COST action FP0703 – ECHOES

Country report

Ireland

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Introduction

Temperate deciduous forests once covered most of Ireland, but centuries of deforestation have reduced the forest cover to 1.4% of the total land area by 1905 (McEvoy 1954). Since the 1940s, there has been a rapid expansion of the forest area (Malone, 2008, Figure 1). Afforestation initiatives were restricted initially to low-fertility soils unsuitable for agriculture (Malone, 2008; Goodale et al., 1998). Planting rates have accelerated rapidly over the past two decades due changes in agricultural subsidy policies within the European Economic Community, and forests now cover 10% of the Republic of Ireland (Black et al., 2008; NFI, 2007).

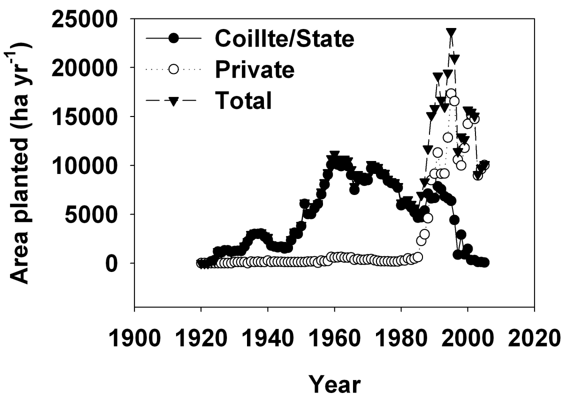

Figure 1: Afforestation rates in the Republic of Ireland since 1920.

Semi-natural forests (forests with 80% of trees regenerating naturally) only account for 81 kHa or 13% of the total forest land (NFI, 2007). The remaining area is rotation forestry comprising of exotic coniferous species (primarily *Picea sitchensis*, *Pinus contorta*, *Picea abies*, and *Pinus sylvestris*), which currently make up 73% of Ireland's plantations (NFI, 2007). Sitka spruce (*P. sitchensis*) covers over half of the forested land in Ireland (NFI, 2007). Since the initial afforestation initiatives were introduced in the 1940s, the average productivity (yield class) of Sikta spruce has increased by 5 to 10 % (Horgan et al., 2004). This is primarily associated with to a change in silvicultural practice, the introduction of genetically superior seed sources and site type. There has been a shift away from afforestation of blanket peats with conifers, in the west of Ireland in the 1950-60s, to more productive sites (or sites suitable for native broadleaves) characterised by fertile soils such as brown earth and gley soils over the past decade (Black et al., in press). These factors, together with the relatively short history of forestry in Ireland, make it difficult to discern any impact of changing climate on forest growth or health. This is confounded by the lack of sustained or long term climate change mitigation, impact or adaptation research activities before the ICP monitoring network was established in Ireland or the Irish Council for Forest Research and Development (COFORD) climate change programme was initiated in 2002. Most of the COFORD research effort has been concerned with climate change mitigation (see Black and Farrell, 2006).

The impacts of climate change on forest growth and species distribution remains a key knowledge gap in the Irish forestry context. Despite this, it is clear that climate change risk assessments and adaptive forest management strategies need to be considered and implemented. Irish forests, in contrast to most European forests, are comprised of intensively managed plantation forestry with a strong emphasis on correct species selection for a specific site type. Decision support tools are urgently required to guide strategic policy, for example, to guide woodland grant incentives to maintain a robust and sustainable forest policy response to climate change.

Summary of Irish forestry facts

- Area is about 625 kHa or 10% of the Irish land cover;
- Afforestation since 1990 accounts for 250 kHa or 40 % of forest cover
- Growing stock is 70 million cubic meters (m^3)
- Average mean annual volume increment for major species Sitka spruce 18 to 20 m^3/ha/year on average;
- Semi natural forests only represent 13 % of the forest area, the rest is comprised of plantation forestry with a mean rotation age of ca 50 years
- National net carbon sink exceeds 3 million tons of carbon dioxide (CO_2) equivalents per year net of wood harvest and deforestation; this is expected to increase to 5 Mt CO_2 by 2020
- Afforerstation abatement cost is estimated to be 43 € per tonne of CO_2. The abatement potential of afforesting 15,000 ha per year (national target) from 2008 to 2030 is 20 Mt CO_2
- Roundwood removals for industrial and domestic energy or heating vary from 2 to 3 million m^3; this is expected to increase to 5 million m^3 by 2015.
- When the indirect and indirect effects were taken into account, the overall value of forestry to the Irish economy was €472.4 million in 2003 (0.27% GDP).

1. Impacts

In this section, we first set the scene with climatic trends from meteorological data followed by **observed impacts** of forests based on limited forest monitoring and research information. The impacts of climate change are poorly understood and are subject to a large degree of uncertainty. However, we attempt to provide a broad background on **expected impacts and possible future risks**. Progress in recent research is used to demonstrate the use of ecological site classification models to describe forest productivity in response to climatic-site variables. These models, together with regional climate change simulations are then used to provide some information on the suitability of species under future climate change scenarios. Some current research activities and outcomes are also discussed.

