A review of the range and value of ecosystem services from Irish forests

Craig H. Bullock[a*], Cormac O'Callaghan[b], Áine Ní Dhubháin[c], Yuuki Iwata[c], Cathal O'Donoghue[d], Mary Ryan[d], Vincent Upton[d], Kenneth A. Byrne[e], Sandra Irwin[b], John O'Halloran[b], Mary Kelly-Quinn[f]

Abstract

Much reference is made to the importance of forests in the delivery of ecosystem services. This paper examines the range of biophysical services provided by forests and the economic and social value of the final ecosystem services. Although information is presented for Ireland where just over one tenth of the land area is forest, most of which is comprised of planted conifer species with a smaller proportion of broadleaf species, this composition is comparable to that of many other developed countries with a temperate climate. The assessment examines the evidence for ecosystem services in relation to habitat, timber production, carbon storage and sequestration, water quality, moderation of run-off, recreation and amenity. It distinguishes between the services provided by forests as distinct from trees and takes into account alternative uses of the land, the role of soils and the contribution of appropriate management to avoiding potentially adverse impacts. It aims to provide a comprehensive, if introductory review of the range of ES, the interactions that exist between them, their economic value and the opportunities for forest policy and management to strengthen these benefits.

Keywords: *Forest, carbon sequestration, water, amenity, biodiversity, economic value.*

Introduction

In 2012, the European Union adopted a Biodiversity Strategy (EU 2011) that aims to halt the loss of biodiversity and ecosystem services (ES) by 2020. As an essential step towards this aim, the strategy requires that Member States map and estimate the value of ES. For forests, this objective had been expressed at the Oslo meeting of the Ministerial Conferences on the Protection of Forests in 2011 and has been followed up in subsequent expert group reports. (Forest Europe 2014).

This paper discusses the principal ES that are provided by forests and the extent to which these are realised in Ireland where much forest consists of planted commercial species. As such, the paper is of relevance to other countries with a temperate climate where forests have been planted for wood production, but which also possess some areas

[a] UCD School of Architecture, Planning and Environmental Policy, University College Dublin, Belfield, Dublin 4.
[b] University College Cork.
[c] UCD Forestry, School of Agriculture and Food Science, University College Dublin, Belfield, Dublin 4.
[d] Rural Economy and Development Programme, Teagasc, Athenry, Co. Galway.
[e] University of Limerick.
[f] UCD School of Biology and Environmental Science, University College Dublin, Belfield, Dublin 4.
[*] Corresponding author: craig.bullock@ucd.ie

of native species forest. The paper includes also economic estimates of the ES value and explores the influence of forest management and composition on the flow of these services.

Ecosystem services

The Millennium Ecosystem Assessment (MEA 2005) defines ES as the benefits that people obtain from natural ecosystems. Forests contribute a range of important ES including habitat for biodiversity, timber and forest products, climate change mitigation, erosion protection, catchment protection, and amenity and recreation. The relative value that people place, directly or indirectly, on these ES has varied over time. In Ireland, previous generations would have placed a particular value on forests for fuel and materials. However, the supply of all ES was compromised by extensive deforestation from the fifteenth century to the beginning of the twentieth century by which time forest accounted for just 1% of land area. That area has now risen to 10.5% due to the planting of mostly non-native conifers for which Ireland has a very suitable climate. These trees have mainly been planted for timber and 83.7% of the planted area is now available for this purpose according to the National Forest Inventory (Forest Service 2012). Conifer plantation accounts for 472,752 ha with the remainder comprising largely mixed and non-native broadleaf species, including commercial broadleaf plantings. Around 164,000 ha are comprised mostly of broadleaf tree species (DAFM 2014) of which just 100,000 ha are regarded as being native species woodland with 20,000 ha being defined as ancient woodland, i.e. woodland dating from before the 1600s (Perrin and Daly 2010). Figure 1 illustrates the distribution of forests in Ireland and Table 1 lists some of the key characteristics of these forests.

While Ireland still has a low proportion of its land area covered by forest compared to other European states, the characteristics of its forests, and the associated ES, do resemble those of other countries that have sought to increase their forest area through commercial afforestation. Globally, the area of plantation forest continues to increase and surpassed 264 million ha in 2010. By comparison, 13 million ha of natural forest is being lost each year, representing a net loss of 5.2 million ha of forest (FAO 2010).

Although planted forests provide their own set of ES, these services do replace those associated with previous land uses. In common with some other countries, most afforestation in Ireland has occurred on lands of marginal agricultural value (Upton et al. 2014; Smith et al. 2006) with the support of afforestation grants and premiums. These areas have included low-intensity upland farmland and, until recently, peatlands (Renou-Wilson and Byrne 2015), both of which can have a high ES or biodiversity value. Irish Forest Service grants are now restricted to cultivable land and support for planting on unimproved land is restricted to no more than 20% of the total area[1]. This paper addresses the net impact of forestry where grown on lands of both high and low ES value.

[1] The Forest Schemes Manual (Appendix 14 –Land Types for Afforestation) excludes designated and infertile raised or blanket bog and unmodified raised bog.

Methodology

The paper undertakes a comprehensive review of the evidence for ES benefits in Ireland's forests. It draws on research published in the fields of forestry science, land use change, soil science, ecology and hydrology to demonstrate the extent of ES flows under different conditions or in different locations. The review distinguishes the ES provided by different types of trees, individual or small numbers of trees, and trees growing in forests. It also considers the implications of forest planting regulations and management. Where possible it applies an economic value to ES benefits which may be captured by market processes or represented by non-market values. In the latter case, various methods are available to demonstrate these values, including cost-based methods, revealed or stated preference, and value transfer.

a) Ecosystem service provision.

b) Classifications.

c) The MEA (2005) identified four types of ES, namely:
   i) provisioning services, i.e. the products obtained from ecosystems;
   ii) regulating services, i.e. benefits obtained from the maintenance and regulation of ecosystem processes;
   iii) cultural services, i.e. the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences; and
   iv) supporting services, i.e. those that are necessary for the production of all other ES.

Although the MEA was an important step in the overview of global ES, classification systems are not definitive and continue to evolve as our understanding of ES increases (Fisher et al. 2009). The Common International Classification of Ecosystem Services (CICES 2013) was prepared on behalf of the European Environment Agency to assist with biodiversity accounting and is now the principal classification used by researchers and policy makers. CICES acknowledges the contribution of ecological structures and processes in supporting final ES, but places the focus on the relationship between provisioning, regulating and cultural ES as final services that supply goods and benefits for human well-being. In this way, the risk of double-counting of benefits is minimised. The flow of these services from the biophysical environment to the human environment is represented by the Cascade Model (Haines-Young and Potschin 2010, Potschin and Haines-Young 2011) in Figure 1.

Various studies have demonstrated the public good value of Ireland's forests, including Ní Dhubháin et al. (1994), Clinch (1999), Scarpa et al. (2000), Fitzpatrick

Figure 1: *Forest distribution in Ireland.*

Table 1: *Some principal characteristics of Irish forests.*

Ownership		**Area (ha)**
Public forests		389,356
Private forests:	grant aided	248,554
	other	93,742
Species composition		**Area (ha)**
Conifer		436,980
Broadleaf		111,340
Mixed species		88,810
Other, e.g. temporarily unstocked, open areas, etc		94,522
Total		731,652

Associates (2005), Howley et al. (2011) and Upton et al. (2012). Irish forest policy acknowledges the diverse services that forests provide. Its strategic goal is to develop an internationally competitive and sustainable forest sector that provides a full range of economic, environmental and social benefits to society and which accords with the Forest Europe definition of sustainable forest management (DAFM 2014).

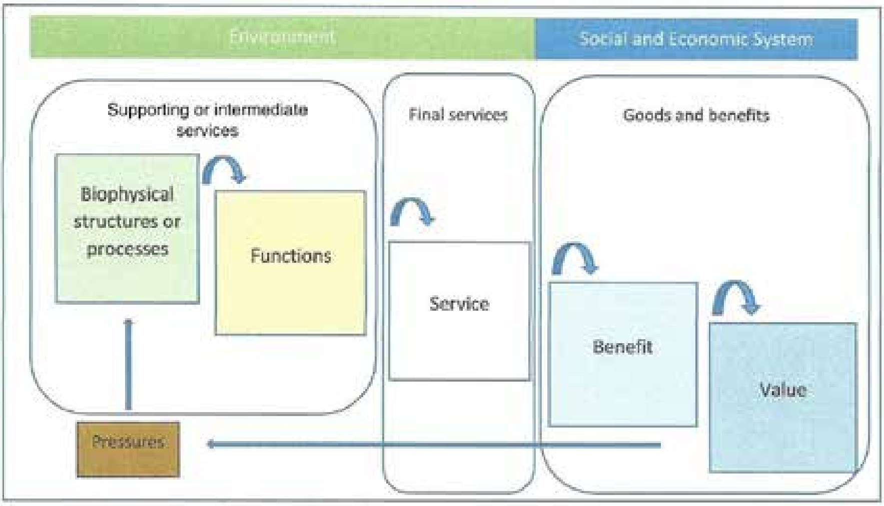

Figure 2: *The cascade model of ecosystem services (after Haines-Young and Potschin 2011).*

Criteria and funding mechanisms have therefore been set to achieve appropriate afforestation and management. Receipt of funding is conditional on the inclusion of a minimum 10% area of broadleaf species and a biodiversity enhancement area[2]. However, an ecosystem approach that seeks to maximise these benefits has not been explicitly adopted to date.

Provisioning services

Provisioning services relate to many of the most familiar and tangible benefits that forests provide, namely wood and non-wood products. The management of forests to supply these products can be complimentary to the supply of other ES, but the net benefits will depend on where and what trees are planted, including the intensity of production, use of chemical inputs and mix of tree species.

The overall value of the forestry sector to the Irish economy is estimated at €2.3 billion of which the net contribution to gross domestic product from growing and harvesting is put at €137 million (DAFM 2014). As an ES, timber production is best understood in terms of harvest volumes. Annual roundwood production from Irish forests has ranged between 2.8-3.0 million m^3 in recent years (O'Driscoll 2014). The price of wood products covers labour and capital inputs added during the harvesting and processing stages. Therefore to avoid double counting, the value of the core provisioning service is best represented by that of the standing crop less the cost of the capital, and labour inputs needed during ground preparation, planting and subsequent management[2].

