Despite these draw backs decision makers and scientists are trying to create systematic methods for application to a wide range of areas. This is important as the MA and the international community tries to improve and manage ecosystem services to maximise Society’s benefits and as a result well-being.
3. The main aims of this project:

This project aims to identify areas suitable for development of woodland that will contribute the most benefit to ecosystem services in Co. Wicklow, Ireland. The project will focus on four services derived from woodland; biodiversity, recreation, carbon sequestration and landscape. GIS is used extensively throughout this project to integrate the large range of information and to present the findings clearly on a map.

Primary aims of this project include:

- A critical examination of an integrated multi criteria method in GIS
- A critical assessment of the transferability of the method developed by Bailey, Lee, & Thompson (2006) for the United Kingdom to Ireland.
- Assessment of the different distributions predicted for woodland ecosystem services in the study area.

To explore these aims, four maps will be created based on benefits from each ecosystem service. These will be combined, resulting in an optimum map for Co. Wicklow. This optimum map will identify areas where the greatest potential ecosystem services can be found by developing woodland.

This project could highlight landowners who have the potential to carry out afforestation delivering high ecosystem service benefits on their land. This could help the Irish Government come up with appropriate policies and plans for this specific targeting for the benefit of ecosystem services (Duesberg, Upton, Connor, & Dhubháin, 2014).
4. Method and Data

4.1 The study site

Co. Wicklow (Wicklow) is a county in the Republic of Ireland with an area of 2,444km$^2$. The eastern side is bordered by the Irish Sea and is where the majority of the large towns where the majority of the population live. Much of Wicklow is dominated by the Wicklow Mountains, whose highest peak is Lugnaquilla at 925 metres (3,035 feet) (OS Ireland, 2014). These mountains are covered in blanket bog and forest and because they are deemed both of national and of European importance, they are classified as areas of Special Areas of Conservation (SAC) and Special Areas of Protection (SPA). These areas also contain the Wicklow National Park and Glendalough, an area of huge historic significance to Ireland and which is a popular tourist attraction for the country. It is from here that Wicklow gets its nickname as "the garden of Ireland".

Co. Wicklow’s proximity to Dublin, the capital of Ireland makes the numbers of visitors to the area significantly larger especially during summer months. On the western side of the county is the Blessington reservoir, which is the leading regional water supply, supplying much of Dublin and the surrounding area with clean drinking water.

Much of the area is rural with a large proportion of the land employed in agriculture such as sheep, cattle or horses. Many roads run through it especially from south to north linking the area with Dublin. Many residents in the north of the county commute into Dublin on a daily basis for work. See Figure 3 for information on location and topography of Wicklow.
Figure 3: Location of and detailed enlargement of Co. Wicklow in the Republic of Ireland
### 4.2 Data and Sources

*Table 1: Required data for each benefit map and sources*

<table>
<thead>
<tr>
<th>Benefit Map</th>
<th>Data</th>
<th>Data Sources</th>
<th>Date</th>
<th>Format and Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiversity and Final map</td>
<td>Habitat map</td>
<td>Teagasc GIS research centre (Fealy, Green, Loftus, Meeham, Radford, Cronin, &amp; Bufin, 2009)</td>
<td>1995</td>
<td>Raster cell, THIM95, Resolution of 1ha</td>
</tr>
<tr>
<td>Biodiversity and Carbon</td>
<td>Soil map</td>
<td>Environmental Protection Agency</td>
<td>2006</td>
<td>Shapefile, coordinates TM65_Irish_Grid</td>
</tr>
<tr>
<td>Recreation</td>
<td>Road network map</td>
<td>Wicklow County Council, (2013)</td>
<td>2013-revision</td>
<td>Shapefile, coordinates TM65_Irish_Grid</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>Elevation (DEM)</td>
<td>Geospatial Data Catalogue, (European Environment Agency, 2013)</td>
<td>2013</td>
<td>Digital Elevation Model, 5° x5° tiles, 1 arc second</td>
</tr>
<tr>
<td>Landscape</td>
<td>Special Areas of Conservation and Special Areas of Protection</td>
<td>National Parks and Wildlife Service (NPWS, 2014b)</td>
<td>2014</td>
<td>Shapefile, coordinates TM65_Irish_Grid</td>
</tr>
</tbody>
</table>

---

1 Soils and subsoils data generated by Teagasc with co-operation of the Forest Service, EPA and GSI. Project completed May 2006. (Fealy, Green, Loftus, Meeham, Radford, Cronin, & Bufin, 2009; Fealy, Green, Loftus, Meeham, Radford, Cronin, & Bulfin, 2009)
This method was developed by Bailey et al., (2006) in their study assessing the Chilterns area for development and expansion of natural capital in this case woodland (see Figure 4 for overview). This project aims to replicate this method with available data in Wicklow. Spatial data for Wicklow was gathered through online freely available sources or through contacting government departments to gain data (Table 1). This spatial data was assessed using ArcGIS 10.1 to create four benefit maps assessing biodiversity, recreation, landscape and carbon sequestration, finally resulting in an overall benefit map for Wicklow.

Agricultural areas were identified as areas labelled grassland in the habitat map, as no finer data was available at the time of this study for the Republic of Ireland. The grassland in the habitat map includes both pasture and arable land. This produced an area of 113359.05 ha available for afforestation.

The Woodland layer was obtained through contact with the National Parks and Wildlife Service (NPWS) (Table 1). This produced two layers; native woodlands and ancient woodlands. These were both included as there was much overlap and both the native and ancient woodland are well-established woodlands. Native woodland consisted of records from the Irish Forestry Service and local knowledge of where native woodlands were established. The ancient woodland refers to those woods that have had a continuous history of cover since before the period when planting and afforestation became common practice (mid-1600s). These layers were combined for the purpose of this study and woods were clipped so only those within the study area were included, henceforth referred to simply as “woodland(s”).

Tree species assessed here are the native Oak (*Quercus petrae*) and native Ash (*Fraxinus excelsior*).
Figure 4: Systematic diagram of creation of benefits maps.
4.3 Modelling of potential biodiversity benefits

Bailey et al., (2006) determined areas with potential for biodiversity benefits by creating three layers:

a) Adjacent to woodlands
b) Percentage coverage of woodlands
c) Tree species yield class

These were then combined with the area of woodlands, which prioritised woods larger than 3ha but smaller than 20ha to give a final map of potential biodiversity benefits. All woodlands in this study were included regardless of size.