1.1. Observed impacts

1.1.1. Observed climatic trends

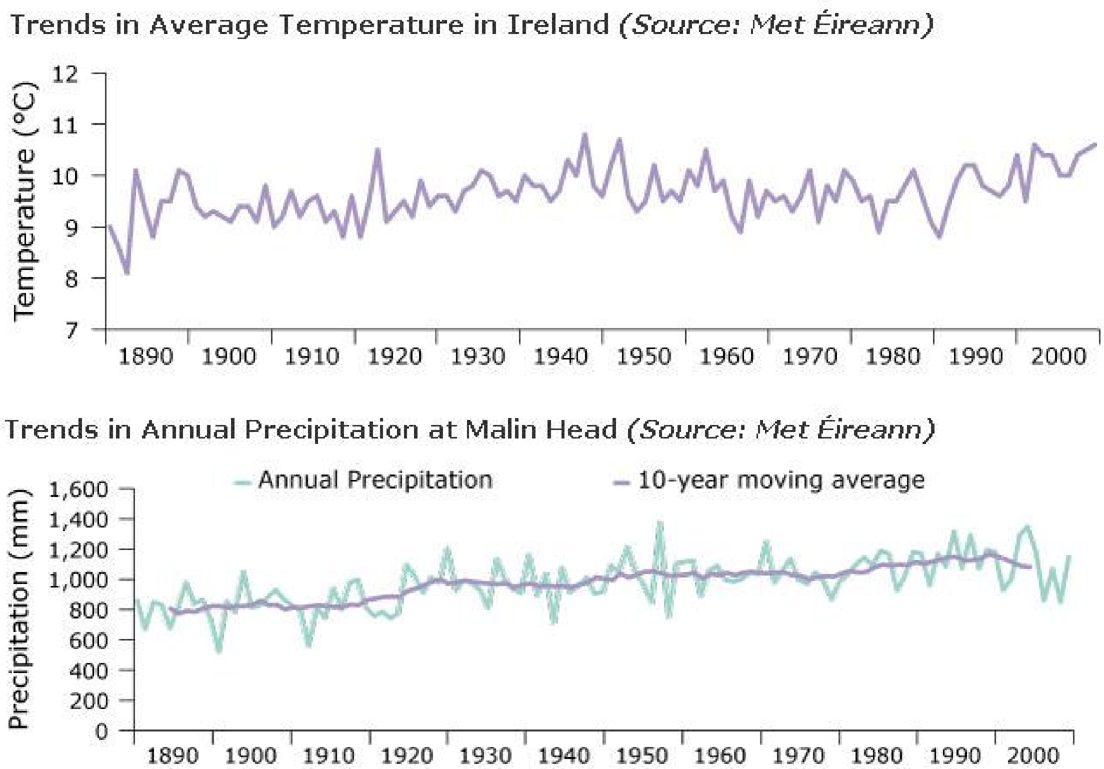

Figure 1 : Observed increase in °C of the average annual temperature (top) and annual precipitation (below) from 1890 to 2004

Figure 2 shows the mean annual air index derived from the average temperature since 1890 for the four long-term monitoring stations in Ireland – Malin Head, Valentia, Birr, and Armagh. The trend in the average temperature record for Ireland is similar to that observed globally. The average temperature in Ireland increased by 0.7°C during the period 1890-2004, at an average rate of 0.06°C per decade. In Ireland this warming is most evident during the periods 1910 to 1949 and 1980 to 2004. The temperature increase in the latter period has been larger, and the rate of increase more rapid than in the 1910-1949 period. Generally the temperature is warmer in the south and south eastern regions of the country for both the summer and winter months.

There is an increase in the frequency of hot days (defined by days where the temperature exceeds 18 °C) from 5 days per year in the 1940 to 10 days per year in the 1990s. This is consistent with a decrease in the number of days with a temperature below 0°C and the frequency of frost (Donnelly et al 2004).

There is also evidence of an increase in the length of the growing season based on accumulated temperature above 5 °C (Keane and Collins, 2004). Generally, mean temperatures are above 5 °C from mid-March to late-November.

An index of total annual precipitation for Ireland, based on averaging 11 of 14 weather stations (Figure 2), shows a general trend of increasing precipitation over a 40-year period, with notable increases since the 1970s. However, 2001 and 2003 were two of the driest years recorded since 1960. An increased gradient in precipitation with wetter winters and drier summers, particularly in the south-east, is becoming evident from the meteorological records (Keane and Collins, 2004).
Annual precipitation greatly exceeds annual evopotranspiration (pET), especially in the west and south west. However, there is a moisture deficit (pET – precipitation) in th summer months, and evidence of an increase in the frequency of moisture deficits during the growing season (March to October).

There are no observed trends wind speed and storms, but these are highly variable on both a spatial and temporal basis.

Based on analysis of solar radiation, pan evaporation (pan ET) data from synoptic stations, there was a slight decrease in incident solar radiation, pan ET and calculated pET up to the 1970s (Black et al., 2006). However, this decreasing trend has levelled off since the 1970, and this may be associated with a decrease in sulphate and black particle emissions or other changes in the optical property of the atmosphere over the same period (Black et al., 2006).

1.1.2. Impacts on forest ecosystems

Forest growth, function and productivity is influenced not only by climate, but by the interaction of climate, soil type and site specific factors. The interpretation of observed climatic impacts is further exacerbated by changes in silvicultural practice and the introduction of more productive genotypes, as is the case in Ireland. In addition, interactive effects of climatic variables with biotic factors such as insect infestation, or even CO_2 fertilisation, are poorly characterized.
Observed impacts on national forest ecosystem dynamics and functioning include vegetation phenology, species suitability and productivity.

1.1.2.1. Vegetation phenology

The International Phenological Gardens (IPG) network was established in 1957 by Schnell and Volkert (Chmielewski and Ro¨tzer 2001) with the aim of collecting phenological data from 50 sites across Europe. Clones of tree and shrub varieties were planted at each site in order to exclude genotypic variations in response to environmental conditions. In Ireland, four phenological gardens were established between 1966 and 1967.
Analysis of Irish data collected between 1970 and 2000 (Donnelly et al., 2004), suggest that over 50 % of the broadleaved species investigated showed significant changes in the timing of leaf unfolding (early growth season (EGS) initiation) and leaf fall (i.e. end of growth season). For many species the length of the growing season (LGS) increased due to both an

earlier start to the growing season and a delay in the date on which leaf fall occurred. The greatest increase in LGS was observed in the south-west of the country.

In Ireland, along with an increase in mean spring and mean annual temperature, the timing of phenological events has advanced in the case of BGS and delayed in the case of EGS over the last 30 years. However, the spring phenological response could not be explained simply by average spring temperature alone, indicating an influence of other environmental factors on phenology (Donnelly et al., 2004).
There is currently no information on changes in phonological development for the major conifer species in Ireland. Difficulties in interpreting any climatically induced changes in conifer species phenology is exacerbated by the introduction of more productive provenances of Sitka spruce, in recent years, which show differences in the onset of dormancy (Thompson, 1998).