2 According to the Irish afforestation scheme.

3 The cost of these inputs is largely offset by establishment grants of €2,000 to €5,000 ha^{-1}.

In Ireland, this production mainly enters the domestic sawmilling sector which relies largely on softwoods to produce construction and lower grade timber products. The average standing timber price for 2015[4] was €59 m^{-3}. By comparison, quality hardwood currently attracts prices of €100 per m^3 or more for use in the craft sector, furniture and interior decoration. The very limited supply of Irish hardwoods means that this value is usually realised by imported hardwoods[5]. However, the increasing area of broadleaf will increase future supplies. The Forest Policy Review also identifies the potential to make greater use of small diameter hardwoods.

Fuelwood or biomass is another outlet for harvested products that has grown substantially in recent years. Due to the interest in renewable energy and the periodically high price of oil, demand for biomass for heat and energy is now estimated at 800,000 m^3 per annum. Wood-based biomass is equal to 34% of domestic production with the market estimated to be worth €33 million per year (Knaggs and O'Driscoll 2013). These market returns have provided an incentive for renewed management of many private woodlands, specifically thinning (Bullock and Hawe 2013).

As well as wood products, forests supply supplementary products such as berries, nuts, edible fungi, foliage and game (Harrington and Cullen 2008, Bastrup-Birk et al. 2011, Collier et al. 2004). While these outputs can be an important provisioning service benefit, they are relatively minor in Ireland (although the value of foliage production has been estimated at €2.5 million (Ní Dhubháin et al. 2012)). Deer are shot for management purposes and sport providing income through hunting leases and client fees, but there are no estimates of the amount of game that enters the food chain. The expansion of commercial forest has led to an explosion in the population of deer and around 25,000 deer were culled in Irish forests in 2009 (Purser et al. 2009), suggesting a possible value of €1.2-€2.3 million per year[6]. Culling is extremely difficult in young plantations and has been inadequate to prevent continued tree damage. In entirely natural circumstances, deer would themselves provide regulating ES, and their numbers would be kept in check by predators. Without fencing and active management of the growing deer population, browsing could significantly reduce the regeneration and value of forests, including other ES values. For conifer forests, financial losses have been estimated as being as much as 22%, i.e. up to €3,800 ha^{-1} and potentially more for broadleaf (Purser et al. 2009).

[4] Taken from Teagasc website (https://www.teagasc.ie/crops/forestry/advice/markets/timber-sales-and-prices-index/).

[5] Timber prices are available from the state forest company, Coillte, and the Forestry Yearbook, but hardwood supplies are currently sporadic and prices were obtained through consultation with three milling companies.

[6] At average market values assuming 50 kg carcass and 60% allowance for waste.

Regulating and maintenance services

Nature of regulating services

Forests provide a range of regulating and maintenance services, although these vary depending on the forest environment, for example, plantation, species, native, age, area, etc. Regulating services are amongst the most challenging ES to quantify. Many regulating services relate to ecosystem processes that influence the manner and rate at which trees grow. This means that there is a particular need to avoid double-counting in that many of these services are intermediate, contributing also to provisioning and cultural services. For example, ES involved in soil formation and the decomposition and recycling of organic matter are critical to supplying the nutrients needed for tree growth. The value of these services is captured by the standing value of trees grown for commercial harvest but is also reflected in a range of ES benefits provided by forests in general. Among the most valuable regulating services that are not captured by the commercial value of the trees are carbon sequestration and storage, the contribution to water quality and the moderation of run-off (Howley et al. 2014). Trees also provide a regulating service by moderating temperature (Bolund and Hunhammer 1999) and noise levels (Leonard and Parr 1970), by intercepting airborne particulates or by reducing sulphur dioxide and ozone (Powe and Willis 2002). The value of these ES is highest in cities where individual trees and community woodlands can provide ES benefits to a large population along with significant amenity or recreational benefits (Gomez-Baggethun and Barton 2012). However, most forests, including those in Ireland, are grown in rural areas with relatively low populations, noise and pollution.

Carbon sequestration and storage

The sequestration and storage of carbon by forests are fundamental to climate regulation. Key factors are the rate of growth and the maturity of the trees. In Ireland, the majority of commercial plantings are in their growth phase such that active sequestration is a particular feature of the Irish forest estate relative to other countries with more mature forest. Carbon sequestration by forests is largely determined by gross primary productivity and, as such, is strongly influenced by growth rates, species and management (Chen et al. 2014). In Ireland, most sequestration is due to commercially grown conifers which represent the largest proportion of the total forest estate. The very small area of native species forest consists almost entirely of mature broad-leaf species for which carbon storage is the more relevant factor (Bullock et al. 2014).

In principle, it is the forest soils, or more specifically the biomass of organisms and organic debris, that are the more important carbon pool as these account for 85% of the forest carbon store (Forest Service 2013)[7]. Much of this store will have accumulated

[7] On average, woody biomass amounts to 12.7% of the carbon store, of which 10.4% is above ground and 2.3% below ground. The remaining carbon is found in the leaf litter (1.6%) and deadwood (0.6%) (Forest Service 2013).

over a long period of time or under previous land cover. Once forested, more carbon is accumulated in the soil than for permanent grassland or, especially, for arable use which tends to result in net losses of carbon (Gobin et al. 2011).

The initial preparation of land for tree planting can result in the oxidation of soil organic matter and carbon losses. However, it is now a requirement that forests are replanted so that disturbance of the soil is minimised along with carbon losses especially when existing seed sources are used. Initial losses are highest for peat based soils on which many older forests were planted and which account for 46% of the forest estate in Ireland. Although much carbon would have already been released from these locations when originally drained or cut for domestic and industrial fuel, others would have been under rough grazing and have retained a significant store of carbon. The net carbon balance (i.e. between carbon uptake and loss) is likely to be highly variable across a range of temporal and spatial scales as a result of factors such as soil type, species, age and management. Research by Hargreaves et al. (2003) in Scotland found that forests on peat soils become net carbon sinks 4-8 years after planting. On the other hand, samples taken from streams and lakes in the west of Ireland indicate substantial losses of both particulate and dissolved organic carbon (DOC) from forested peatlands amounting to 0.10 t C ha^{-1} yr^{-1} and 0.62 t C ha^{-1} yr^{-1} year (Ryder et al. 2014), adding to the risk of acidification and loss to the atmosphere. Feely et al. (2014) and Kelly-Quinn et al. (2016) have also reported that DOC in streams draining peaty soils in Ireland is significantly higher than those in non-forested moorland. Excluding this factor, Irish forests are estimated to be a carbon store of 57 million tonnes (DAFM 2012) and to be net carbon sinks responsible for sequestering 4-8 t C ha^{-1} yr^{-1} (Black and Farrell 2006).

Sequestration by planted forests effectively buys time for society to begin to agree to reductions in greenhouse gas emissions (GHG). This ES benefit is realised at a global level, but carbon sequestration has been a factor in allowing Ireland to be compliant with emissions targets for the first Kyoto commitment period (2008-2012) and can help to offset future emissions in line with EU policy (NESC 2012). The young age of much of Ireland's forest is relevant in this regard as only sequestration by forests planted after the 1990 baseline counts towards the national target (Black and Farrell 2006, McGettigan 2009, Byrne 2010). The post 1990 portion of the estate accounts for over 40% of the 731,650 ha forest estate (Forest Service 2013). As of 2014, carbon sequestration by these trees (less deforestation) amounted to 3.5 M t CO_2 eq yr^{-1}. Trees planted prior to 1990 do not contribute to Ireland's international mitigation obligations, but nevertheless provide for net sequestration. Sequestration at 45 years is estimated at just over 75% of that for trees of 15 years (after Tobin et al. (2006) allowing for the lower density of older stands).

The use to which felled timber is put is relevant to estimating the carbon balance too. Harvested wood products are an important carbon pool (Donlan et al. 2012). Close to 40% of the total volume of felled timber goes to construction-related uses where its longevity is extended and the carbon consequently locked up for decades. However, the aforementioned increase in demand for wood for bioenergy now accounts for between one third and half of the annual harvest of wood products (Knaggs and O'Driscoll 2013, Phillips 2011, UNECE/FAO 2013). Nevertheless, this use helps to offset emissions from fossil fuel use. If this latter proportion is excluded, net sequestration by post 1990 plantings is estimated at 3.1 M t CO_2 eq yr^{-1} for 2014 once net harvesting and management is taken into account[8]. Total sequestration by the forest estate is estimated[10] to be 6.9 M t CO_2 eq yr^{-1}.

There are three main ways of quantifying carbon sequestration in economic terms, namely:

- the social value of future climate change;
- the traded price of carbon;
- the marginal abatement cost of energy conservation or of switching to alternative fuels.

In principle, estimates of the social value of sequestration would be most relevant as these reflect reductions in the future cost of climate change (Pearce 2003). However, estimates of these costs are subject to tremendous uncertainty (Bellard et al. 2012, Millar et al. 2007, Walther 2010, Tol 2005). Alternatively, the traded price of carbon on the European Emissions Trading Scheme (ETS) can be used as a proxy for social value[9]. This approach is recommended by Public Spending Code guidance[11]. However, prices are subject to exogenous factors such as current economic growth and trading permit criteria. Policy decisions markedly influence supply/demand factors, and these current factors undermine the usefulness of ETS prices for valuing long-term carbon sequestration (Guitart and Rodriguez 2010). In 2014, for instance, the carbon price on the ETS averaged €7 per tonne. While this price had been expected to rise as the international economy recovered, this has not happened due a combination of sluggish growth and political disagreement.

An alternative approach to quantifying the economic benefits of carbon sequestration is to take the marginal abatement cost of energy conservation or switching. For the UK, McKinsey (2007) has estimated this cost as a much higher figure than the ETS price at up to €90 t CO_2, falling to €40 t CO_2 as more abatement options become available. The approach is still subject to uncertainty with regard to

[8] Forest Service submission: Information on LULUCF actions to limit or reduce emissions and maintain or increase removals from activities defined under Decision 529/2013/EU.