4.3.1 Areas adjacent to woodlands:

Bailey et al., (2006) determined adjacency to woods as being within 20m and then scored these areas depending on the size of the adjacent woodlands. However, due to the very large nature of the woodland dataset available and the large numbers of woods being positioned within close proximity to each other, it was decided that the viability of carrying out this method accurately wasn’t possible. As a result adjacency was determined as 25m and was calculated through use of the Euclidean distance tool. Areas within 25m scored 10, 25-50m of woodlands scored 5 while the remaining areas scored 0.

Habitat considered suitable (discussed 4.2) was then scored with grasslands scoring 5 as it was considered agricultural land and the remaining habitats not considered agricultural land scored 0.

These two scored layers were then combined with equal weighting to produce a layer indicating areas suitable for expansion of woodlands in close proximity to existing woods and on available agricultural land. This layer was scored with areas meeting all the requirements as most suitable (10), only one criteria suitable (5) and unsuitable (0).

4.3.2 Percentage cover

This section of the method was heavily adapted from Bailey et al., (2006) due to limited time, resources and capability of ArcGIS to run the large dataset needed for this project.

Bailey et al., (2006) created a 50m grid and calculated the percentage of woodland cover for that grid within 1.5km. This grid was overlaid with the agricultural field’s layer. From here
they could then calculate the most frequent proportion of percentage coverage of woodland for each agricultural field.

For this study a layer containing detailed information on individual fields was unavailable. Instead a fishnet of 1500mx1500m was created. This was combined with the woodlands layer through a union. Spatial analysis tools calculated the spatial area of this union and the attribute table was exported to excel, where pivot tables were used to create a new field containing total percentage cover of woods found within each 1500mx1500m grid. This excel file was imported to ArcMap and joined to the original fishnet 1500mx1500m using the original fishnet ID (Figure 5). This could then be displayed and scored in ArcMap according to Bailey et al., (2006), (see Table 2).

<table>
<thead>
<tr>
<th>% Cover</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20</td>
<td>3</td>
</tr>
<tr>
<td>20-25</td>
<td>4</td>
</tr>
<tr>
<td>25-26</td>
<td>5</td>
</tr>
<tr>
<td>26-27</td>
<td>6</td>
</tr>
<tr>
<td>27-28</td>
<td>1</td>
</tr>
<tr>
<td>28-29</td>
<td>8</td>
</tr>
<tr>
<td>29-30</td>
<td>10</td>
</tr>
<tr>
<td>30-31</td>
<td>8</td>
</tr>
<tr>
<td>31-32</td>
<td>7</td>
</tr>
<tr>
<td>32-33</td>
<td>6</td>
</tr>
<tr>
<td>33-34</td>
<td>5</td>
</tr>
<tr>
<td>34-35</td>
<td>4</td>
</tr>
<tr>
<td>35-40</td>
<td>3</td>
</tr>
<tr>
<td>&gt;40</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 2: Percentage coverage score for surrounding woodland adapted from Bailey et al. (2006)

Figure 5: Percentage coverage of existing woodland before scored
4.3.3 Tree suitability

Areas were assessed for their suitability for growth of each tree species i.e. yield class. To create this layer information on aspect, elevation and soil conditions needed for each tree species to grow were assessed. Suitability was found through reference to the literature available for tree growth in Ireland, this was mainly through COFORD (National Council for Forest Research and Development) and Teagasc (Horgan, Keane, Mccarthy, Lally, & Thompson, 2003; Teagasc, 2014). Elevation up to 400m was found to be suitable for Ash and Oak with reduced viability in growth above 500m. This meant an elevation below 400m scored 5, 400-500m scored 1 and above 500m scored 0 as unsuitable. See Table 3 and 4 for details on scoring used for aspect and soil. The scoring of aspect for the study site had to account for the prevailing weather conditions and climate of Ireland. Soil was scored according COFORD (Horgan et al., 2003).

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat</td>
<td>5</td>
</tr>
<tr>
<td>North</td>
<td>2</td>
</tr>
<tr>
<td>Northeast</td>
<td>2</td>
</tr>
<tr>
<td>East</td>
<td>5</td>
</tr>
<tr>
<td>Southeast</td>
<td>5</td>
</tr>
<tr>
<td>South</td>
<td>5</td>
</tr>
<tr>
<td>Southwest</td>
<td>5</td>
</tr>
<tr>
<td>West</td>
<td>5</td>
</tr>
<tr>
<td>Northwest</td>
<td>2</td>
</tr>
<tr>
<td>North</td>
<td>2</td>
</tr>
</tbody>
</table>

Layers were created for each tree species by combining elevation, aspect and soil. They were weighted with soil being given more importance due to it being one of the determining factors of tree growth. Elevation was weighted second as once a critical height is reached no trees will grow, due to the temperature and dampness of the climate resulting in bog and heath becoming the dominant habitat in upland areas. Aspect was weighted lowest as trees will grow on less amiable areas despite draw backs such as increased precipitation or decreased light.

These layers created separate yield class suitability for both ash and oak. Scores were assigned based on an areas ability to contribute to the yield class of the tree species with >75% considered suitable scored 5, 50-75% suitable scored 2 and <50% was considered unsuitable scoring 0.

By combining both tree species suitability together the overall layer of tree suitability could be calculated and scored. Areas most suitable scored 10, while areas were conditions were
ideal for one species but acceptable for the other scoring 7, areas only suitable for one species scored 5, areas marginal for both species scored 4, areas marginal for only one species scored 2 and areas unsuitable for all trees species considered in this study scoring 0 (see Figure 6).

Table 4: Scores assigned to the different soils present in the study site according to the suitability of afforestation with Ash or Oak.

<table>
<thead>
<tr>
<th>Tree species</th>
<th>Soil</th>
<th>Suitability</th>
<th>Reclassed value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oak</td>
<td>Brown Earth</td>
<td>A</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Grey brown podzolics, brown earth</td>
<td>B</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Podzols (peaty)</td>
<td>C</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Shallow acid brown earths/brown podzolics</td>
<td>B</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Acid brown earths/brown podzolics</td>
<td>B</td>
<td>5</td>
</tr>
<tr>
<td>Ash</td>
<td>Brown Earth</td>
<td>A</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Grey brown podzolics, brown earth</td>
<td>B</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Shallow acid brown earths/grey-brown podzolics, rendiena</td>
<td>C</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Peaty gleys</td>
<td>C</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Shallow Brown earth/brown podzolics</td>
<td>B</td>
<td>5</td>
</tr>
</tbody>
</table>

4.3.4 Final Biodiversity potential map

The final biodiversity potential map was created by giving equal weighting to each of the three elements created, areas adjacent to woodlands, percentage cover of woodlands and tree growth suitability layers. Biodiversity benefits could then be described in three broad categories. Low biodiversity benefits scored (2-12), were in general in areas were the dominate habitat was bog, coastal areas or urban centres. Medium biodiversity benefits (scored 13-20), covered much of the main agricultural area in lowland areas. High biodiversity benefits (scored 21-30), are generally in areas adjacent to existing woodland, were soil type was most favourable in agricultural areas.
4.4 Carbon Sequestration potential benefits