1.1.2.2. Species distribution and suitablility

a) Species distribution: Trees growing at the limits of their ecological tolerance would be more sensitive to climate. Most trees in Ireland, with the exception of a non-forest species (*Arbutus*), are not at the extreme of their range and, therefore, may not show any distribution shifts related to climatic change. This lack of any apparent climatically driven association with natural species distribution in Ireland may also be due to a limited geographical range and climatic gradient. The small area of remaining natural forest and a large degree of plantation forestry means that species distribution is primarily a result of silvicultural management, where species selection (and hence distribution) is determined by site type (Horgan et al., 2004; Ray et al, in press). For example, much of the peat land forestry is comprised of lodge pole pine and Sitka spruce. Small areas of other conifers, such as Douglas fir are found on the well drained brown earths, or Scots pine on podsolic soils. National forest service afforestation policy and biodiversity incentives have resulted in an increase in the planting of native broadleaved species on mineral soils over the past two decades.
Land cover satellite data, such as the CORINE database, and national statistics suggest that there is encroachment of Hazel scrub on the Burren landscape (characterized by limestone pavements and lithisols) and Birch/Alder on abandoned cutaway peatlands (Black et al., 2009). However, this is primarily associated with changes in land use management rather than climatically driven distribution responses. For example, the increase in Hazel scrub on the Burren has been associated with a reduction in livestock grazing in these areas.
b) Species suitability: Site classification systems have been used in Scandinavia (Cajander, 1926) and central Europe (Ellenberg, 1988) to describe the natural forest cover of regions using biophysical variables describing site and climatic characteristics. An ecological site classification system (ESC) has been developed for Ireland, based on a similar GIS system for the UK (Clare and Ray, 2001; Ray et al., 2003) and has since been used to assess the impacts of projected climate change scenarios on species suitability. The introduction of climate change projections to study impacts on species suitability is facilitated by the multi-factor design of the system. Each of the climatic variables can be substituted for future projections, and with the dynamic coupling of climate and soil factors, adjustments in soil moisture and nutrient supply can be made to investigate particular site types under projected future climate scenarios.
Multi-factor forest site classification systems, by definition, separate the effects of climate and edaphic factors on tree species, woodland community, or forest type suitability (Figure 3). The ESC approach describes the response of all major forest species in Ireland and the UK to four climatic factors: warmth (accumulated temperature -AT), droughtiness (i.e. moisture deficit -MD), wind exposure, and continentality, based on Delphi models (see Pyatt *et al* 2001 for definitions). The suitability class (Very Suitable, Suitable, or Unsuitable) of different tree species and semi-natural woodland communities was linked to each of the climatic factors, and to two soil quality factors representing soil wetness (soil moisture regime – SMR) and soil fertility (soil nutrient regime – SNR).

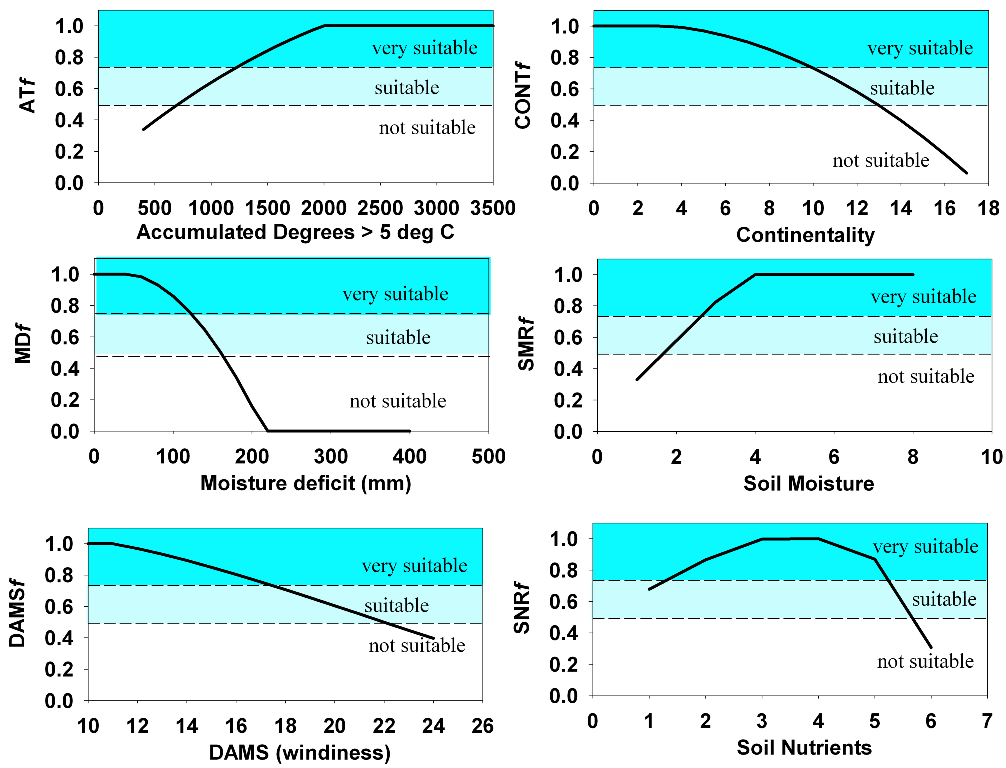

Figure 3: The suitability of Sitka spruce according to a) Accumulated Temperature (AT - day.degrees above 5^{o}C) and b) Moisture Deficit (MD - mm), DAMS or windiness, Continentality, SMR-soil moisture regime and SNR- soil nutrient regime. Suitability is classified on a scale from 0 to 1, where *f* values >= 0.75 is Very Suitable, >= 0.5 is Suitable and <0.5 is Unsuitable (Ray et al in prep).

Suitabliity curves, as shown in Figure 3, have been constructed for all major forest species. Together with soil map and vegetation data these models are applied to GIS to generate species suitablilty maps for Ireland and the UK (see Figure 4).

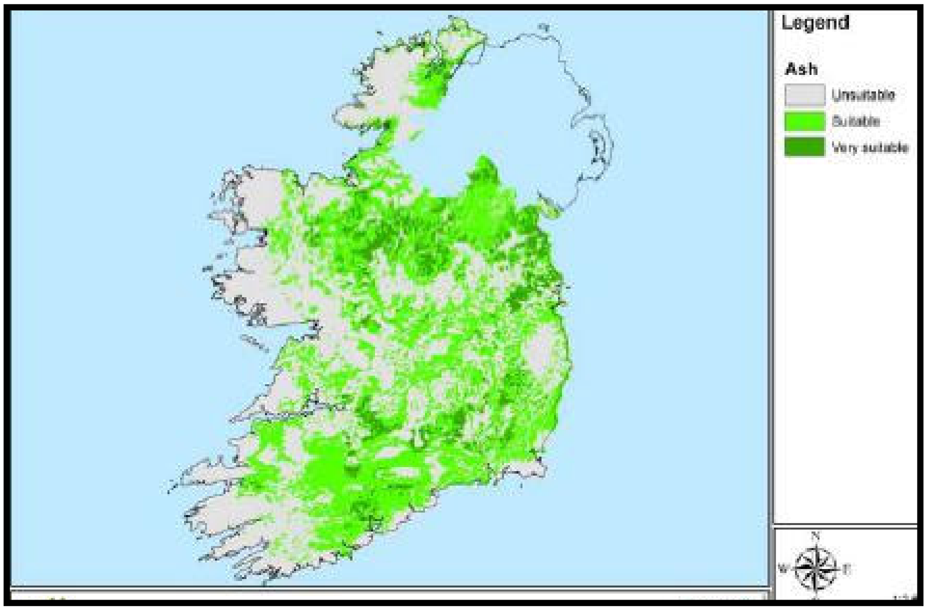

Figure 4: A suitability map for Ash under current climatic conditions. Note the unsuitability on peat soils and higher elevations (Ray et al in prep)

1.1.2.3. Forest health, insects and pathogens

a) **Forest health** has been monitored in Ireland since the late 1980s at more than 35 experimental plots across the country. This research is coordinated by the Forest Protection section of Coillte's Research and Development Division, Coillte (funded by both the EU and the Forest Service) and is carried out under the directive of EU Regulation 3528/86 on the protection of forests against atmospheric pollution. The survey is coordinated internationally by the International Cooperative Programme Forests (ICP Forests) in collaboration with the Directorate-General for Agriculture of the European Commission.
In Ireland, there are at present 22 Level I plots and 12 Level II plots in the forest condition survey. Four different tree species are represented in both surveys, Sitka spruce, Norway spruce and lodgepole pine in the Level I survey and these three species plus oak make up the Level II survey.