[9] These figures refer to the trees only and do not include net carbon storage in the soils.

[10] Other greenhouse gases can be converted to an equivalent price using IPCC conversion factors for Global Warming Potential.

[11] Available at http://publicspendingcode.per.gov.ie/wp-content/uploads/2015/09/E5.pdf (accessed October 2016).

the availability or type of abatement, but does provide a reasonable representation of the current cost of mitigation. On the basis of an abatement curve supplied for Ireland by Motherway and Walker (2009), an average value post-2014 of €39 t CO_2 has been adopted post-2014 by Ireland's Department of Finance. Given the estimates above for total sequestration, this would imply that Irish forests are sequestering over €260 million worth of carbon per year, although the actual value is at any one time is influenced by prevailing international emission targets.

Water flow regulation

Through their uptake, transport and apportioning of water, forests have an inherent ability to regulate the volume of water entering rivers, lakes and reservoirs. Although forests have been linked to reduced aquifer recharge or surface runoff (van Dijk and Keenan 2007, Farley et al. 2005), water shortage is rarely a problem in Ireland (Allen and Chapman 2001). Rather, reductions in surface runoff from forested areas provide an ES by potentially reducing the incidence or severity of downstream flooding (Bradshaw et al. 2007, Thomas and Nisbet 2007). Trees and ground cover intercept rainfall and evapotranspiration is higher than for other land uses (Zhang et al. 2001). Forest soils also act as a sponge, infiltration is greater and water is released more slowly into streams, extending and delaying peak flows (Calder et al. 2002, Laurance 2007, Nisbet and Thomas 2006) This means that forests can mitigate catchment scale flash flooding events (Robinson et al. 2003, Calder 2007, FAO 2005) of the type that often cause most material damage, although the buffering effect appears to be less for prolonged high rainfall (Birkinshaw et al. 2014). While water tables typically fall, the contribution of forests to flood mitigation is difficult to predict as it is determined by many factors, including the nature of the rainfall event, forest type and age, forest design and management, soil type, ground cover, establishment drains and subsequent natural infilling of these drains (Nisbet and Thomas 2006, Robinson et al. 2003, Crockford and Richardson 2000, Teklehaimanot and Jarvis 1991). As felling inevitably removes some of the benefits, Nisbet and Thomas believe that semi-natural forests can offer greater scope for flood mitigation, but note that broadleaf woodland involves lower water uptake.

Cost-based valuation methods can be used to indicate the potential damage cost averted due to the hydrological regulating services provided by forests. Economic losses as a result of flooding have risen sharply in recent decades largely because of land use modification within river catchments (Harrigan et al. 2014, OPW 2003). For example, the 2009 floods in Cork in south-west Ireland cost the city authorities €35 million with a total cost to homes and businesses estimated at between €80 and €100 million[12]. The economic losses include transport disruption and loss of business

[12] Owens McCarthy insurance assessors as quoted in The Irish Times (18/7/02).

(Merz et al. 2010) as well as social impacts such as temporary relocation, stress and anxiety (Otto et al. 2006, Wolf et al. 2006). However, the spatial distribution of forests in Ireland means that any mitigation of flooding is likely to impact most on agricultural land. In the UK, flood damage to grazing land has been estimated at between €100 and €750 ha^{-1} per event depending on the season and intensity of the flooding (Posthumus et al. 2009). More significant avoided costs would be realised where there are settlements downstream of forests. This ES benefit could also be increased through the targeting of future forest planting.

While there is evidence to support the flood mitigation potential of forests, many plantations have been planted on peat-based or wet mineral soils of low permeability. Management practices may also exacerbate rather than alleviate flooding. The presence of drainage ditches for forestry planted on peat soils in the Coalburn catchment in Wales was found to result in an immediate 15% increase in peak flows (Birkinshaw et al. 2014). However, streamflow in the catchment fell below that associated with the original vegetation as the trees matured, by which stage reductions in peak flow in the region of 10-20% were recorded (Robinson et al. 2003). In Ireland, discharge during rainfall events from a high gradient peaty catchment with mature conifer forest was found to be significantly higher than in a comparable moorland system (Kelly-Quinn et al. 1996).

Overall, the ES value of forests in Ireland in moderating run off depends on where the trees are planted, including soil type, drainage network and the susceptibility of downstream infrastructure to flooding. The current benefits may be modest, but this does not preclude the potential benefit of targeting planting to mitigate flood risk.

Water quality and aquatic ecology

The presence of natural riparian woodland provides a further regulating ES as it reduces bankside erosion and contributes to the removal of pollutants and contaminants from surface run-off (Calder 2007, Dudley and Stolton 2003). This reduces the pressures placed on the aquatic ecosystem which itself has a remarkable capacity to assimilate organic matter and nutrients (Lewandowski et al. 2011, Gray 2004).

Riverside trees have a direct positive impact on stream temperature which has been shown to influence multiple aspects of stream ecology (Poole and Berman 2001, Beschta et al. 1987, Larson and Larson 1996, Wilkerson et al. 2006, Webb and Crisp 2006). In their absence, acute temperature stress can impact on the development and survival of juvenile salmonids (Elliott and Elliott 1995, Armstrong et al. 2003, Rimmer et al. 1985). Conversely, too much shade can reduce the abundance and productivity of macro-invertebrates (Behmer and Hawkins 1986). Consequently, discontinuous riparian cover is ideal. Riparian woodland also supplies aquatic fauna with nutrients from woody debris and leaf fall (Lehane et al. 2002) and provides a variety of terrestrial invertebrates for fish (Ryan and Kelly-Quinn 2015). It is also a habitat for aquatic insects which further improve water quality by grazing algal growth (Sturt et al. 2013).

The bulk of these ES are provided by broadleaf riparian vegetation such as riverside willow or alder rather than by forests. Riparian vegetation is, for example, useful for intercepting nutrient pollution from agricultural run-off or domestic septic tanks (Howley et al. 2014, Lowrance et al. 1997). At the national level, the proportion of general forest cover in Irish catchments also tends to be associated with better water quality (Howley et al. 2014, Donohue et al. 2005). Older coniferous plantings often introduced excess riverside shade, but current regulations require that a buffer strip is provided between rivers and commercial conifer species and there is an opportunity for native riparian species to colonise this space or to be planted (see McConigley et al. 2015).

In economic terms, these ES reduce the cost of measures needed to meet Ireland's obligations under the EU Water Framework Directive (WFD). Vegetated buffer strips, including riparian woodland, can also provide a barrier against pathogens or organic pollutants that contribute to health risks such as water-borne gastroenteritis, cryptosporidium and carcinogenic trihalomethanes (Artwill et al. 2002). To achieve the WFD requirement of "good status" for all surface waters, EU Member States have had to make substantial investments in water and wastewater treatment and catchment management. Ultimately, these measures rely on public support. Value transfer studies indicate that the public is willing to pay on average €32 and €66 per household per year for respectively small and large improvements in water quality (Norton et al. 2012)[13]. In a primary valuation study of the River Boyne by Stithou et al. (2011), conditions supporting aquatic biodiversity were identified as important elements of economic welfare along with health and visual criteria. Angling values are also relevant given the contribution of riparian woodland to salmonids. On average, each rod-caught salmon in Ireland has been valued at €1,000 as well as being a significant driver of the tourism economy (Indecon 2003).

Potential adverse impacts on water quality and aquatic ecosystem services

From the opposite perspective, there are also potentially adverse effects from forestry on water quality, and particularly from plantation forestry, although these ecosystem disservices can be addressed through appropriate management. Problems can arise from eutrophication (Drinan et al. 2013, Thimonier et al. 1994, Machava et al. 2007), sedimentation (Madej 2001, Kreutzweiser and Capell 2001) and freshwater acidification (Kelly-Quinn et al. 1996, Giller and O'Halloran 2004) at various stages in the forest cycle. Of these, most eutrophication affects 38% of surface waters in

[13] Transfer of willingness-to-pay values from overseas adjusted for the characteristics of the Irish population and rivers.

Ireland but is due mainly to poor agricultural practice rather than forests (McGarrigle et al. 2010). Nitrate losses from planted forests in Ireland are low (McGarrigle et al. 2010, Silgram et al. 2008) and much phosphorus is retained by the trees or intercepted by undergrowth (Jennings et al. 2003, Reynolds and Davies 2001). An exception occurs on peat soils which can leach phosphorus readily (Finnegan et al. 2014, Kelly-Quinn et al. 2016). Forest induced eutrophication is a major threat to peatland lakes and rivers due to their inherent oligotrophic status (Ryder et al. 2014, Drinan et al. 2013, Renou-Wilson et al. 2008).

Forests have been linked to the mobilisation of sediment particularly during site preparation and harvesting (Moffat 1988, Giller and O'Halloran 2004). Excess sedimentation in water courses clouds the water and inhibits photosynthesis by macrophytes which perform an important oxygenating service (Gallagher et al. 2001, Wood and Armitage 1997, Madsen et al. 2001). Sediment from various sources can smother gravel beds and impact adversely on the habitat for invertebrates and salmonids (Wood and Armitage 1997, Johnson et al. 2000). A particular concern is the freshwater pearl mussel (*Margaritifera margaritifera* L.) whose population has fallen dramatically (Geist 2005, Geist 2010). Excess sediment is detrimental to the early post settlement stage as it clogs the animal's gills (Moorkens 2010).

Mature plantations in-situ have lower rates of sediment loss than those recorded from agriculturally dominated catchments (Reubens et al. 2007, Montgomery 2007). However, forest roads and harvesting can release large volumes of sediment (Quinn and Stroud 2002, Grace 2005, Perry et al. 1999). Harvesting and replanting protocols, including use of buffer zones and sediment traps, can intercept run-off and sediment (Silgram et al. 2008, Bastrup-Birk and Gundersen 1999, Rodgers et al. 2012). This advice is now included in Irish Forest Service guidelines, reducing the potential impact on fish and other freshwater biodiversity.