Forest is considered a potential source of carbon storage for offsetting emissions. This can be enhanced by careful planning of where forests are positioned to maximise this potential. The carbon sequestration of an area was determined in Bailey et al., (2006) by the creation of two layers:

a) The Mean carbon biomass of tree species
b) Calculating the long term change in soil organic carbon storage

4.4.1 Mean carbon biomass of tree species

Predicted tree growth layer calculated for the biodiversity potential map was used to estimate the yield classes of the two tree species included in this study. Using figures from Bailey et al., (2006) (see Table 5) yield classes were used to calculate carbon biomass of Ash and Oak. This was done by converting the yield classes into standing timber volume (m$^3$/ha) using the maximum age of the tree (Hamilton & Christie, 1971; Horgan et al., 2003). Conversion rates of specific gravity, biomass multiplier and percentage carbon enabled the conversion of timber volume into carbon biomass for each tree species (Milne & Brown, 1997).

This results in between 70-82tC/ha for an average yield class of oak (4) and ash (5) or a mean carbon biomass of 76t C/ha. In Bailey et al., (2006) the net change of carbon biomass was calculated by subtracting average carbon biomass of an area by 1tC/ha; to account for existing agricultural vegetation. However, this step wasn't completed in this study as land use change was accounted for in the next step.

The tree suitability layer created previously for the biodiversity map was edited to account for the mean carbon biomass (Table 5).
Figure 6: Tree suitability layer used for calculating Biodiversity and Carbon sequestration benefits

Table 5: Tree species estimated carbon biomass (tC/ha). (replicated from Bailey et al. 2006)

<table>
<thead>
<tr>
<th>Tree suitability layer</th>
<th>Estimated yield class oak</th>
<th>Carbon biomass for OAK (tC/ha)</th>
<th>Estimated yield class Ash</th>
<th>Carbon biomass for ASH (tC/ha)</th>
<th>Mean carbon biomass on site (tC/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>82</td>
<td>5</td>
<td>70</td>
<td>76</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>82</td>
<td>5</td>
<td>70</td>
<td>76</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>104</td>
<td>8</td>
<td>101</td>
<td>102.5</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
<td>115</td>
<td>12</td>
<td>140</td>
<td>127.5</td>
</tr>
</tbody>
</table>
4.4.2 Change in Organic Carbon under differing land uses.

Bailey et al., (2006) calculated the long term change in Soil organic carbon (SOC) in the main soil groups under the three land uses, grassland, arable and forests. Due to the nature of the datasets available and to the focus on changes in land use, it was decided to focus on the change in carbon when land use differs.

In this case the availability of several papers related to the Republic of Ireland and organic carbon storage under various land uses were used (Eaton et al., 2008; Kiely et al., 2009; Xu, Liu, Zhang, & Kiely, 2011; Zhang, Tang, Xu, & Kiely, 2011).

While Tomlinson, (2005) had detailed figures on the carbon stocks of Irish soils, the time frame of carbon change was only 10 years and it was decided that this was too short for accurately assessing long term change in Irish soils, especially as the tree species being assessed are long lived, with some oak trees capable of living for hundreds of years.

As a result carbon biomass (tC/ha) was estimated for the study site with figures of carbon storage for land use from Eaton et al., (2008) see Table 7. These estimates were deducted from carbon biomass stored when land is forested Table 6. The habitat layer was reclassified to indicate this change in carbon storage if land uses were converted to woodland.

Table 6: Carbon biomass change due to land use changing to woodland

<table>
<thead>
<tr>
<th>Original land cover</th>
<th>Carbon change when land use changed to woodland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grassland</td>
<td>+90</td>
</tr>
<tr>
<td>Peatland</td>
<td>-193.5</td>
</tr>
<tr>
<td>Water bodies</td>
<td>0</td>
</tr>
<tr>
<td>Non-veg</td>
<td>0</td>
</tr>
<tr>
<td>Heterogeneous</td>
<td>110</td>
</tr>
<tr>
<td>Urban</td>
<td>0</td>
</tr>
<tr>
<td>Forest</td>
<td>0</td>
</tr>
</tbody>
</table>
### Table 7 Land use organic carbon storage

<table>
<thead>
<tr>
<th>Land cover</th>
<th>Value</th>
<th>Grouped for application of Eaton 2008</th>
<th>Carbon density 0-30cm</th>
<th>Carbon density 0-100cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet grassland</td>
<td>8</td>
<td>Grassland</td>
<td>100</td>
<td>160</td>
</tr>
<tr>
<td>Dry grassland</td>
<td>9</td>
<td>Grassland</td>
<td>100</td>
<td>160</td>
</tr>
<tr>
<td>Water</td>
<td>10</td>
<td>Water bodies</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rocky complex</td>
<td>13</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mature forest</td>
<td>14</td>
<td>Forest</td>
<td>130</td>
<td>250</td>
</tr>
<tr>
<td>Forest and scrub</td>
<td>15</td>
<td>Forest</td>
<td>130</td>
<td>250</td>
</tr>
<tr>
<td>Built land</td>
<td>16</td>
<td>Urban</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Coastal complex</td>
<td>18</td>
<td>Non-vegetated (semi-natural area)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fen</td>
<td>21</td>
<td>Water bodies</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Reclaimed fen</td>
<td>24</td>
<td>Heterogeneous (agricultural areas)</td>
<td>90</td>
<td>140</td>
</tr>
<tr>
<td>Raised bog/Fen</td>
<td>31</td>
<td>Peatland</td>
<td>133</td>
<td>443.5</td>
</tr>
<tr>
<td>Reclaimed raised bog</td>
<td>34</td>
<td>Grassland</td>
<td>100</td>
<td>160</td>
</tr>
<tr>
<td>Upland blanket bog</td>
<td>41</td>
<td>Peatland</td>
<td>133</td>
<td>443.5</td>
</tr>
<tr>
<td>Cutover/eroding</td>
<td>43</td>
<td>Peatland</td>
<td>133</td>
<td>443.5</td>
</tr>
<tr>
<td>Reclaimed upland blanket bog</td>
<td>44</td>
<td>Peatland</td>
<td>133</td>
<td>443.5</td>
</tr>
<tr>
<td>Heath</td>
<td>61</td>
<td>Peatland</td>
<td>133</td>
<td>443.5</td>
</tr>
<tr>
<td>Wetland</td>
<td>71</td>
<td>Water bodies</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