Level 1 plots: Results to date show that for all species there is an increased year-to-year variation in the percentage of damaged trees (discoloration or defoliation). It is uncertain whether these changes in damage levels are driven by climatic or other natural variations or whether they truly reflect periodic changes in health status of Irish forests (Table 1, Figure 5). However, in most cases tree damage can be attributed to more than one factor. This could highlight the current lack of knowledge on interactions between climatic, site and biotic variables, and their combined effect on forest health. In 1998, the increase in insect damage was associated with a spruce aphid outbreak. This association was observed again in 2002 (Figure 5, also see section on green spruce aphid).

In comparison with other countries, the level of defoliation and discolouration are well below the European average, which points to the healthy status of Irish forests. This may be primarily due to the young age of Irish forests.

Table 1: Causes of tree damage in Level 1 ICP plots during the 1990s

	Percentage of trees damaged				
Causes of Damage	1994	1995	1996	1997	1998
No Damage	2.3	5.4	20.9	18.6	11.6
No identifiable damage	26.3	22.9	35.4	25.6	30.6
Exposure	17.2	16.8	20.2	34.0	20.6
Insect	2.7	5.9	5.6	1.8	14.5
Shoot die-back	7.5	5.7	0.7	2.9	4.8
Top-dying	0.0	0.0	0.0	3.2	2.0
Nutrient	3.9	2.0	1.1	0.7	0.9
More than one cause of damage	40.1	41.3	16.1	13.2	15.0

([1]) Data are not presented for the Level II plots as there is considerable overlap with the Level I data. Results from the Level I and II plots are submitted annually to the European Commission.

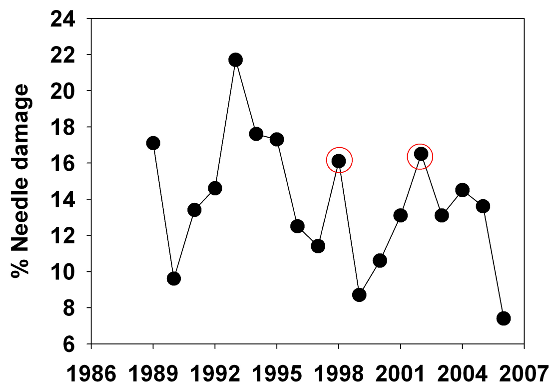

Figure 5: The annual trends in % needle damage in Level 1 ICP plots. The red circles highlight where the occurrence of needle damage was associated with aphid outbreaks in 1998 and 2002 (Neville et al unpublished data).

Level 2 plots: These plots consist of a semi-natural oak (*Quercus petraea*) woodland and two Sitka spruce (*Picea sitchensis*) plantations, one on an acid mineral soil, the other on peatland. Two of the plots are located on the Atlantic coast where deposition is dominated by marine derived ions (e.g. sulphate), the third on the east coast where the influence of anthropogenic emissions (e.g. NOx) is stronger. Based on an analysis of input-output loads, proton budgets and critical loads at a eastern site over the period 1990 to 1998 (Farrell et al., 2001), it is suggested that long term sustainability of these forest types (Sitka spruce) is threatened if anthropogenically related deposition continues at the same rate.

Long term ICP forest monitoring trends suggest there is an increase in N-deposition in the eastern half of the country (Neville, pers comm.). In Ireland, N availability is most influenced by a lack of drainage or competing vegetation (Purser et al 2004).

b) **Insects and diseases**

In most cases, changes in the epidemiology of insects and diseases in Irish forests are a direct result of forest management or afforestation history. For example, the increased outbreak of large pine weevil in reforested stands during the re-establishment phase is associated with an increase in the area of forest clearfelled in recent decades. This increase in forest rotation is related to a dramatic increase in afforestation since the 1940s (see Figure

1). However, there are a number of pests and diseases that can either currently or potentially inflict damage to Irish forests because of climate change.

Green spruce aphid (Elatobium abietinum): Aphid outbreaks occur on a 3-6 year cycle resulting in a delayed reduction in volume productivity of ca. 10% (Day, 2002). The population size and structure of the green spruce aphid is related to the pattern of change and the phenology of bud burst, which heralds a marked change in needle sap quality. This suggests that yearly differences in the winter temperature regime may affect the duration of the population growth phase and hence the peak numbers attained in late spring (Day, 2002). A combination of the level of the population in the summer and the number of severe cold periods below -7°C in the winter months, determine the size of the population the following year. An aphid outbreak results in significant losses of two and three year old needles during the following growing season and thus a reduction in productivity the year after peak infestation. Based on ecosytem flux studies, it is suggested that stand productivity is possibly associated with a 'knock-on effect' of aphid outbreaks (Black et al., unpublished data). High population densities of spruce aphid in 2002 caused significant browning and a subsequent loss of foliage, resulting in an 80-90 % increase in litterfall in 2003 and 2004 (Tobin et al., 2006). Whilst a reduction in net ecosystem productivity in 2004 (18-23 %) may have been exacerbated by the 2003 drought and self thinning, following canopy closure, our results highlight the importance of the indirect influences of climate change, such as insect outbreaks, on forest productivity in the future.

Large pine weevil (Hylobius abietis): The large pine weevil breeds in stumps and feeds on the vascular tissue of young trees during the establishment phase. This is a particular problem in reforested stands, replanted 1 to 2 years after clearfell in warmer regions in the south and south east of the country. A increase in summer temperatures could result in greater weevil activity, particularly in combination with drought events and recent legislative policy banning the use of the insecticide linane (Purser et al 2004).

Great spruce bark beetle (Dendroctonus micans): This species does not occur in Ireland at present. However, large areas of spruce monoculture may become vulnerable to bark beetle outbreaks, particularly in the south and south east of the country (Purser et al., 2004), where drought-induced stress may become significant (Ray et al, 2007)

Phytophthora disease of alder: This species has only recently been identified as present in Ireland; it is possible that its expansion may be an indication of a) an increased planting of alder species over the past decade and b) environmental changes (Purser et al., 2004).