Of the third environmental effect, acidification occurs when trees scavenge nitrogen and sulphur compounds from the atmosphere and release these into water bodies following rainfall (Fowler et al. 1989, Ormerod et al. 1991, Jenkins et al. 1990). Acidification can also arise from release of organic acids from peaty soils, now a key driver of acidification in Irish conifer forests (Feeley et al. 2014). It can impact on plants and invertebrates (Mulholland et al. 1986, Vinebrooke and Graham 1997, Guerold et al. 2000, Dangles et al. 2004) and impair the development of salmon eggs and smolts (Gensemer and Playle 1999, McCormick et al. 2009, Harrison et al. 2014). Whereas high densities of aquatic invertebrates have been associated with deciduous woodland whose leaf litter is rapidly broken down (Richardson et al. 2004), dense conifer plantations do present a risk due to the permanence of needles. In Ireland, the prevalence of Atlantic weather systems and predominance of limestone bedrock does reduce the risk from acidification (Kaste and Skjelkvåle 2002) compared with some other countries. However, while the atmospheric driver has reduced over time, high DOC concentrations due to forestry planted on peat soils are a source of acidification on base-poor geology (Feeley et al. 2013).

Habitat services

Habitat or supporting services were listed by the MEA, but to avoid double-counting the CICES classification treats these as ecological processes or functions that contribute to final ES. Four Irish forest habitats are listed as priority habitats in Annex 1 of the EU Habitats Directive; old sessile oak woods (91A0), alluvial forests (91E0), yew woodlands (91JO) and bog woodland (91DO). These habitats are valued for the species they support, but also, in their own right, as relatively rare examples of semi-natural woodland. Other forest types provide an important habitat service for both threatened and familiar wildlife species (Irwin et al. 2013). Active management for biodiversity is required on 15% of the forest area of all new grant-aided forest plantings, including private plantings (Forest Service 2000).

Linking final ES values back to biophysical conditions is extremely difficult. Economic valuation has been used in Ireland to demonstrate species or habitat values of introducing more tree species (Mill et al. 2007), nature reserves (Scarpa et al. 2000) and biodiversity areas (Upton et al. 2012). A strong relationship is evident between these stated values and respondents' access to forests (Upton et al. 2014). However, there is often a lack of information with which to link flows of final ES of social and economic value to the underpinning biological processes (Durance et al. 2016). It is believed that a diverse range of species, or specifically functional diversity, supports ecosystem resilience to change or external shocks and its capacity to support essential ES (Perrings et al. 2010, Durance et al. 2016). Typically, such a diverse range of specialist species is found in native and semi-natural woodland rather than plantation forest, which is usually characterised by a rather small number of tree types (Coote et al. 2012, Irwin et al. 2013, Sweeney et al. 2010, Gamfeldt et al. 2013). Due to its geographical separation from mainland Europe, combined with the fragmented nature of remaining semi-natural woodland, Ireland has retained only a small subset of the specialist woodland species found in Britain and other parts of the continent (Kelly 2008). The remaining area of native species woodland provides continuity of habitat for some species, although many woodlands are in poor condition due to lack of management, deer browsing and invasive non-native plant species, in particular rhododendron (Bullock et al. 2014).

Nevertheless, in many parts of the world, plantation forest can provide surrogate habitat for forest wildlife. Indeed, recent research in Ireland has demonstrated that conifer plantations can harbour a range of plant and animal biodiversity, including protected native species (Irwin et al. 2013). The net value of this planting depends on where it occurs and what it replaces. As native woodland is protected, much plantation forest has replaced open habitats on peatland soils and wet upland grazing land (Smith et al. 2006). Forest Service rules have reduced the recent level of planting on the former, but wet grassland is of habitat value if low intensity grazing is maintained (Wilson et al. 2012),

Although 23% of planting between 2002 and 2010 has involved broadleaf species, this proportion has been increasing. This trend reflects current grant support and biodiversity guidelines that stipulate that 10% of the planted area should comprise of broadleaf species and that further areas are set aside specifically for biodiversity enhancement. Potentially, new afforestation could be targeted to maximise biodiversity, particularly in relation to the siting of new forests in the landscape to complement the existing mosaic of habitats or to provide connectivity with existing woodland[14].

Cultural services

Natural ecosystems provide the setting for a variety of human interactions with the outdoor environment (Church et al. 2011). According to the MEA (2005), cultural ES can encompass aesthetic, spiritual, health and social benefits and associations as well as more direct physical interaction. Recreation and amenity benefits are among the most important cultural services provided by Ireland's forests, but a quantification of the extent of these benefits is compounded by the lack of reliable figures on visitation. Coillte refers to a figure of 18 million visits for its own forest estate based on the median number of trips reported from in-forest interviews conducted by Fitzpatrick Associates (2005). The household survey that supplemented these interviews indicated a higher total of 38 million visits per year to all forest areas in Ireland. Although considerably more than earlier estimates, a high figure is possible given repeat visits, noting also the evidence of visits to local authority owned forest located close to urban centres. Upton et al. (2014) have estimated forest visitation at 29 million by combining survey data collected on behalf of COFORD (Irish Council for Forest Research and Development) with spatially explicit forest recreational demand estimates for a simulated population of Ireland (SMILE model). A travel cost estimate based on these figures indicates an average travel cost of €6.16 per visit. This compares with an average of stated preference values of €5 per visit for seven of the main surveys undertaken to date[15]. On this basis, the direct recreational value alone would be worth €179 million per year.

As well as utility benefits, forest visits provide indirect ES benefits through their contribution to physical and mental health. Physical exercise is vital in combating obesity, cardio-vascular and musculo-skeletal diseases, stroke and cancer. If applied to Ireland, figures for the UK (CJC Consulting 2005) suggest that just a 1% reduction

[14] See Peterken (2002) for more discussion of spatial afforestation benefits.

[15] i.e. Ní Dhubháin (1994), Clinch (1999), Fitzpatrick Associates (2005a), Fitzpatrick Associates (2005b), Hynes et al. (2007a), Hynes et al. (2007b) and Cullinan (2011).

in the 24% of the population who are physically inactive would reduce premature deaths and morbidity amongst people under 75 years by 715 cases per year and save €37 million in annual healthcare costs and productivity losses. If the Health Economic Assessment Tool (HEAT) (www.heatwalkingcycling.org) developed for the World Health Organisation is applied to just the 8% of respondents to the Coillte survey who visit forests at least once per month and are engaged in active exercise (mostly walking), this would suggest savings on premature mortality of at least €113 million per year and potentially as much as €259 million per year[16]. While the direct and indirect value of forest recreation is substantial, it is notoriously difficult to attribute health benefits to any one activity (Sunderland 2012). In addition, recreation and health benefits do not necessarily imply a strong relationship with the forest ecosystems. For example, Coillte has installed several popular mountain bike trails in recent years, but this activity could be argued to involve only a partial relationship with forests as facilities could be provided in other environments. However, as Ireland is poorly supplied with walking opportunities relative to many other European countries given the absence of laws permitting access to private land (Buckley et al. 2009), this lack of provision means that publicly-owned forest can make a distinct contribution given that it is amongst the few rural environments where people can walk.

There are other activities such as nature viewing or birdwatching that do have a strong relationship with forests. These interests are relevant to non-use values too. Nature – or naturalness – makes a significant contribution to casual visits and cultural services as noted earlier (Termansen et al. 2013, Edwards et al. 2012). In Ireland, a stated preference survey by Upton et al. (2012) found that people were willing to pay €21 per year for “biodiversity enhancement areas” totalling 15% of a forest’s area and would pay €33 per year for an increase in this area from 0% to 30%, in addition to higher sums for broadleaf or mixed species forest compared with conifers. Nature has also been identified as inducing psychological improvements in mood, concentration and attention (Ulrich 1981), reduced mental fatigue (Kuo 2001) and reductions in stress-related diseases (Hartig et al. 1991). A variety of studies have demonstrated the benefits that walking in natural environments can have by increasing positive mood, concentration and mental performance in cognitive tests (Townsend 2006, Berman et al. 2008). Effects have been detected for elderly people (De Vries et al. 2003, Ottosson and Grahn, 2005), children with Attention Deficit Disorder (ADD) (Kuo and Taylor 2004) and people with major depressive disorder (MDD) (Berman et al. 2012).

In a survey of visitors to two Irish forests, Iwata et al. (2016; this issue) found that the main psychological well-being benefit experienced by forest visitors was mental

[16] Range is based on 30 and 60 minutes exercise and assumes an equal share of weekly and daily visits for the 41% of adult population engaged in active exercise. The model only allows for daily and weekly exercise. As daily exercise accounts for over 70% of the estimated benefits, the most accurate figure is likely to be between these ranges. The tool estimates the value of a statistical life at €2,587,175.

relaxation. Mental relaxation can be considered synonymous with psychological restoration, a recognized benefit of spending time in the natural environment which has been described as a product of emotional interaction with the natural environment (Ulrich 1983). Iwata et al. evaluated a pilot programme of forest walks organised for people suffering from depression and found that those participants registered improvements immediately following the visits. They also realised a significant reduction in depression symptoms following therapy in which these visits were an important element. Social interaction, being outdoors, and physical exercise were described as key factors. However, similar problems of attribution apply to mental health benefits as to physical exercise. It is acknowledged that the specific role of forest visits would be extremely difficult to identify given the complementary treatment provided and the complex nature of mental health.

Discussion

Forestry in Ireland provides many of the same ES as other countries located in similar climate zones and with a similar forest composition. These ES have both an economic and a socio-cultural value, although it would be unreliable to aggregate benefits estimates for an average forest due to the varying degree to which these values depend on the commercial or non-commercial nature of the forest, its species composition, age, location and management.

Forestry provides a valuable provisioning service in the form of timber and wood products. Conifer species grow well in the Irish climate and have enabled the country to build up a prosperous forestry sector. Although the timber may be considered lower quality than native hardwoods in terms of strength or grain, it nevertheless has a sizeable market particularly for construction purposes. There are related regulating service benefits in that these are relatively long-term uses by which the carbon content remains locked away for many decades. The market for forest products also provides the rationale for planting and the young age of much of Ireland's forest means that there is a high level of sequestration during the trees' growth. Losses of soil carbon occur at various times in the forest cycle, but can be mitigated to allow the carbon sequestration by forests to exceed that of other land uses. Recent growth in the market for fuelwood has also provided an expanded outlet for thinnings and residue which can substitute for non-renewable carbon fuels.