#### 4.4.3 Final Carbon Sequestration potential map:

Finally, net carbon change per land use and carbon biomass stored in trees were combined with equal weighting. Symbology was changed to show high carbon sequestration benefits (300-377), medium carbon sequestration benefits (102-300) and low carbon sequestration benefits (-193-102).
4.5 Recreation potential benefits map:

Bailey et al., (2006) identified two layers needed for the calculating of recreational potential areas:

- Accessibility
- Potential Demand

4.5.1 Accessibility

Accessibility to a site was calculated through obtaining a GIS layer of Wicklow’s road network. Bailey et al., (2006) used roads and “public rights of way” to assess accessibility. Unfortunately in Ireland a complete dataset of “public rights of way” has yet to be fully developed or freely available; those available were of questionable accuracy. As a result analysis was restricted to the available road network which was obtained through contact with Wicklow County Council (Table 1). A Euclidean tool was used to calculate the distance from woodlands and was then reclassified so to account for areas within 20m, as this was deemed the distance easily accessible in Bailey et al., (2006). The agricultural areas within this 20m were then deemed most suitable for expansion, scoring 5.

Bailey et al., (2006) compiled an open land layer from common land (obtained from Department for Environment) and combined this with their “public rights of way” layer. As a result, due to their different datasets Bailey et al., (2006) were able to subdivide this classification into areas of open land or rights of way that were within 20m scoring 10, or those adjacent to open land or rights of way scored 5 and those not adjacent scored 1.

4.5.2 Potential Demand:

A GIS layer of settlements in Ireland, including the populations living within their boundaries, was obtained from the Central Statistics Office, Ireland. Settlements within 8km of the study site were selected for analysis. While Dublin is very close to the study site, just on the border of the 8km inclusion, it wasn’t included in the selected settlements as it wasn’t considered part of the local resident population for this study.

The selected settlements were buffered by 8km and joined through the union tool with the woodlands layer. In ArcMap, a fishnet of 250m was created this was then clipped to the
study site. By using the union tool, the fishnet of 250m was combined with the already unionised settlements and woodlands layer. This allowed the calculation of the average population per ha of woodland within each fishnet grid and hence the average potential demand within a grid cell (Figure 7).

Bailey et al., (2006) were able to produce woodland per capita for each individual town and assign each field within a 5 mile radius of that town the average people per hectare. Scores were then assigned based on high, medium and low population. The use of the fishnet was needed in this method to substitute the lack of agricultural fields in the datasets available.

Figure 7: Average capita per hectare of woodland found within 8km buffer from settlements

4.5.3 Final recreation potential benefit:

The potential demand was converted to raster format and combined with the accessibility layer with equal weighting producing a final recreational potential benefit. Low recreational benefits (scored 1-5). Medium recreational benefits (scored 6-11). High recreational benefits (scored 12-20).
4.6 Landscape benefits map

Creating a landscape benefits map is extremely subjective and open to interpretation. Bailey et al., (2006) attributed landscape benefits based on physiography, ground type and culture. As a result, this project also took into account elevation, habitats and literature that highlighted areas that were culturally important, such as nationally and internationally protected sites or Public preference for upland bog and heath habitat. Protected sites are classified as Specific Areas of Conservation (SAC), Specific Areas of Protection (SPA) or National Heritage Areas (NHA). However, Wicklow currently has no officially designated NHAs, but there are several proposed NHAs (pNHAs). These pNHAs were published in 1995 and though they have no statutory status, they have been observed and given special provision when planning development (NPWS, 2014a).

Areas identified through the literature as important to remain woodland free such as protected coastal areas or upland blanket bog were reclassified as unsuitable for woodland through modifications of the habitat layer (scored 0). Further detailed analysis of protected areas indicated reasons behind protection; in some of these cases it included protection of existing woodland. These sites could benefit further by expansion of woodland within close proximity. However, these areas require special planning permission to allow any expansion and therefore scored 1. These areas combined with areas that weren’t valued by public opinion as highly e.g. grassland or existing forested areas were reclassified as suitable for landscape changes.

Elevation was assigned values on high, medium or low. These weren’t based on scores assigned by Bailey et al., (2006) as the Chiltern study site had very little upland areas. Lowland was considered less important for landscape and so more suitable for woodland expansion (scored 3). Mid elevation was marginal (scored 2) these areas could have more benefit to Society by becoming woodlands, but as joined the upland areas could impact on the traditional peat/bog landscape present if wooded. Upland areas were considered unsuitable for woodland expansion due to Public preference to preserve upland peat as it is of cultural importance especially for the conservation of Ireland’s biodiversity (Upton et al., 2014).
4.6.1 Final Landscape potential benefit:

The scored elevation, habitat and protected areas were then combined with equal weights using the raster calculator to produce a final landscape map. Low landscape potential areas (2-4 scored 1), medium landscape potential areas (5-7 scored 5) while high landscape potential areas (8 scored 10).

4.7 Final combination of benefit maps

A final map was created through the weighted linear combination approach (Drobne & Lisec, 2009; Malczewski, 2000). This allowed for Public preferences to be included in the final map. A constraint map was created by reclassing all dry and wet grassland as 1 and the remaining habitats as “NoData”. This reduced the size of map down to only areas considered for possible expansion.

The constraints map was then multiplied with all four of the above potential benefit maps. A fuzzy membership tool was used to standardise the scales of all these maps to a linear scale between 0 and 1 to enable comparisons between benefits.

The final benefit map was created by summing all the layers together (Figure 8). This was done through use of the weighted sum tool to account for individual Publics’ preferences which adds weight to the various areas that were deemed more important than others. Bailey et al., (2006) used weights taken from Forestry Commission, (2001). Forestry Commission, (2001) and equal weightings were used to assess differences if Public preferences change.
Figure 8: Systematic diagram of creation of final potential benefits map
5. Results

5.1 Ecosystem services assessed

In total Wicklow is predicted to provide 0.54% of its area towards providing high biodiversity ecosystem services (Table 8). Figure 9(a) indicates in red where these high biodiversity services can be found if woodlands are expanded with the majority of these areas found in the east of the county. 40.56% of the Wicklow provides medium to high benefits found throughout the county with the main exceptions found in the mountainous areas and along the east coast which provide only low biodiversity benefits (58.9%, Table 8).

Carbon sequestration benefits are scattered throughout the county and areas providing high ecosystem services account for 9.22% (Table 8). These high benefit areas are situated on land suitable for Oak and Ash, the tree species assessed in this study, and on land use that currently doesn’t sequester a large amount of carbon, so conversion to woodland could increase this ecosystem service benefit. The majority of Wicklow provides medium to high carbon sequestration benefits accounting for 63.06% of the area (Table 8). Low sequestration potential (27.72%) is mainly found in the upland areas where Peatland dominate and carbon sequestration is already high, without the need to establish woodland (Figure 9(b)).