Fomes (Heterobasidion annosum): Root and butt rot fungus is the most economically damaging disease affecting Irish forestry. It is suggested that the fructification are resistant to drought and moderate frost implicating a greater threat in a warmer and drier climates (Purser et al., 2004)

Honey fungus (Armillaria mellea): Drought conditions are considered to make trees more liable to infection (Phillips and Burdekin, 1982).

1.1.2.4. Forest productivity

Although there has been an increase in productivity of some forest species over the past 50 to 60 years, this is primarily associated with changes in site type and improved silvicultural practice.

Previous dendrochronology studies for Irish Oak, extending back 7000 years (Baillie and Brown, 1995) show notable downturns in growth relating to catastrophic environmental events Baillie, 1999). The effect of recent increases in temperature on growth is not clearly evident in the oak chronology study. However, preliminary results from a more recent dendroclimatology study, conducted on Sitka spruce, do suggest a significant climate related increase in growth over a 70 year chronology (Tene et al., 2009).

1.1.3. Disturbances and extreme events

Disturbances and extreme events in Ireland include: drought (1976 and 1995) and windstorms (1982, 1987, 1990 and 1999). Fire outbreaks are rare in Ireland. The largest areas burned by natural fire occurred in 2003, where numerous fire outbreaks affected some 1030 ha of plantation forests.

1.1.3.1. Recent windstorms

The location of Irish forests, generally on exposed, windy sites with poor drainage renders them inherently vulnerable to wind damage. In 1997, 1998 and 1998 Coillte, the Irish forestry board, reported 0.5, 0.85 and 1.6 M m^3 respectively of roundwood being wind thrown (Purser et al., 2004). Up to 30% of the annual harvest in Ireland can comprise wind thrown material. Ni Dhubhain (1998) suggests that forests on relatively exposed, ploughed sites are reaching critical heights in relation to wind throw and this level of damage may increase. Pre-mature felling (premature of maximum mean annual increment less 20 %, i.e. commercial rotation) in wind throw prone sites is not a common practice and this may have a profound influence on timber sustainability and result in a transition from a forest carbon sink to a source in some managed forest plantations (see Mitigation section). In other sectors of the industry, sites that are prone to wind throw are not thinned in an effort to reduce damage through stand stabilisation.

1.2. Expected impacts

Expected impacts are primarily determined using process based and ESC models, which describe forest processes as a function of climate (see section 1.1.2.2). Regional climatic models (IPCC - A2 and B1 scenarios) for Ireland have been calculated using a dynamic downscaling method, published by the Community Climate Change Consortium for Ireland (C4I), and validated using back-casting techniques (McGrath et al. 2005).
In some cases, the models are not detailed enough to characterise the potential impacts of climate change due to a lack of scientific knowledge. In these cases, we provide a broad synopsis of the literature to infer expected impacts in Ireland.

1.2.1. Expected climatic evolution

The simulated daily mean temperatures, daily total rainfall, and daily total evaporation have been compiled into mean monthly values for simulated future 30 year averages. Accumulated temperature and climatic moisture deficit were calculated for the growing season (March to October inclusive). Total evapotranspiration (AET) and potential evapotranspiration (PET) were estimated using a relationship published by Ray *et al* (2002) from which the maximum seasonal moisture deficit was calculated from mean AET and rainfall.

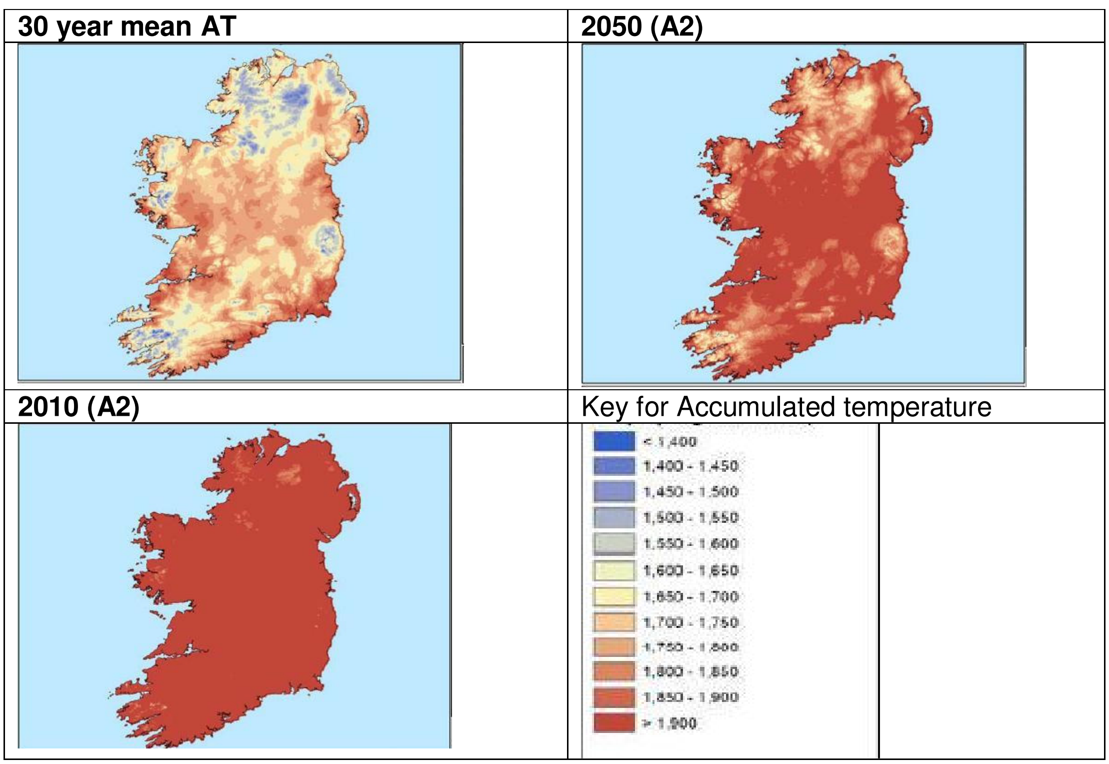

Figure 6: Projected change in warmth index for forest growth, based on accumulated day degrees above 5 °C, using the IPCC A2 scenario (Ray et al., in press).

As expected, the Irish climate is predicted to warm by 1.3 °C by mid century, increasing to 3.4 °C by 2100. Increased mean temperatures are predicted for the whole year in the future climate of Ireland, although the largest increase is predicted in January, particularly for the midlands where an increase of 1.2^{0}C is expected. The increased temperatures will cause a significant increase in accumulated temperature across Ireland. Accumulated temperature is an index of climatic warmth, with a threshold set at 5^{0}C, above which both plant respiration and growth begin. In Ireland the mean increase in accumulated temperature above 5^{0}C calculated between the months of March and October (inclusive) is predicted to be about 200-300 day.degrees (15% increase, Figure 6).