Other important regulating ES include water flow moderation and benefits for water quality. The benefits should be viewed objectively. The capacity to moderate run-off may diminish for more severe rainfall events and is less likely to be realised in economic terms in remote rural areas than in the vicinity of urban areas where valuable real estate is at risk. Likewise, the benefits to water quality are supplied more by alluvial woodland than by conifer forest in general. Forest, especially mature broadleaf or mixed species forest, also provides habitats for biodiversity, supporting regulating, provisioning and cultural ES.

Many cultural ES benefits relate to a range of opportunities that forests provide for amenity, although some of these activities are not specific to this environment, but are often due to the accessibility of forests relative to areas of other land use. Nevertheless, these benefits are enhanced by the visual setting and the biodiversity that forests support. They are borne out by stated preference surveys and by the external benefits for local economies from recreation and tourism. Although it is difficult to attribute and quantify the benefits to health, studies of both physical and mental health referenced in this paper, indicate the rounded contribution that forests make to well-being.

For all these services appropriate management is essential. The Forest Service's mix of regulation and incentives has contributed to timber and carbon sequestration by increasing the proportion of broadleaf planting, both to provide a sustainable supply of hardwoods for a diverse wood processing sector and for long term carbon storage in-situ by amenity plantings. Existing regulations also reduce the risk of soil disturbance and minimise the use of fertilisers or pesticides that present a risk to aquatic water quality. There are particular benefits in using buffer strips comprised of open areas and native riparian species to protect against nutrient and sediment run-off. There are also opportunities to provide a diversity of forest habitat and biodiversity. A continuous supply of ES benefits is supported by premium payments, but could be strengthened through a renewed supply of incentives for proactive habitat management, invasive plant control and deer management.

Many of these benefits are complementary to one another and can ensure that existing plans for forest expansion simultaneously meet Ireland's international and European policy obligations with regard to climate change, water quality, biodiversity and landscape. For example, protecting river quality attracts biodiversity as well as active and passive recreation benefits. Planting broadleaves, including native species, provides habitat for biodiversity, but also settings for amenity use. There are economic benefits such as employment and business opportunities for local communities and socio-cultural benefits such as security of homes and livelihoods, well-being and health. The complementary nature of these ES leads naturally to an argument for targeting incentives to where the benefits are highest or most effectively achieved. For example, targeted and cooperative initiatives between neighbouring landowners can be used to extend planting beside vulnerable stretches of river to protect water quality; to connect isolated areas of forest including remaining native woodland; or to plant and link woodlands close to where people live or are under-provided with forest.

Conclusion

This paper has set out to provide an objective assessment of the level of ES provided by forests in Ireland, including evidence of the scale of the economic and social benefits. When planted in suitable locations, on suitable soils, forests can provide a wide range of valuable ES. Negative impacts can occur when these conditions do not apply. Regulations and incentives can be used to ensure that planting take places in appropriate areas and with subsequent management minimises the risk of adverse outcomes.

Forests, including plantation forests, can be managed to supply many important benefits covering the full range of intermediate and final ES. These include timber supply, carbon sequestration, moderation of run-off, protection of water quality, amenity, recreation and health. These types of ES, and the means to maximise their flow, are relevant to other countries with a similar forest structure. This review has sought to provide a comprehensive overview, but also to demonstrate the interactions that exist between ecological processes, functions and services that could be overlooked by singular disciplinary perspectives. Ireland's forest policy accepts the need to recognise the role of ES benefits. If linked to management incentives and targeted planting, this will contribute to our international policy obligations with regard to climate change, water quality, biodiversity and landscape.

Acknowledgements

The research was undertaken as part of the EcoValue project (11/C/204) coordinated by Dr. Áine Ní Dhubháin and funded by the Department of Agriculture, Food and the Marine.

References

Allen, A. and Chapman, D. 2001. Impacts of afforestation on groundwater resources and quality. *Hydrogeology Journal* 9: 390–400.

Armstrong, J., Kemp, P., Kennedy, G., Ladle, M. and Milner, N. 2003. Habitat requirements of Atlantic salmon and brown trout in rivers and streams. *Fisheries Research* 62: 143–170.

Artwill, E.R., Hou, L., Karle, B.M., Hartenr, T., Tate, K.W. and Dahlgren, R.A. 2002. Transport of *Crytosporidium parvum* oocysts through vegetated buffer strips and estimated filtration capacity. *Applied Environmental Microbiology* 68: 5517–5527.

Bastrup-Birk, A. and Gundersen, P. 1999. Water quality improvements from afforestation in an agricultural catchment in Denmark illustrated with the INCA model. *Hydrology and Earth System Sciences* 8: 764–777.

Bastrup-Birk, A. and Marchetti, M. 2011. *Maintenance and Encouragement of Productive Functions of Forests (Wood and non-Wood)*. State and trends in sustainable forest management in Europe. Food and Agriculture Organization of the United Nations, FAO, p. 51–63.

Behmer, D.J. and Hawkins, C.P. 1986. Effects of overhead canopy on macroinvertebrate production in a Utah stream. *Freshwater Biology* 16: 287–300.

Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W. and Courchamp, F. 2012. Impacts of climate change on the future of biodiversity. *Ecology letters* 15: 365–377.

Berman, M.G., Jonides, J. and Kaplan, S. 2008. The cognitive benefits of interacting with nature. *Psychological Science* 19: 1207–1212.

Berman, M.G., Kross, E., Krpan, K.M., Askren, M.K., Burson, A. and Deldin, P.J. 2012. Interacting with nature improves cognition and affect for individuals with depression. *Journal of Affective Disorders* 140: 300–305.

Beschta, R.L., Bilby, R.E., Brown, G.W., Holtby, L.B. and Hofstra, T.D. 1987. Stream temperature and aquatic habitat: fisheries and forestry interactions. *Streamside management: Forestry and Fishery Interactions* 57: 191–232.

Birkinshaw, S.J., Bathurst, J.C. and Robinson, M. 2014. 45 years of non-stationary hydrology over a forest plantation growth cycle, Coalburn catchment, Northern England. *Journal of Hydrology* 519: 559–573.

Black, K. and Farrell, E. 2006. *Carbon Sequestration and Irish Forest Ecosystems*. COFORD, National Council for Forest Research and Development, Dublin.

Bolund, P. and Hunhammer, S. 1999. Ecosystem services in urban areas. *Ecological Economics* 29: 293–301.

Bradshaw, C.J., Sodhi, N.S., Peh, K.S.H. and Brook, B.W. 2007. Global evidence that deforestation amplifies flood risk and severity in the developing world. *Global Change Biology* 13: 2379–2395.

Buckley, C., Hynes, S., van Rensburg, T.M. and Doherty, E. 2009. Walking in the Irish countryside: landowner preferences and attitudes to improved public access provision. *Journal of Environmental Planning and Management* 52: 1053–1070.

Bullock, C. and Hawe, J. 2013. The Natural Capital Value of Native Woodland in Ireland. Woodlands of Ireland.

Bullock, C., Hawe, J. and Little, D. 2014. Realising the ecosystem service value of native woodland in Ireland. *New Zealand Journal of Forestry Science* 44: (Suppl 1).

Byrne, K.A. 2010. The role of plantation forestry in Ireland in the mitigation of greenhouse gas emissions. *Irish Forestry* 67: 86–96.

Calder, I.R. 2007. Forests and water – ensuring forest benefits outweigh water costs. *Forest Ecology and Management* 251: 110–120.

Calder, I.R., Reid, C.T., Nisbet, T.R., Armstrong, L.K., Green, J.C. and Parkin, G. 2002. Impact of lowland forests in England of the potential impact on water resources of afforestation. Department of the Environment, Food and Rural Affairs. London.

Chen, J., Ustin, S.L., Suchanek, T.H., Bond, B.J., Brosofske, K.D. and Falk, M. 2004. Net ecosystem exchanges of carbon, water, and energy in young and old-growth Douglas-fir forests. *Ecosystems* 7: 534–544.

Church, A., Burgess, J. and Ravonscroft, N. 2011. Cultural ecosystem services. In *UK National Ecosystem Assessment (UK NEA)*.

CICES. 2013. Common International Classification of Ecosystem Services. Prepared by the University of Nottingham and Centre for Environmental Management for European Environment Agency.

CJC Consulting. 2005. Economic Benefits of Accessible Green Spaces for Physical and Mental Health. *CJC Consulting with Prof. Ken Willis and Dr. Liesl Osman*. Final report for the UK Forestry Commission. Edinburgh.

Clinch, J.P. 1999. *Economics of Irish Forestry: Evaluating the Returns to Economy and Society*. COFORD: Dublin, pp. 276.

Collier, P., Short, I. and Dorgan, J. 2004. *Markets for Non-Wood Forest Products*. COFORD, National Council for Forest Research and Development. Dublin.

Coote, L., French, L., Moore, K., Mitchell, F. and Kelly, D. 2012. Can plantation forests support plant species and communities of semi-natural woodland? *Forest Ecology and Management* 283: 86–95.

Crockford, R.H. and Richardson, D.P. 2000. Partitioning of rainfall into throughfall, stemflow and interception: effect of forest type, ground cover and climate. *Hydrological Processes* 14: 2903–2920.

DAFM. 2014. *Forests, Products And People: Ireland's Forest Policy – A Renewed Vision*. Department of Agriculture, Food and the Marine. Dublin.

Dangles, O., Gessner, M.O., Guerold, F. and Chauvet, E. 2004. Impacts of stream acidification on litter breakdown: implications for assessing ecosystem functioning. *Journal of Applied Ecology* 41: 365–378.

De Vries, S., Verheij, R.A., Groenewegen, P.P. and Spreeuwenberg, 0. 2003. Natural environments –healthy environments? An exploratory analysis of the relationship between greenspace and health. *Environment and Planning* 35: 1717–1731.