High recreational benefits are widespread (21.81% of the county, Table 8) with concentrated clusters found around settlements, such as Baltinglass and Aughrim (Figure 9(c)). These areas of high recreational services are within 25m of the road network and close to areas of high population density, where demand is greatest. 63.99% of the Wicklow provide medium to high ecosystem services while only 14.20% of the area is deemed of low recreational benefit if woodlands were established, these areas are mostly in the upland mountainous region of the county (Table 8, and Figure 9(c)).
Figure 9: Ecosystem services (benefits) predicted for potential delivery in Co. Wicklow
Table 8: Percentage coverage (%) of ecosystem services for Co. Wicklow and for only Agricultural land uses

<table>
<thead>
<tr>
<th>Ecosystem Services</th>
<th>High (%)</th>
<th>Medium (%)</th>
<th>Low (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Agricultural</td>
<td>Total</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>0.54</td>
<td>0.3</td>
<td>40.56</td>
</tr>
<tr>
<td>Carbon</td>
<td>9.22</td>
<td>1.68</td>
<td>63.06</td>
</tr>
<tr>
<td>Landscape</td>
<td>1.46</td>
<td>0.47</td>
<td>37.18</td>
</tr>
<tr>
<td>Recreation</td>
<td>21.81</td>
<td>28.76</td>
<td>63.99</td>
</tr>
</tbody>
</table>

1.46% of Wicklow is predicted to provide high landscape areas; these are often in areas associated with protected sites of existing woodland with species such as Hazel, Ash and Oak already. The majority of Wicklow provides only low landscape potential (61.37%) this is the largest area deemed of low benefit in this initial study as can be seen in Figure 10(a) and illustrated in Figure 9(d) and is found in areas of high elevation where upland boc and heath habitats are protected as SAC or SPA.

Figure 10(a) illustrates the comparison of ecosystem services across all four assessed here; biodiversity, carbon sequestration, landscape and recreation for Wicklow. Wicklow is predicted to provide most benefit to recreational services, followed by carbon sequestration. Biodiversity services are predicted to gain least benefit from this analysis as Wicklow can only provide very limited high and medium benefits, with the majority of Wicklow being deemed of low potential for biodiversity services when compared to the remaining three ecosystem services (Figure 10).
Figure 10: Graphs (a) and (b) showing percentage coverage of ecosystem services in Co. Wicklow for the total county and for Agricultural land.
5.2 Total benefit derived from woodland expansion in Co. Wicklow

The four ecosystem services assessed here were combined using weighting from Bailey et al., (2006) to produce an overall map of ecosystem services potential in Wicklow. Figure 11 illustrates those areas in Wicklow that have high, medium and low ecosystem service benefits. Overall it can be seen that the area predicted to provide the highest benefit from all four services is very low, with only an area of 1120.14 ha or 0.56% (Table 9). These areas are illustrated in red in Figure 11, are found mainly in the east of the county.

Low ecosystem services benefit from woodland is predicted to cover an area of 106832.3ha, this results in just over half the total area of Co. Wicklow (53.05%, Table 9) being of questionable quality for establishment of woodland. These areas are mainly found in the Wicklow Mountains and along the east coast (Figure 11).

High to medium benefits to ecosystem services (illustrated in blue in Figure 11) cover the remaining portion of Wicklow (93430.26 ha or 46.39%, Table 9). These areas cover much of low land Wicklow except the coastal regions.

Figure 11: Combined Ecosystem services predicted potential in Co. Wicklow
### Table 9: Ecosystem services potential predicted for Co. Wicklow

<table>
<thead>
<tr>
<th></th>
<th>Area (ha)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>1120.14</td>
<td>0.56</td>
</tr>
<tr>
<td>Medium</td>
<td>93430.26</td>
<td>46.39</td>
</tr>
<tr>
<td>Low</td>
<td>106832.3</td>
<td>53.05</td>
</tr>
</tbody>
</table>

#### 5.3 Restricting the area to Agricultural land

Agricultural land is the main land use type which is freely available for expansion of woodland through the use of government policies and grants. However, using this land for woodland would reduce the areas suitable for the provision of other ecosystem services.

Figure 12 illustrates the agricultural land predicted to provide ecosystem services in Wicklow. The area predicted to provide high ecosystem services has been reduced for all four ecosystem services assessed. This is illustrated in Figure 10(b) and Figure 12.

Comparison between graphs in Figure 10(a) and (b) show that, when restricted to agricultural land use, the benefits derived from woodland expansion is mainly of medium benefits. This is seen clearly in Figure 10(b) and Figure 12. 97.66% of agricultural land use in Wicklow provides medium benefits to landscape services, while the lowest percentage of medium benefits can be found when assessing biodiversity service benefits which provide 64.94% (Table 8).

High biodiversity services are reduced from 0.54% to 0.3% when the land area considered is reduced to agricultural areas. The same pattern is seen for carbon sequestration and landscape with reductions from 9.22% to 1.68% for carbon and 1.46% to 0.47% for landscape. Recreational ecosystem service benefit is the only one that increases its overall percentage area for high potential benefits from 21.81% to 28.76%.
Ecosystem benefits restricted to agricultural land

low
medium
high

(a) Biodiversity
(b) Carbon sequestration
(c) Recreation
(d) Landscape

Figure 12: Area of agricultural land classified as low, medium or high benefit to ecosystem services.
5.4 Total benefit derived from expanding woodland restricted to Agricultural land

Combining all services found on agricultural land produces a final potential benefit map Figure 13(a). These were combined using weightings from the UK Forestry Commission, (2001). The area predicted to provide high benefits is 0.09% this accounts for 105.84 ha (Table 10). No particular area stands out for providing high benefits to ecosystem services, but the east of the county is marginally more favourable (Figure 13). The majority of agricultural land, almost 70% is predicted to provide medium benefits to ecosystem services. Low benefits account for the remaining 33943.77 ha, approximately 30% of the agricultural land in Wicklow (Table 10).

Equal weighting was applied to agricultural areas to assess the change in area predicted as providing high ecosystem service benefits, if public preferences were to change. This is illustrated in Figure 13(b).

Table 10 shows how the areas have changed for high, medium and low ecosystem service benefits between the two weightings used. Areas providing high benefits have increased by 0.7% resulting in an additional 784.98 ha predicted to provide high ecosystem benefits. Clusters of these can be seen in the south and south west of the county. A decrease in agricultural areas providing low benefits from 33943.77ha to 21454.65ha means that more agricultural land is providing medium to high benefits.