The future predictions of moisture deficit, show large increases of 40-60 mm in the south and east of the country, when comparing the climatic 30 year mean between the baseline period and the 30 year period at the end of this century (Figure 7). This is partly due to predicted warmer summers, and also due to a shift in the seasonality of rainfall, with less in summer months (up to 15% decrease) in parts of Ireland and more in winter months (20% increase).

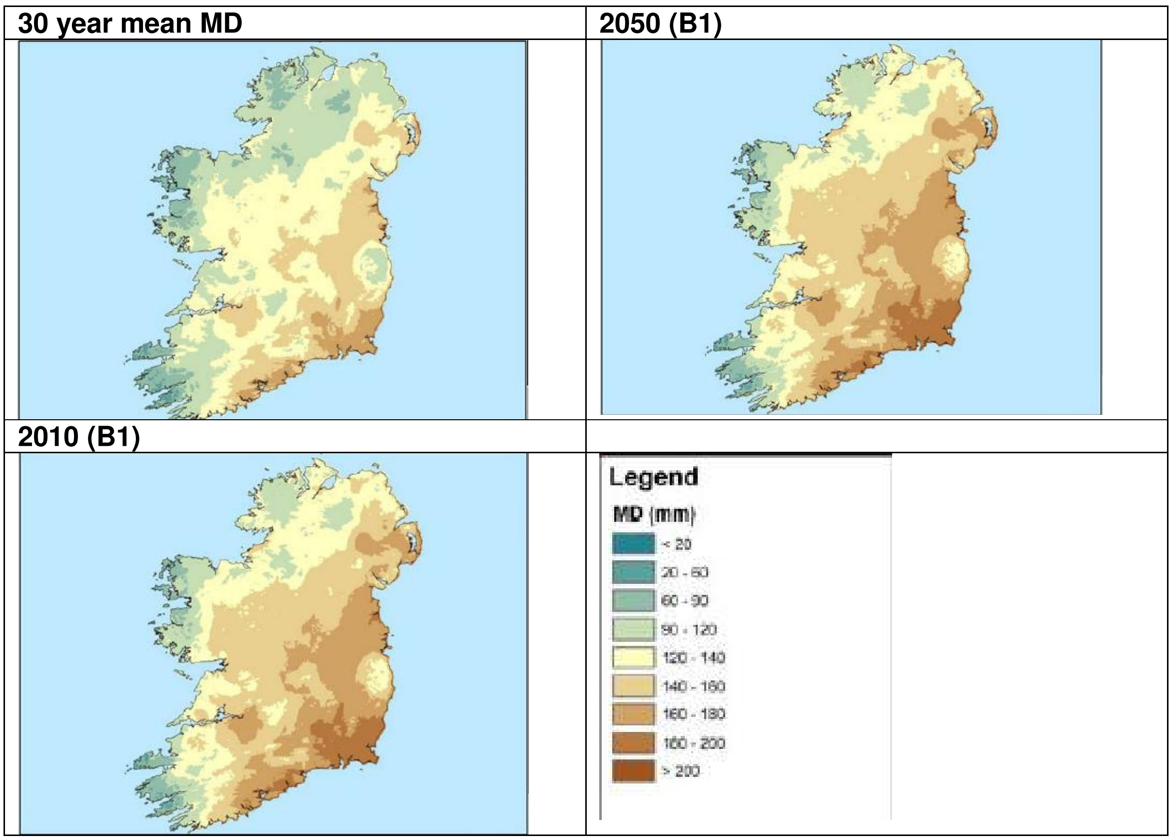

Figure 7: Average moisture deficit (mm) for a) the Baseline Period 1961-1990, and from simulations for the 30-year climate period 2020-2050 for b) the B1 Medium-Low emissions scenario, and c) the A2 Medium-High emissions scenario (Ray et al in press).

It is also predicted that there will be differences between the regions in the number of the consecutive dry days which will increase more in South-West of the country while the frequency of windstorms are predicted to increase in Northern parts of the country,

- in South-West the rise of the summer temperatures and the decrease of the spring rainfalls will be more important than in other regions, with higher frequencies of dry periods and increased rainfall intensity.,
- an increase in the frequency of storms, particularly in the North-west
- the most severe moisture deficits will occur in the South-Eastern regions for 2050-2080 period.

In addition, projections suggest that the climate will become more variable. Therefore, it is very likely that there will be an increase in the incidence of extreme events such as dry and hot summers and intense rainfall events leading to flooding episodes in both summer and winter. One example links the projected frequency of dry summers to areas of Ireland (Figure 8) providing a mechanism to assess the risk of drought damage to sensitive species caused by frequent dry summers. These data suggest that the frequency of water deficits above 180 mm will increase from 2 years per decade to 7 years per decade by 2080 in eastern parts of the country (Figure 8).