Donlan, J., Skog, K.E. and Byrne, K.A. 2012. Carbon storage in harvested wood products for Ireland 1961–2009. *Biomass and Bioenergy* 46: 731–738.

Donohue, I., McGarrigle, M.L. and Mills, P. 2005. Linking catchment status and water chemistry with the ecological status of Irish rivers. *Water Research* 40: 91–98.

Drinan, T., Graham, C., O'Halloran, J. and Harrison, S. 2013. The impact of catchment conifer plantation forestry on the hydrochemistry of peatland lakes. *Science of the Total Environment* 443: 608–620.

Drinan, T., Graham, C., O'Halloran, J. and Harrison, S. 2013. The impact of conifer plantation forestry on the Chydoridae (Cladocera) communities of peatland lakes. *Hydrobiologia* 700: 203–219.

Dudley, N. and Stolton, S. 2003. Running pure: the importance of protected forest areas to drinking water. *The Arguments for Protection Series*. World Bank. WWF Alliance for Forest Protection and Sustainable Use.

Durance, I., Bruford, M.W. and Chalmers, R.E.A. 2016. The challenges of linking ecosystem services to biodiversity: lessons from a large-scale freshwater study. *Advances in Ecological Research* 54: 87–134.

Edwards, D.M., Jay, M. Jensen, F.S. Lucas, B. Marzano, M. Montagné, C. Peace, A. and Weiss, G. 2012. Public preferences across Europe for different forest stand types as sites for recreation. Ecology and Society 17: 27–38.

Elliott, J. and Elliott, J. 1995. The effect of the rate of temperature increase on the critical thermal maximum for parr of Atlantic salmon and brown trout. *Journal of Fish Biology* 47: 917–919.

EU. 2011. *The EU Biodiversity Strategy to 2020*. European Union. Luxembourg.

FAO. 2005. *Forests And Floods: Drowning in Fiction or Thriving on Facts*. FAO and CIFOR. Bangkok, Thailand.

FAO. 2010. *Planted Forests in Sustainable Forest Management – a Statement of Principles*. FAO Organisation, Rome.

Farley, K.A., Jobbágy, E.G. and Jackson, R.B. 2005. Effects of afforestation on water yield: a global synthesis with implications for policy. *Global Change Biology* 11: 1565–1576.

Feeley, H.B., Bruen, M., Blacklocke, S. and Kelly-Quinn, M. 2013. A regional examination of episodic acidification response to reduced acidic deposition and the influence of plantation forests in Irish headwater streams. *Science of the Total Environment* 443: 173–183.

Finnegan, J., Regan, J.T., Fenton, O., Lanigan, G.J., Brennan, R.B. and Healy, M.G. 2014. The short term effects of management changes on watertable position and nutrients in shallow groundwater in a harvested peatland forest. *Journal of Environmental Management* 142: 46–52.

Fisher, B., Turner, K. and Morling, R. 2009. Defining and classifying ecosystem services for decision making. *Ecological Economics* 68: 643–653.

Fitzpatrick Associates. 2005. *Economic Value of Trails and Forest Recreation in the Republic of Ireland*. Dublin.

Forest Europe. 2014. Expert Group and Workshop on Valuation of Forest Ecosystem Services. Ministerial Conferences on the Protection of Forests in Europe. Madrid.

Forest Service. 2013. *National Forest Inventory – Republic of Ireland –Results*. Forest Service, Department of Agriculture, Food and the Marine. Wexford, Ireland.

Forest Service. 2000. *Forest Biodiversity Guidelines*. Dublin, pp. 10.

Fowler, D., Cape, J., Unsworth, M., Mayer, H., Crowther, J., Jarvis, P.G., Gardiner B. and Shuttleworth, W.J. 1989. Deposition of atmospheric pollutants on forests. *Philosophical Transactions of the Royal Society of London B, Biological Sciences* 324: 247–265.

Gallagher, M., Johnson, M., O'Gorman, K., O'Halloran, J., Giller, P. and Clenaghan, C. 2001. The impact of clearfelling operations on physico-chemical parameters of aquatic ecosystems in southwest Ireland. *Internationale Vereinigung fur Theoretische und Angewandte Limnologie Verhandlungen* 27: 1108–1115.

Gamfeldt, L., Snäll, T., Bagchi, R., Jonsson, M., Gustafsson, L., Kjellander, P., Ruiz-Jaen, M.C., Fröberg, M., Stendahl, J., Philipson, C.D., Mikusiński, G., Andersson, E., Westerlund, B., Andrén, H., Moberg, F., Moen, J. and Bengtsson, J. 2013. Higher levels of multiple ecosystem services are found in forests with more tree species. *Nature Communications* 4: 1340–1348.

Geist, J. 2005 Conservation genetics and ecology of European freshwater pearl mussels *(Margaritifera margaritifera* L.*)*, PhD Thesis, Technischen Universität Müchen.

Geist, J. 2010 Strategies for the conservation of endangered freshwater pearl mussels (Margaritifera margaritifera L.): a synthesis of conservation genetics and ecology. *Hydrobiologia* 644: 69–88.

Gensemer, R.W. and Playle, R.C. 1999. The bioavailability and toxicity of aluminum in aquatic environments. *Critical Reviews in Environmental Science and Technology* 29: 315–450.

Giller, P.S. and O'Halloran, J. 2004. Forestry and the aquatic environment. Studies in the Irish context. *Hydrology and Earth System Sciences Discussions* 8: 314–326.

Giller, P.S. and O'Halloran, J. 2004. Forestry and the aquatic environment: studies in an Irish context. *Hydrology and Earth System Sciences Discussions* 8: 314–326.

Gobin, A., Campling, P., Janssen, L., Desmet, N., van Delden, H., Hurkens, J., Lavelle, P. and Berman, S. 2011. *Soil Organic Matter Management across the EU – Best Practices, Constraints and Trade-offs*. European Commission, DG Environment.

Gomez-Baggethun, E. and Barton, D.N. 2012. Classifying and valuing ecosystem services for urban planning. *Ecological Economics* 86: 235–246.

Grace, J. 2005. Forest operations and water quality in the South. *Transactions of the ASAE* 48: 871–880.

Gray, N. 2004 *Biology of Wastewater Treatment*. 2nd ed. Imperial College Press.

Guerold, F., Boudot, J.P., Jacquemin, G., Vein, D., Merlet, D. and Rouiller, J. 2000. Macroinvertebrate community loss as a result of headwater stream acidification in the Vosges Mountains (NE France). *Biodiversity and Conservation* 9: 767–783.

Guitart, A.B. and Rodriguez, L. 2010. Private valuation of carbon sequestration in forest plantations. *Ecological economics* 69: 451–458.

Haines-Young, R. and Potschin, M. 2010. The links between biodiversity, ecosystem services and human well-being In *Ecosystem Ecology: A New Synthesis*. Eds. Raffaelli, D. and Frid, C., Cambridge University Press, pp. 110–139.

Hargreaves, K.J., Milne, R. and Cannell, M.G.R. 2003. Carbon balance of afforested peatland in Scotland. *Forestry* 76: 299–317.

Harrigan, S., Murphy, C., Hall, J., Wilby, R.L. and Sweeney, J. 2014. Attribution of detected changes in streamflow using multiple working hypotheses. *Hydrology and Earth System Sciences* 18: 1935–1952.

Harrington, T. and Cullen, M. 2008. Assessment of wild edible fungi production in Irish woodlands. COFORD.

Harrison, S.C., Hutton, S., Jan-Robert, B., Cruickshanks, R.H., Johnson, J., Guillaume, J., Tadeuz, K., Matson, R., O'Halloran, J., Phelan, P. and Kelly-Quinn, M. 2014. Contrasting impacts of conifer forests on brown trout and Atlantic salmon in headwater streams in Ireland. *Biology and Environment* 114B 219–231.

Hartig, T., Mang, M. and Evans, G.W. 1991. Restorative effects of natural environment experiences. *Environment and Behaviour* 23: 3–26.

Howley, P., Buckley, C., Jordan, R., O'Donoghue, C., Hynes, S. and Green, S. 2014. A spatial analysis of the distribution of river water quality benefits and the major forces affecting river water quality across the Republic of Ireland. *EPA Strive Report*. Environmental Protection Agency. Johnstown Castle, Wexford.

Howley, P., Ryan, M. and Donoghue, C.O. 2011. Forestry in Ireland: An examination of individuals' preferences and attitudes for the non-market benefits of forests. *Irish Geography* 44: 291–302.

Indecon. 2003. An economic/socio-economic evaluation of wild salmon in Ireland. Indecon International Economic Consultants for Central Fisheries Board.

Irwin, S., Kelly, D.L., Kelly, T.C., Mitchell, F.J.G., Coote, L., Oxborough, A., Wilson, M.W., Martin, R.D., Moore, K.A., Sweeney, O., Dietzsch, A. and O'Halloran, J. 2013. Do Irish forests provide habitat for species of conservation concern? *Biology and Environment, Proceedings of the Royal Irish Academy*. 113: 273–279.

Irwin, S., Pedley, S.M., Coote, L., Dietzsch, A.C., Wilson, M.W., Oxborough, A., Sweeney, O., Moore, K.M., Martin, R., Kelly, D.L., Mitchell, F.J.G., Kelly, T.C. and O'Halloran, J. 2013.The value of plantation forests for plant, invertebrate and bird diversity and the potential for cross taxon surrogacy. *Biodiversity and Conservation* 23: 697–714.

Iwata, Y., Ní Dhubháin, Á. and Bullock, C.H. 2016. The psychological and physical impacts of spending time in forests: A case study of two forests in Ireland. *Irish Forestry* 73: 180–199 (this issue).

Jenkins, A., Cosby, B., Ferrier, R., Walker, T. and Miller, J. 1990. Modelling stream acidification in afforested catchments: an assessment of the relative effects of acid deposition and afforestation. *Journal of Hydrology* 120: 163–181.