Figure 13(c) shows a difference map showing the areas where these two weightings differ. Areas in dark blue and green highlights areas with the greatest differences in weightings occur.

Table 10: Comparision of weightings used for combining predicted ecosystem services on Co. Wicklow’s Agricultural land using percentage coverage and hectares (ha)

<table>
<thead>
<tr>
<th>Weighting</th>
<th>High</th>
<th>Medium</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>ha</td>
<td>ha</td>
<td>ha</td>
</tr>
<tr>
<td>UK Forestry Commission</td>
<td>0.09</td>
<td>105.84</td>
<td>69.96</td>
</tr>
<tr>
<td>Equal</td>
<td>0.79</td>
<td>890.82</td>
<td>80.29</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>29.94</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>18.93</td>
</tr>
</tbody>
</table>
Figure 13: Final combination maps showing weighting from the UK Forestry Commission (2001) used in Bailey et al., (2006) (a), equal weighting (b) and Difference map (c) showing areas of highest and lowest differences occur between (a) and (b)
6. Discussion:

6.1. Ecosystem services in Co. Wicklow.

This study has examined the transferability of a spatial analysis method for ecosystem services between countries. It has provided a focused and targeted method for identifying areas that could provide maximum ecosystem services benefits through the expansion of woodland. Wicklow was the chosen study area and a method developed by Bailey et al., (2006) was used to identify areas of key importance.

Ecosystem services have received increasingly more interest, especially through the UN’s Millennium Ecosystem Assessment (2005) and the EU Biodiversity Strategy to 2020 (European Commission, 2013) which calls on EU member states to map their ecosystem services. Interest in woodland has increased as they provide a multitude of goods and services from marketed goods, e.g. timber, to non-market goods such as those assessed here. Ireland has yet to carry out an assessment of its ecosystem services and as such this project provides a useful introduction to the idea in an Irish context, while providing useful application of identifying ecosystem services within a spatial area associated with woodlands.

The Irish Forestry Service has increased its emphasis in the future on providing multifunctional woodland in reaction to a change in public opinion as interest in multiple benefits in woodlands increases (Forest Policy Review Group, 2013). 2001 saw the establishment of a Native Woodland grant scheme which provided funding for restoration and expansion of native woodlands; however, the expansion was limited and there was an emphasis on planting in Greenfield sites. The incentives may not have the ability to maximise ecosystem services.

Areas identified in this study indicate clearly where maximum ecosystem benefits can be achieved. The use of this spatial information should then be used to streamline policies and plans to avail of these benefits. This could be done through incentivising landowners or through Coillte purchasing these sites. Since the recession of 2008, Ireland has been in debt resulting in budget cuts surrounding “non-essential” services. Only recently in 2013, the Irish government proposed selling off its woodland (Coveney, 2013). As a result, a method streamlining use of financial resources for improved expansion of native woodland should be considered. However, the current political will may be lacking a focused pushed towards native afforestation. Despite this, the method presents a convenient way of assessing non-
market services together in a spatial representation, creating a useful planning or research tool for non-market benefits for the future. Bacon et al. (2004) estimated the non-market value of woods could increase as far as €126 million. With the use of this method and allowing for inflation this could potentially rise.

Biodiversity benefits have imposed the greatest constraint on areas predicted to provide high ecosystem services. This is possibly due to the area being dominated by uplands which are deemed unsuitable for the tree species assessed here. This results in a low level of areas providing high ecosystem service benefits. This could be due to incompatibly between benefits restricting the area of suitable sites. Incompatibly has been found in other studies carried out such as R. Naidoo et al., (2008), where they found that carbon sequestration only occurs in areas where there are low population densities. Despite this risk, there are still areas providing all four ecosystem services within Wicklow, which provide locations for targeted afforestation.

The Irish government has an afforestation target of 20,000ha per year from 2000 - 2030 (DAFF: Department of Agriculture Food and Forestry, 1996; Ryan et al., 2013) however this will not be met by only planting in areas identified here. Thus this method should be expanded to assess Ireland nationally, as other counties could provide better conditions for maximising ecosystem services. Alternatively, to meet afforestation targets the adaption of medium areas would need to be considered, or a reassessment of weightings used through further studies on Public preferences (see 6.3).

This project shows that cost effective methods are available to target and avail of other services provided by woodland that do not have an easily assessed market price. The streamlining of targeted afforestation will save money, increase wellbeing of Society and help targeting of future policies in afforestation.

However, no consideration has been made to other habitats such as Peatland which provide services which are highly valued internationally and perhaps, in future studies, the expansion of this multi-criteria spatial analysis should be considered to other habitats.
6.2 Ecosystem services in Agricultural land area in Co. Wicklow

While Wicklow has an ability to provide ecosystem services, the practicality and ease of creating woodlands on these targeted sites is limited. Land use that is easily targeted and converted into woodland is agricultural land. While limiting the land available for expansion of woodland decreases the potential area, it also makes it easier to integrate a targeted approached to afforestation into policies and grant schemes.

Comparing sites suitable over the total area of Wicklow and restricting the available area to agricultural areas leads to a decrease from 0.56% to 0.09%. This suggests that Wicklow’s agricultural land doesn’t provide the best opportunities for expansion of native woodland. Despite this, these areas are easily and quickly converted to woodland meaning that benefits to Society can be achieved quicker and at minimum cost.

However, attempts to encourage farmers to move into forestry has had limited success due to farmers’ traditional attitudes and preferences. In 2007, the launch of the Forestry Environment Protection Scheme (FEPS) through REPS was used to encourage farmers to establish and maintain forestry for biodiversity and water quality (Teasgasc, 2014). Under this scheme farmers received an additional payment of between €159 and €200 per ha for five years on top of their afforestation payment to cover these non-market benefits. This was only a pilot scheme and with the closure of entrants to REPS in July 2009, the number of farmers partaking in this scheme dropped off until closure of the scheme in June 2014 (Teasgasc, 2014).