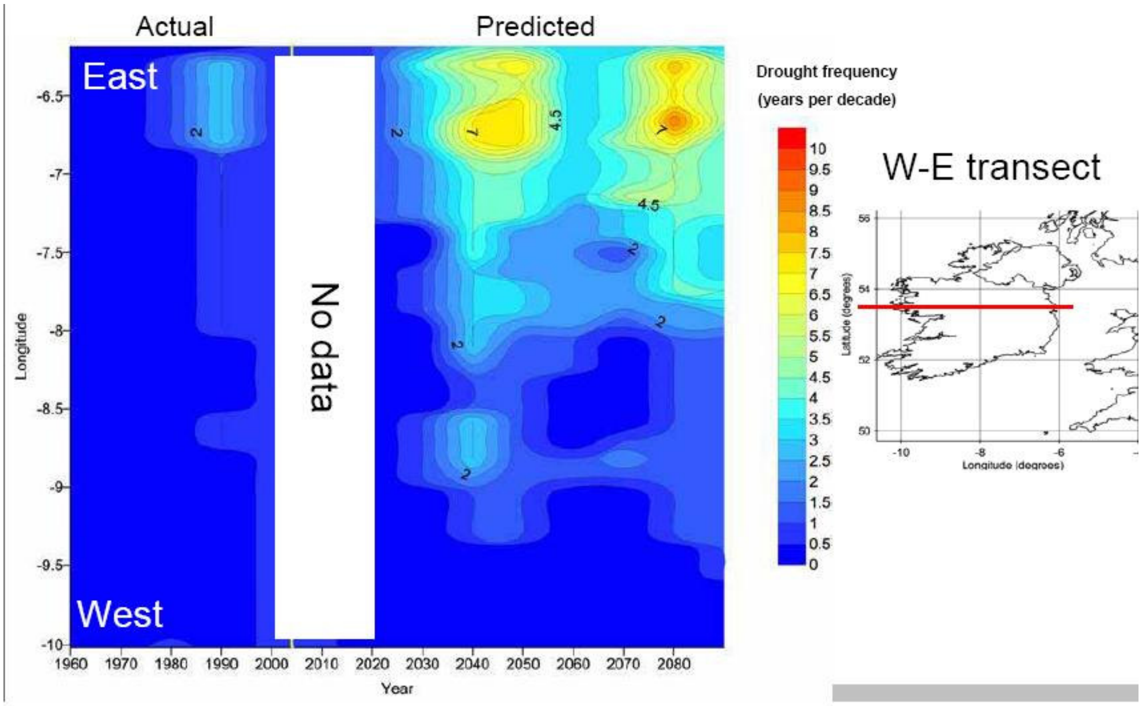

Figure 8: The frequency of dry or drought impacted summer periods across a transect through the centre of Ireland, defined at the number of years per decade that the moisture deficit is projected to equal or exceed 180 mm (Ray et al in press)

1.2.2. Impacts on ecosystem dynamics and functioning

1.2.2.1. Vegetation phenology

Based on the Irish IPG network data (see section 1.1.2.1), an increase of 1°C in annual average temperature may result in a 5 to 14 day extension to the length of the growing season (Donnelly et al., 2004). Assuming a linear trend in changes of phenology and temperature, these changes would translate to a 7 to 18 day increase in the length of the growing season (i.e. extended time between bud burst and leaf fall) by 2050, increasing to 17 to 48 days by 2100.

However, this could potentially make some species more susceptible to early or late frost, which could occur less frequently.

For some species, such as Ash, a chilling period is required to break seedling dormancy. In these cases, there could be a delay in germination or even a change in distribution of regenerating Ash stands.

It is also expected that an increase in average winter temperatures could result in later flushing of certain species, such as Ash, Sitka spruce, Norway spruce and beech. These species require a certain number of chilling hours before initiation of bud flushing (Thompson, 1998). However, this would have a smaller impact on upland sites.

1.2.2.2. Species distribution and suitability

The CLIMADAPT project has developed ESC methodology for Irish forest species and potential future species (Ray et al., in press, see section 1.1.2.2). Together with the use of GIS soil maps and future climate projections ESC produce future species suitability and distribution information. However, some potential future drivers, such as CO_2 fertilisation, elevated ozone and deposition are not considered due to a lack of knowledge on how these variables interact with main ESC factors. Site analyses also use digital climatic data for baseline and future climate projections, supplemented by more precise site quality assessments gathered by the user, based on soil and vegetation surveys of the site type. The complete system is under development as a web-application, and is due for release at the end of 2009, offering a wide range of user accessibility.

Preliminary CLIMADAPT analyses suggest that the predicted warmer and drier climate may offer the possibility of extending the range of species, to those less well represented in Ireland. The climate will improve for southern beech 'rauli' (*Nothofagus nervosa*) and 'roble' (*Nothofagus obliqua*), Monterey (radiata) pine, maritime pine (*Pinus pinaster*), walnut (*Juglans regia* and *Juglans nigra*) (Anon, 2000a), and for more southerly provenances of conifers from the Pacific North West (D. Thompson pers. comm.).

However, the increasing frequency of drought conditions, where the summer moisture deficit is greater than 200mm will severely affect a number of species. In particular, Sitka spruce (*Picea sitchensis*), Norway spruce (*Picea abies*), Japanese larch (*Larix kaempferi*) and beech (*Fagus sylvatica*) are likely to become less suitable in a drier climate (Broadmeadow and Ray, 2005a), and in addition downy birch (*Betula pubescens*), common alder (*Alnus glutinosa*), pedunculate oak (*Quercus robur*), and ash (*Fraxinus excelsior*) will become less suitable on shallow freely draining soils (Pyatt et al., 2001) in the drier areas of the south and east of Ireland.

1.2.2.3. Insects and pathogens

Pathogens Warmer weather may lead to increased threats from disease, for example fungal diseases of pine (eg Red-band needle blight) and Swiss needle cast disease of Douglas fir.

Red band needle blight caused by the fungus *Dothistroma septosporum* is currently expanding its range across Europe. The disease affects many species of pine; radiata or Monterey pine (*P.radiata*), Corsican (*P.nigra* ssp. *Laricio*), and lodgepole (*P. contorta*) are particularly susceptible, and the disease can be transferred to other species including European larch (*Larex deciduas*), Douglas fir (*Pseudotsuga menziesii*) and Norway and Sitka spruce. The fungus requires high humidity and warm spring temperatures (12-18^{0}C) (Brown et al., 2003). Currently on Corsican pine in eastern England, the pathogen causes the premature loss of needles, severely reducing the productivity of affected trees, and continued fungal attack increases the rate of tree mortality (S. Green pers. comm.). However, the predicted warmer and drier spring weather in Ireland may not provide ideal conditions for the spread of this pathogen in the future. Root pathogens such as *Phytophthora* species are increasing in Europe. They are generally associated with mild winters, warm summers and wet and waterlogged soils (J. Webber pers. comm.). *Phytophthora alni* which affects alder and infests the trees during flooding events is more prevalent in warmer water and thus may become more of a problem in the future. A number of latent pathogens manifest in drought stressed trees, such as sooty bark disease (*Cryptostroma corticale*) in sycamore. The pathogen remains dormant in the tree, and are triggered by extreme hot and dry summer weather (S. Green pers. comm.).

Insects

The warmer climate and changing rainfall distribution will have a profound effect on the ecology of tree pests. Insects will respond to the warmer climate by increasing their rate of development and the number of generations per year. Milder winters will allow larger populations to over-winter. Outbreaks of the green spruce aphid (*Elatobium abietinum*) have caused severe defoliation of spruce plantations in Ireland, severely reducing productivity (Black et al., 2007). The aphid population is vulnerable to low winter temperatures, so the increasing probability of milder winters seems certain to lead to more frequent outbreaks (Day et al., 1998). Drought stressed trees attacked by aphids are also more susceptible to bark beetle attack (D. Wainhouse, pers. comm.). The pine weevil (*Hylobius abietis)* is a serious pest of both pine and spruce plantations, particularly in areas where fell-restock systems are used. The life-cycle on spruce is semi-voltine, and a consequence of this is that adults can emerge from stumps in two or more consecutive years (D. Wainhouse, pers. comm.). Newly planted trees are therefore vulnerable to attack for several years. A warmer climate will reduce the life-cycle period, particularly shortening the juvenile stage, thus driving greater synchrony of emergence. This will provide some relief in the reduction of the current 5-year fallow period following felling, to a shorter period (D. Wainhouse pers. comm.).