Jennings, E., Mills, P., Jordan, P., Jensen, J.P., Søndergaard, M., Barr, A., Glasgow, G. and Irvine, K. 2003. Eutrophication from agricultural sources: seasonal patterns & effects of phosphorus – Final Report. Environmental Protection Agency, Ireland.

Johnson, M.J., O'Gorman, K., Gallagher, M., Clenaghan, C., Giller, P.S. and O'Halloran, J. 2000. The identification and amelioration of the impacts of clearfelling operations on macroinvertebrates and salmonids in Ireland. *Verhandlungen des Internationalen Verein Limnologie* 27: 1565–1570.

Kaste, Ø. and Skjelkvåle, B.L. 2002 .Nitrogen dynamics in runoff from two small heathland catchments representing opposite extremes with respect to climate and N deposition in Norway. *Hydrology and Earth System Sciences Discussions* 6: 351–362.

Kelly, T.C. 2008. The origin of the avifauna of Ireland. *The Irish Naturalist*,29 (Special Supplement: Mind the gap. Postglacial colonization of Ireland pp. 97–107.

Kelly-Quinn, M., Tierney, D., Coyle, C. and Bracken, J.J. 1996. Factors affecting the susceptibility of Irish soft-water streams to forest-mediated acidification. *Fisheries Management and Ecology* 3: 287–301.

Kelly-Quinn, M., Bruen, M., Harrison, S., Healy, M., Clarke, J., Drinan, T., Feeley, H.B., Finnegan, J., Graham, C., Regan, J. and Blacklocke, S. 2016. Assessment of the impacts of forest operations on the ecological quality of water (HYDROFOR). EPA Synthesis Report (2007-WQ-CD-2-S1). Environmental Protection Agency, Johnstown Castle, Co. Wexford, Ireland. Available at: http://erc.epa.ie/safer/reports [Retrieved October 2015].

Knaggs, G. and O'Driscoll, E. 2013. Woodflow and forest-based biomass energy use on the island of Ireland. Coford, Dublin.

Knaggs, G. and O'Driscoll, E. 2013. Woodflow and forest-based biomass energy use on the island of Ireland. Coford, Department of Agriculture, Food and the Marine. Dublin.

Kreutzweiser, D.P. and Capell, S.S. 2001. Fine sediment deposition in streams after selective forest harvesting without riparian buffers. *Canadian Journal of Forest Research* 31: 2134–2142.

Kuo, F.E. 2001. Aggression and violence in the inner city: Effects of environment via mental fatigue. *Environment and Behavior* 33: 543–571.

Kuo, F.E. and Taylor, A.F. 2004. A potential natural treatment for attentiondeficit/hyperactivity disorder: evidence from a national study. *American Journal of Public Health* 94: 1580–1586.

Larson, L.L. and Larson, S.L. 1996. Riparian shade and stream temperature: a perspective. *Rangelands* pp. 149–152.

Laurance, W.F. 2007. Environmental Science: Forests and floods. *Nature* 449: 409–410.

Lehane, B., Giller, P., O'halloran, J., Smith, C. and Murphy, J. 2002. Experimental provision of large woody debris in streams as a trout management technique. *Aquatic conservation: Marine and Freshwater ecosystems* 12: 289–311.

Leonard, R.E. and Parr, S.B. 1970. Woodland trees as a sound barrier. *Journal of Forestry* 68: 282–283.

Lewandowski, J., Putschew, A., Schwesig, D., Neumann, C. and Radke, M. 2011. Fate of organic micropollutants in the hyporheic zone of a eutrophic lowland stream: Results of a preliminary field study. *Science of the Total Environment* 409: 1824–1835.

Lowrance, R., Altier, L.S., Newbold, J.D., Schnabel, R.R., Groffman, P.M., Denver, J.M., Correll, D., Gilliam, J.W., Robinson, J.L., Brinsfield, R.B., Staver, K.W., Lucas, W. and Todd, A.H. 1997. Water quality functions of riparian forest buffers in Chesapeake Bay watersheds. *Environmental Management* 21: 687–712.

Machava, J., McCabe, O., O'Dea, P., Cabral, R. and Farrell, E. 2007. Forestry Operations and Eutrophication – Penrich. *Environmental Research Technological Development and Innovation (ERTDI) Programme 2000–2006 No.78*. Environmental Protection Agency.

Madej, M.A. 2001. Erosion and sediment delivery following removal of forest roads. *Earth Surface Processes and Landforms* 26: 175–190.

Madsen, J., Chambers, P., James, W., Koch, E. and Westlake, D. 2001. The interaction between water movement, sediment dynamics and submersed macrophytes. *Hydrobiologia* 444: 71–84.

McConigley, C., Lally, H., O'Callaghan, M., O'Dea, P., Little, D., Kelly-Quinn, M. 2015. The vegetation communities of unmanaged aquatic buffer zones within conifer plantations in Ireland. *Forest Ecology and Management* 353: 59–66.

McCormick, S.D., Keyes, A., Nislow, K.H. and Monette, M.Y. 2009. Impacts of episodic acidification on in-stream survival and physiological impairment of Atlantic salmon (Salmo salar) smolts. *Canadian Journal of Fisheries and Aquatic Sciences* 66: 394–403.

McGarrigle, M., Lucey, J. and Ó Cinnéide , M. 2010. Water Quality in Ireland 2007–2009. Environmental Protection Agency, Ireland.

McGettigan, M., Duffy, P., Hyde, B., Hanley, E., O'Brien, P. 2009. Ireland National Inventory Report 2009 Greenhouse Gas Emissions 1990–2007: Reported to the United Nations Framework Convention on Climate Change. Environmental Protection Agency, Johnstown Castle Estate, Wexford, Ireland.

McKinsey. 2007. Climate change: Everyone's business—options for greenhouse gas reduction in the UK.

McKinsey. 2007. Costs and potentials of greenhouse gas abatement in Germany, *BDI initiative – Business for Climate*.

MEA. 2005. *Ecosystems and Human Well Being: Synthesis Report*. Millennium Ecosystem Assessment Washington, USA.

Merz, B., Kreibich, H., Schwarze, R. and Thieken, A. 2010. Review article" Assessment of economic flood damage". *Natural Hazards and Earth System Science* 10: 1697–1724.

Mill, G.A., Van Rensburg, T.M., Hynes, S. and Dooley, C. 2007. Preferences for multiple use forest management in Ireland: Citizen and consumer perspectives. *Ecological economics* 60: 642–653.

Millar, C.I., Stephenson, N.L. and Stephens, S.L. 2007. Climate change and forests of the future: managing in the face of uncertainty. *Ecological Applications* 17: 2145–2151.

Moffat, A. 1988. Forestry and soil erosion in Britain–a review. *Soil Use and Management* 4: 41–44.

Montgomery, D.R. 2007. Soil erosion and agricultural sustainability. *Proceedings of the National Academy of Sciences*. 104: 13268–13272.

Moorkens, E.A. 2010. Addressing the conservation and rehabilitation of Margaritifera margaritifera (L.) populations in the Republic of Ireland within the framework of the Habitats and Species Directive. *Journal of Conchology* 40 P. 339.

Motherway, B. and Walker, N. 2009. Ireland's Low-Carbon Opportunity: An analysis of the costs and benefits of reducing greenhouse gas emissions. Sustainable Energy Ireland.

Mulholland, P.J., Elwood, J., Palumbo, A. and Stevenson, R. 1986. Effect of stream acidification on periphyton composition, chlorophyll, and productivity. *Canadian Journal of Fisheries and Aquatic Sciences* 43: 1846–1858.

NESC. 2012. Towards a New National Climate Policy: Interim Report of the NESC Secretariat. National Economic and Social Council.

Ní Dhubháin, Á., Bullock, C., Molooney, R. and Upton, V. 2012. An Economic Evaluation of the Market and Non-Market Functions of Forestry. Coford (Council for Forest Research and Development). Dublin.

Ní Dhubháin, Á., Gardiner, J., Davies, J., Hutchinson, W.G., Chilton, S.M., Thompson, K., Psaltopoulos, D. and Anderson, C. 1994. The socio-economic impacts of afforestation on rural development: Final Report CAMAR. European Community.

Nisbet, T.R. and Thomas, H. 2006. *The Role of Woodland in Flood Control: a Landscape Perspective*. Eds. Davies, B. and Thompson, S., pp. 118–125.

Norton, D., Hynes, S., Doherty, E., Buckley, C., Campbell, D. and Stithou, M. 2012. Benefit Transfer for Irish Water. *STRIVE Programme 2007–2013*. Environmental Protection Agency.

O'Driscoll, E. 2014. UNECE Forestry and Timber Market Report for Ireland 2013. Department of Agriculture, Food and the Marine. Dublin, P. 55.

OPW. 2003. Report of the Flood Policy Review Group. Office of Public Works, Dublin.

Ormerod, S., Rutt, G., Weatherley, N. and Wade, K. 1991. Detecting and managing the influence of forestry on river systems in Wales: results from surveys, experiments and models. *Irish Rivers: Biology and Management. Royal Irish Academy, Dublin* pp. 163–184.

Otto, K., Boos, A., Dalbert, C., Schöps, D. and Hoyer, J. 2006. Posttraumatic symptoms, depression, and anxiety of flood victims: The impact of the belief in a just world. *Personality and Individual Differences* 40: 1075–1084.

Ottosson, J. and Grahn, P. 2005. A comparison of leisure time spent in a garden with leisure time spent indoors: on measures of restoration in residents in geriatric care. *Landscape Research* 30: 23–55.

Pearce, D. 2003. The social cost of carbon and its policy implications. *Oxford Review of Economic Policy* 19: 362–384.

Perrin, P.M. and Daly, O.H. 2010. A provisional inventory of ancient and long-established woodland in Ireland *No. Irish Wildlife Manuals Series*. BEC Consultants for Environment, Heritage and Local Government.

Perrings, C., Naeem, S., Ahrestani, F., Bunker, D.E., Burkill, P., Canziani, G., Elmqvist, T., Ferrati, R., Fuhrman, J., Jaksic, F., Kawabata, Z., Kinzig, A., Mace, G.M., Milano, F., Mooney, H., Prieur-Richard, A-H., Tschirhart, J. and Weisser, W. 2010. Ecosystem services for 2020. *Science* 330: 323–324.