Past studies have suggested that farming community’s attitudes to forestry differ considerably from those of the General Public. The majority of the General Public feel that forestry is beneficial and an overall good use of land (Á. Ní Dhubháin et al., 2011). However, many farmers feel that afforestation is a waste of land or a threat to farming practises and communities (Collier et al., 2002; Duesberg, Dhubháin, & Connor, 2014; Elands, O’Leary, Boerwinkel, & Wiersum, 2004; Á. Ní Dhubháin, Flechard, Moloney, & O’Connor, 2009; O’Leary & McCormack, A.G., Peter Clinch, 2000). Many farmers feel that afforestation is a huge commitment with land being tied up for up to 20 years or more, creating direct competition with agriculture for land (McDonagh, Farrell, Mahon, & Ryan, 2010; Á. Ní Dhubháin et al., 2011). Traditional farming practises are still in use and encouragement into forestry has been met with considerable resistance. While grants provide financial incentives to farmers to commit to afforestation schemes, uptake isn’t large enough. If Ireland is to meet its afforestation goals, it is important that farmers’ attitudes are changed. Those that have
made use of grants see afforestation as a way to make use of marginal land unsuitable for agriculture, these areas aren’t always ideal for providing ecosystem services.

A carefully targeted approach is needed to encourage landowners (mostly farmers) of highly suitable sites to move towards afforestation with native trees.

Public rights of way, is another obstacle when agricultural land is targeted for afforestation schemes benefiting all of Society. The Irish Public need to have open access to private woodland like they have in woodlands owned by Coillte. If afforestation only takes place on private land, adaption of legislation surrounding public rights of way in Ireland is needed to avail of these benefits. Currently, the Public do not have any rights to access private forests and support from farmers to allow public access is a debated subject. For afforestation to take place on private land using grants, provision needs to be made within the grant conditions to allow for access. Only after successful implementation of such legislation will the full benefits from woodland ecosystem services be met.

6.3. Applying different weightings

Weightings derived from Public preferences were applied to the final predictions to estimate benefits. These Public preferences come from previous studies. While studies have been undertaken to assess the Irish Public’s preference for woodland benefits, these have focused on ranking these preferences or assessing the Public’s willingness to pay for a woodland providing a range of ecosystem services (Bacon and Associates, 2004; Fitzpatrick and Associates, 2005; Á. Ní Dhubháin et al., 2011). Ní Dhubháin et al. (2011) found that the Irish Public rank biodiversity above other benefits such as recreation or employment. The Ní Dhubháin et al. (2011) study was not suitable for inclusion in ecosystem services weightings in this study. As detailed assessment of landscape benefits did not consider the context of cultural or subjective value but were assessed in terms of forestry management and timber clearance (Á. Ní Dhubháin et al., 2011). Also the remaining ecosystem services were ranked via importance rather than given a percentage preference. However, these rankings follow a similar trend shown in the UK Forestry Commission (2001) Public preferences.

The Forestry Commission (2001) weightings are slightly out dated and based on the UK’s Public preferences rather than the Irish preferences for ecosystem services. Applying these weightings in the Irish context is misleading but in the absence of suitable studies is adequate. Future assessments of Irish Public preferences for woodland benefits should be carried out so future polices and plans can account for them.
Weightings have a huge influence on which sites will be considered most suitable for woodland expansion. By applying equal weightings, differences could be assessed to see what influence public opinion could have. Figure 13(c) shows the extent of where these differences could lay. The area showing changes due to changes in weighting is extensive suggesting that a change in Public preferences could have a huge impact on sites identified as suitable for providing high ecosystem service benefits from native woodland.

6.4 Critique of methodology

The method used here was adapted from the method developed by Bailey et al., (2006). As a result there are some inbuilt issues in its delivery of an effective assessment of ecosystem services in Wicklow. Originally these methods were developed for assessment of services in the Chilterns area in the UK.

Transferring methods from the UK to Ireland creates a lot uncertainty. Data accessibility and quality was a major obstacle to overcome. There is no central database in Ireland, from which to gain access to the multitude datasets needed. While a central reference collection is available (Marine Institute, 2014), it still requires direct contacting and communicating with multiple government departments. However, the collection is not exhaustive and personal contacts were required to locate some key data sources. Once received this data was often outdated or not ideal for application to the method.

Future GIS research in Ireland should assess the establishment of a national central source for databases allowing easy download from the online source allowing quicker and easier searching and accessing of data.

Land use was one dataset which if available would have made completion of this study more in keeping with Bailey et al., (2006). A similar dataset in Ireland of suitable detail has yet to be published, but it is in development (per communication, Dept. of Agriculture, Food and the Marine) but was unavailable for this study. An alternative dataset covering habitat types was available through Teagasc, and although it was outdated, it served to demonstrate this method. Detail was lacking and adaption was needed in many cases through use of grid cells to represent agricultural fields. Future studies should ideally have access to a detailed land use map of Ireland.
Public rights of way was another useful dataset that is unavailable. There are many trails in Wicklow ((Wicklow Mountains National Park, 2014; Wicklowway, 2014), but there is no adequate database, so these have been omitted from the analysis.

Uncertainty inbuilt in the method includes the conceptualisation of the study site, as this method was designed in the UK resulting in possible misrepresentation when applied to Wicklow. Homogenising and classification of some datasets for analysis in the Chilterns isn’t applicable to Wicklow. For example the homogenising of roads in Wicklow these vary drastically in size from motorways to rural country tracks, and these do not all have similar impacts on woodlands.

Further the use of various indicators to assess the different ecosystem services used in assessing the Chilterns could become obsolete or inaccurate when assessing Wicklow, this is due to ambiguity between political and cultural differences in Ireland compared to the UK. Irish legislation differs to UK especially in regards to the right to roam, these differences should be taken into account especially when assessing the establishment of woodland on private property as this will restrict access to recreational benefits.

The quality of datasets that were used create further uncertainty as they use polygons/rasters to represent a place/thing. These are only representations and conceptions of real world natural environments, creating a hard line for interpretation between these can be misleading hiding errors and misclassifications. Furthermore, the integration of these different conceptualised layers carries with them their existing errors.

Buffers were used in this method creating hard unnatural boundaries in many cases; these boundaries should be open to interpretation and merge with the surrounding areas, as there is no hard line in nature. For example soil type or where recreational demand originates. Glendalough is a 90 minute drive from Dublin however people regularly make the journey. The use of distance, buffers and proximity to a road, wood or settlement is done frequently throughout Bailey et al., (2006). They fail to make any justification for their decisions and there is little consistency in their choices. No indication is given as to how rigid these distances or parameters are or if they could be altered and if so by how much.

Fuzzy membership was used in the creation of the final maps, as this removes many of these hard lines and creates a gradient between areas that are or aren’t included in a zone (Longley et al., 2011). Bailey et al., (2006) didn’t specify the use of this leaving this open to the reader’s interpretation. But, this membership reduces any inappropriate inference from combination of the data. However, heterogeneity which increases the likelihood of this “ecological fallacy” is present in the creation of the original maps so should be carefully considered (Longley et al., 2011).
6.5 Creation of benefit maps
Detailed critique and analysis of the creation of each benefit map.