Perry, C.D., Vellidis, G., Lowrance, R. and Thomas, D.L. 1999. Watershed-scale water quality impacts of riparian forest management. *Journal of Water Resources Planning and Management* 125: 117–125.

Phillips, H. 2011. *All-Ireland Roundwood Production Forecast 2011–2028*. COFORD, Department of Agriculture, Fisheries and Food. Dublin.

Poole, G.C. and Berman, C.H. 2001. An ecological perspective on in-stream temperature: Natural heat dynamics and mechanisms of human-caused thermal degradation. *Environmental Management* 27: 787–802.

Posthumus, H., Morris, J., Hess, T., Neville, D., Phillips, E. and Baylis, A. 2009. Impacts of the summer 2007 floods on agriculture in England. *Journal of Flood Risk Management* 2: 182–189.

Potschin, M. and Haines-Young, R. 2011. Ecosystem Services: Exploring a Geographical Perspective. *Progress in Physical Geography* 35: 575–594.

Powe, N.A. and Willis, K.G. 2002. Mortality and morbidity benefits of air pollution absorption by woodland. *Social and Environmental Benefits of Forestry Phase 2*. Forestry Commission. Edinburgh.

Purser, P., Wilson, F. and Carden, R. 2009. *Deer and Forestry in Ireland: A Review of Current Status and Management Requirements*. Woodlands of Ireland.

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

Renou-Wilson, F. and Byrne, K.A. 2015. Irish peatland forests: lessons from the past and pathways to a sustainable future. In *Restoration of Boreal and Temperate Forests*. Eds. Stanturf, J.A and Madsen, P., 2nd ed., CRC Press pp. 321–335.

Renou-Wilson, F., Keane, M., McNally, G., O'Sullivan, J. and Farrell, E.P. 2008. Developing a forest resource on industrial cutaway peatland. *The BOGFOR Programme*. COFORD. Dublin.

Reubens, B., Poesen, J., Danjon, F., Geudens, G. and Muys, B. 2007. The role of fine and coarse roots in shallow slope stability and soil erosion control with a focus on root system architecture: a review. *Trees* 21: 385–402.

Reynolds, C. and Davies, P. 2001. Sources and bioavailability of phosphorus fractions in freshwaters: a British perspective. *Biological reviews* 76: 27–64.

Richardson, J.S., Shaughnessy, C.R. and Harrison, P.G. 2004. Litter breakdown and invertebrate association with three types of leaves in a temperate rainforest stream. *Archiv für Hydrobiologie* 159: 309–325.

Rimmer, D., Saunders, R. and Paim, U. 1985. Effects of temperature and season on the position holding performance of juvenile Atlantic salmon (Salmo salar). *Canadian Journal of Zoology* 63: 92–96.

Robinson, M., Cognard-Plancq, A.L., Cosandey, C., Durand, D.P., Führer, D.H., Hall, R., Hendriques, M.O., Marc, V., McCarthy, R., McDonnell, M., Martin, C., Nisbet, T., O'Dea, P., Rodgers, M., and Zollner, A. 2003. Studies of the impact of forests on peak flows and baseflows: a European perspective. *Forest Ecology and Management* 186: 85–97.

Rodgers, M., O'Connor, M., Muller, M. and Xiao, L. 2012. Suspended solid yield from forest harvesting on upland blanket peat. *COFORD Connects*. COFORD Dublin.

Ryan, D.K. and Kelly-Quinn, M. 2015. Effects of riparian canopy cover on salmonid diet and prey selectivity in low nutrient streams. *Journal of Fish Biology* 86: 16–31.

Ryder, E., de Eyto, E., Dillane, M., Poole, R. and Jennings, E. 2014. Identifying the role of environmental drivers in organic carbon export from a forested peat catchment. *Science of the Total Environment* 490: 28–36.

Scarpa, R., Chilton, S.M., Hutchinson, W.G. and Boungiorno, J. 2000. Valuing the recreational benefits from the creation of nature reserves in Irish forests. *Ecological Economics* 33: 13.

Silgram, M., Anthony, S., Fawcett, L. and Stromqvist, J. 2008. Evaluating catchment-scale models for diffuse pollution policy support: some results from the EUROHARP project. *Environmental Science and Policy* 11: 153–162.

Smith, G.F., Gittings, T., Wilson, M.W., Oxbrough, A., Iremonger, S., O'Donoghue, S., McKee, A.M., O'Halloran, J., Kelly, D.L., Pithon, J., O'Sullivan, A., Neville, P., Mitchell, F.J.G., Giller, P., O'Donnell, V. and Kelly, T. 2006. Biodiversity assessment of afforestation sites. *BIOFOREST Project Final Report*.

Stithou, M., Hynes, S., Hanley, N. and Campbell, D. 2011. Estimating the value of achieving "good ecological status" under the Water Framework Directive in the Boyne River catchment: a mixed multinomial logit approach. *SEMRU Working Paper Series No. 11*. Department of Economics, National University of Ireland Galway.

Sturt, M.M., Jansen, M.A.K. and Harrison, S.S.C. 2013. Invertebrate grazing and riparian shade as controllers of nuisance algae in a eutrophic river. *Freshwater Biology* 56: 2580–2593.

Sunderland, T. 2012. Microeconomic evidence for the benefits of investment in the environment – review. *Research Report*. Natural England.

Sweeney, O.F.M., Wilson, M.W., Irwin, S., Kelly, T.C. and O'Halloran, J. 2010. Are bird density, species richness and community structure similar between native woodlands and non-native plantations in an area with a generalist bird fauna? *Biodiversity and Conservation* 19: 2329–2342.

Teklehaimanot, Z. and Jarvis, P.G. 1991. Direct measurement of evaporation of intercepted water from forest canopies. *Journal of Applied Ecology* 28: 603–618.

Termansen, M., McClean, C.J. and Søndergaard Jensen, F. 2013. Modelling and mapping spatial heterogeneity in forest recreation services. *Ecological Economics* 92: 48–57.

Thimonier, A., Dupouey, J., Bost, F. and Becker, M. 1994. Simultaneous eutrophication and acidification of a forest ecosystem in North-East France. *New Phytologist* 126: 533–539.

Thomas, H. and Nisbet, T. 2007. An assessment of the impact of floodplain woodland on flood flows. *Water and Environment Journal* 21: 114–126.

Tobin, B., Black, K.G., Nieuwenhuis, M. and Gardiner, J. 2006. Biomass expansion factors and forest biomass C stares. In *Carbon Sequestration And Irish Forest Ecosystems*. Eds. Black, K.G. and Farrell, E.P., COFORD (National Council for Forest Research and Development), Dublin.

Tol, R.S.J. 2005. Adaptation and mitigation: trade-offs in substance and methods. *Environmental Science and Policy* 8: 572–578.

Townsend, M. 2006. Feel blue? Touch green! Participation in forest/woodland management as a treatment for depression. *Urban Forestry and Urban Greening* 5: 111–120.

Ulrich, R.S. 1981. Natural versus urban scenes: Some psychological effects. *Environment and Behavior* 13: 523–556.

Ulrich, R.S. 1983. Aesthetic and effective response to natural environment. In *Behavior and the Natural Environment*. Eds. Altman, I and Wohlwill, J.F., Pienum Press, New York, pp. 85–125.

UNECE/FAO. 2010. The European Forest Sector Outlook Study II 2010–2030. Geneva.

UNECE/FAO. 2013. Joint Wood Energy Enquiry 2009–2012.

Upton, V., Ní Dhubháin, Á. and Bullock, C. 2012. Preferences and values for afforestation: the effect of location and respondent understanding on forest attributes in a labelled choice experiment. *Forest Policy and Economics* 23: 17–27.

Upton, V., Ní Dhubháin, Á. and Bullock, C. 2012. The valuation of non-market forest benefits in Ireland: a review. *Irish Forestry* 68: 63–76.

Upton, V., O'Donoghue, C. and Ryan, M. 2014. The physical, economic and policy drivers of land conversion to forestry in Ireland. *Journal of Environmental Management* 132: 79–86.

Upton, V., Ryan, M. and O'Donoghue, C. 2014. A spatially explicit national demand model for forest recreation in Ireland. Presented at Agricultural Economics Society 88th Annual Conference, 10th April 2014, Paris, France.

van Dijk, A.I. and Keenan, R.J. 2007. Planted forests and water in perspective. *Forest Ecology and Management* 251: 1–9.

Vinebrooke, R.D. and Graham, M.D. 1997. Periphyton assemblages as indicators of recovery in acidified Canadian Shield lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 1557–1568.

Walther, G.R. 2010. Community and ecosystem responses to recent climate change. *Philosophical Transactions of the Royal Society B: Biological Sciences* 365: 2019–2024.

Webb, B. and Crisp, D. 2006. Afforestation and stream temperature in a temperate maritime environment. *Hydrological Processes* 20: 51–66.

Wilkerson, E., Hagan, J.M., Siegel, D. and Whitman, A.A. 2006. The effectiveness of different buffer widths for protecting headwater stream temperature in Maine. *Forest Science* 52: 221–231.

Wilson, M.W., Gittings, T., Pithon, I., Kelly, T.C., Irwin, S. and O'Halloran, J. 2012. Bird diverstiy of afforestation habitats in Ireland: Curretn trends and likely impacts. *Ecology and Environment Proceedings of the Royal Irish Academy* 1120: 43–56.

Wolf, K., Mass, R., Kiefer, F., Wiedemann, K., Naber, D., Debnath, M., Das, S.K., Bera, N.K., Nayak, C.R. and Chaudhuri, T.K. 2006. An epidemiologic study of posttraumatic stress disorder in flood victims in Hunan China. *Canadian Journal of Psychiatry* 51: 350–354.

Wood, P.J. and Armitage, P.D. 1997. Biological effects of fine sediment in the lotic environment. *Environmental Management* 21: 203–217.

Zhang, L., Dawes, W.R. and Walker, G.R. 2001. Response of mean annual evapotranspiration to vegetation changes at catchment scale. *Water Resources Research* 37: 701–708.