6.5.1 Biodiversity

A distance of 20m was assumed to adequate to determine adjacency to woodlands, this was to expand existing woodlands and allow easy colonisation of new woodlands. But different species have different dispersal abilities and the landscape in which the woodland is positioned should also be considered as hedgerows or major roads can lead to corridors or fragmentation of the landscape (C. Bullock et al., 2008). Bailey et al., (2006) make little reference to their rational behind this decision.

Constraints imposed through ArcGIS, made computation of some tools impracticable due to the large study size and detail required. As a result large grids 1500mx1500m were used to assess woodland producing a very coarse scale for assessing benefits.

Predicting tree growth presented several problems, as assumptions on indicators of this had to be made, leading to ambiguity through the interpretation of past studies. Furthermore, no ground truthing was undertaken to assess these assumptions credibility.

No accounting of other species was included. Assumptions are made on the biodiversity benefits from stands of ash or oak. However, past studies suggest that high benefits come from mixed woodland of conifer and broadleaf (Ní Dhubháin et al., 2011). Different species will differ in their requirements thus greater numbers may benefit from open mixed woodland. More accurate spatial assessment of biodiversity benefits may come from assessing keystone or sensitive species.

6.5.2 Carbon sequestration

While many papers study soil organic carbon (SOC) in Ireland these do not show differences in SOC of different soil types under differing land uses. Only one paper Poeplau & Don, (2013) discusses this, however they focus on agricultural land and make no mention of soils under woodlands.

As a result SOC was assessed using the land use changes from Eaton et al., (2008) and the net change in carbon estimated to occur if land was converted to woodland. Alternative studies focus on the changing SOC when looking at soil type specifically (Tomlinson, 2005). Figure 14 shows a comparison of using net change of carbon by land use and using change over time of SOC. Assumptions are made here as the time frame for SOC change mapped is only 10 years, which is not enough to gauge long term change. These data limitations could
be overcome if direct communication was made with authors of past studies (such as Kiely et al., 2009; Poeplau & Don, 2013).

Carbon sequestration in timber was assumed to be the same as figures calculated in Bailey et al., (2006). Many past studies have been done on carbon sequestration of woodlands and there is now software developed for calculating this, CARBWARE. It requires information on trees species, land productivity and details of management. It was used by Á. Ní Dhubháin et al., (2011) where they found that broadleaf woods sequestered less than conifer woods during a period of 50 years. CARBWARE could be used in future assessments using GIS.

6.5.3 Landscape

Landscape areas are extremely subjective. This makes interpretation of this benefit map open to debate. No precise data exists for assessing Irish preferences on landscape. While assessment of the literature was carried out, this is a poor substitution for real data. From Á. Ní Dhubháin et al., (2011) Irish Public do like woodland, but past afforestation schemes of high density monocultures of Sitka spruce have had negative effects on public perceptions of woodlands, so community preferences need to be assessed on a case by case basis.

If a large area is deemed suitable for afforestation an Environmental Impact Assessment (EIA) needs to be undertaken that accounts for landscape and public participation.

This study focused on protected areas that were highlighted as areas protected for the presence of native woodland, as these landscapes are already deemed of national or of international importance.
Figure 14: Change in Carbon storage for Co. Wicklow. Comparison between different methods using land use changes (above) and Soil type (below)
6.5.4 Recreation

Issues surrounding Irish legislation on the right to roam and the exclusion of the rural population makes the accuracy of applying Bailey et al., (2006) to recreational benefits in Ireland uncertain. Irish legislation protects the rights of the landowner leaving private forestry closed to the public. This political difference versus the UK means that assessing recreational benefits for agricultural land shouldn’t be applied as the Public, unless the land owner allows it, will have no access to avail of these recreational woodlands. Exclusion of the rural population is also due to differences in culture between the UK and Ireland, as much of Ireland’s community are rural with many people still living on farms or in isolated areas across the county. While settlements provide a nucleus to focus on, some accounting for rural populations should be included.

The method also fails to include the significance of local tourist attractions such as Glendalough in Wicklow Mountains National Park, which receives thousands of visitors both domestic and abroad. The areas close proximity to Dublin, the capital holding approximately a quarter of Ireland’s population (CSO, 2011a), provides a large pool of residents who potentially visit the area frequently was also omitted from analysis.

Assumptions made on the distance from roads and settlements also follow little justification as to why these distances were chosen. While accessibility is important, it doesn’t take into account the different road types or people’s willingness to travel to potentially more isolated places. Further various recreation activities are possible within woodlands, which could bring more people into an area. For example, deer hunting, which is already estimated to be worth €1.8 million to the Irish economy, should be considered as Wicklow is one of the main areas deer are found in Ireland (Á. Ní Dhubháin et al., 2011). Unfortunately, not all recreational activities are compatible with each other.
6.5.5 Combination of Ecosystem services

The use of a weighted linear combination technique requires a full understanding of the underlying assumptions to apply correctly. It was used in this project to combine all four benefit maps. All four benefit maps were assumed to be linear in scale when converting to a common scale using fuzzy overlay membership. Fuzzy overlay membership assigns numbers to values based on the chance of it being included in a specific set (ArcGIS, 2010; Longley et al., 2011). However, assumptions that the benefit maps are linear in scale Bailey et al., (2006) should be reconsidered as some benefits may only be more accurately assessed on a non-linear conversion. Using fuzzy membership reduces errors for the assignment process which was undertaken in the formation of the benefit maps.

Weighted overlay sum was used to combine these benefit maps together, using weightings as discussed 6.3. This resulted in the final benefit maps, with a constraint layer excluding all habitat that wasn’t deemed agricultural for isolating agricultural areas for separate assessment. This created a large reduction in suitable area and makes large assumptions as to where agricultural land is as the dataset is quite dated. This may produce inaccuracies in the interpretations.
7. Conclusion

Despite limitations of this study a method that can cost effectively identify areas that can benefit Society's well-being, through identification of ecosystem services such as biodiversity, carbon sequestration, recreation and landscape, has been presented.

It does this through integrating multiple criteria together to produce a map indicating the varying distribution of ecosystem service benefits. The final combination of these services identifies areas within Co. Wicklow that offer the highest benefits. Thus, demonstrating the transferability of the method employed from the UK to Ireland.

Public opinion has a huge influence on where these areas are located, as demonstrated in application of different weightings.

This method provides a starting point from which further research can be carried out. Improvements on the method need to be made for full application in Ireland, taking account of Irish legislation and cultural differences. Future research into Irish Public preferences, is needed as well as development and better access to up to date datasets is essential to create a through map outlining areas for afforestation not only in Co. Wicklow but applied to the whole country.
8. References