1.2.2.4. Productivity and timber quality

A modelling sensitivity study on Sitka spruce in Ireland conducted by Goodale et al (1998), suggested that site-specific conditions and management practices influence productivity to a greater extent, compared to that likely to be induced by climate change or elevated CO_2. These authors suggest the effect of climate change and CO_2 fertilization is strongly depended on N availability. A potential 10 % increase in net primary productivity (NPP) was estimated under high N inputs. This is somewhat lower than recent estimates from FACE experiments (Ainsworth and Long, 2005). This highlights the importance of considering interactive effects. However, we discuss the large uncertainties and assumptions made in these modelling exercises.

Net primary productivity

a)Temperature: Where other factors important for growth are not limiting, the warmer climatic conditions will tend to increase forest productivity. Estimates suggest that a general yield class (YC) increase of 2-4 $m^3ha^{-1}yr^{-1}$ may result from an increase in mean temperature of 1^0C (Cannell, 2002). However, the effect of altered phenology may not yield such an increase in forest productivity (see section 1.2.2.2).

b) Nitrogen deposition: Forest productivity has been increasing across Europe for some time. Although some of the increased productivity is thought to result from improved silviculture and genetic improvement (Worrell and Malcolm, 1990); the main cause is now thought to be nitrogen fertilisation from atmospheric pollution (Goodale et al., 1998; Magnani et al., 2007) in combination with a warming climate. However, elevated ozone may negate the positive effect of N deposition in temperate forests (Felzer et al., 2007).

c) *Elevated CO_2*: The stimulation of photosynthesis (GPP) under elevated CO_2 concentrations is well documented (for review see Ainsworth and Long 2004). However, projections of CO_2 fertilisation effects should be treated with caution because of current limitation in our understanding with respect to acclimation processes, climatic constraints and feedback from interactive processes (for review see Ainsworth and Long, 2005; Hyvonen et al., 2007). These reviews provide evidence suggesting that the projected increase in forest productivity as a function of elevated CO_2 may not be as large as expected due to:

- *Physiological acclimation* such as the decrease in Rubisco activity and regeneration, and evidence of decreased N and chlorophyll content in long term FACE experiments (Ainsworth and Long., 2005)
- In many cases the magnitude of photosynthetic *enhancement does not translate to a similar increase in growth* due to increased maintenance respiration (i.e. a change in the GPP:NPP ratio). Modification of photosynthetic terms in most process based models do not account for this adjustment. So in many cases the projected effects of *CO_2 fertilization is overestimated when models* are used.

- The enhancement of growth due to CO_2 fertilization is temperature limited and will be lower in temperate and boreal regions (Norby et al 2005).
- A lower CO_2 fertilisation effect may occur during non-drought years or under N limiting conditions (Norby et al. 2005, Ainsworth and Long, 2004; Hyvonen et al., 2007). So the extent of enhanced NPP would depend on the availability of other limiting resources. Indeed, resources may become more limiting due to acclimation responses to elevated CO_2 (e.g. enhanced N limitation).
- Increases in NPP are associated with an increase in LAI under elevated CO_2, however, this effect is reduced after canopy closure (Norby et al.,2005; Ainsworth and Long 2005). Plantation forestry in Ireland is characterised by high LAI and co-limitation by light and CO_2 is the major limiting factor of NPP, under N rich conditions (Wang and Jarvis, 1993; Black et al., 2006). Therefore, the effect of elevated CO_2 in these forest types may be lower than expected.
- Experiments using step-change increases in carbon dioxide concentration may cause unrealistic ecological responses**.** Attempts to understand ecological effects of increasing atmospheric CO_2 concentration usually involve exposing ecosystems to elevated CO_2 concentration imposed with a one-time step-change increase of 200 ppm or more. An assumption underlying this approach is that exposing ecosystems to a single-step increase in CO_2 concentration will cause similar ecological responses, when compared to those of a gradual increase over several decades. Klironomos et al. (2005) tested this assumption on a mycorrhizal fungal community over a period of 6 years. The authors suggested that "studies may overestimate some community responses to increasing [CO_2] because biota may be sensitive to ecosystem changes that occur as a result of abrupt increases".
- Much existing evidence from FACE experiments does not include interactive effects of other pollutants or climatic variables. For example, a combined FACE experiment with elevated CO_2 and O_3, suggest that the CO_2 fertilisation effect in Aspen is negated by the presence of O_3 at predicted future levels (King et al., 2005). This result reinforces the need to consider multiple factors in global-change ecosystem experiments because it can clearly be misleading to simply "add" results from single-factor experiments to project potential ecological effects of multiple environmental changes.

d) Increased moisture deficits. In addition to influencing species distribution, it is plausible that an increase in the frequency and magnitude of moisture deficit events could reduce productivity in some species, such as Sitka spruce. Evidence from long-term eddy covariance studies suggest that a delayed reduction in productivity of Sitka spruce in response to water deficits is driven predominantly by increased needle turn-over rather than physiological factors in the shorter term. We hypothesise that this ‘knock-on or lag’ response to water deficits and interactions with insect infestations may be more important than short-term physiological factors under present and future climates (Black et al., 2007). This hypothesis is currently being tested using dendroclimatology and natural isotope abundance studies across a climatic and drought gradient.

Net ecosystem exchange

It is important to consider the impact of climate change on NEE from a carbon balance and mitigation perspective. NEE is the product of NPP and heterotrophic respiration. Whilst the impact on NPP have been discussed in the previous section the balance between NPP and respiratory loss is influenced by CO_2 fertilisation, N deposition, temperature and forest management (see Hyvonen et al., 2007). It is suggested that there could be a sink saturation response to global change due to the concomitant increase in heterotrophic respiration, driven by increased temperature, with CO_2 fertilisation and increased NPP. This could result in no appreciable change in net ecosystem carbon balance.

Timber quality
The Irish climate is not ideal for growing high grade timber from Sitka spruce; to improve timber quality it would be preferable for trees to grow at a slower rate, not faster under certain future climate predictions. However there are opportunities to select material (and provenance) to improve timber quality for a warmer climate in a breeding programme, such that microfibril angle and density remain optimal. Increasing productivity of Sitka spruce usually results in a slightly lower wood density, and as a result the quality of wood products such as battens will be reduced. This is because the increased productivity will primarily effect the production of early wood, which provides the cell structure and mechanism for transporting water and nutrients within the tree stem. In contrast, the pines, larches and Douglas fir will grow faster without a reduction in wood density. The timber quality of hardwood species varies in response to increased growth in a warmer climate. Ring porous species such as oak, ash, and elm produce harder and stronger timber when grown at a faster rate. Diffuse porous species such as sycamore and birch do not respond in this way. Chestnut and beech are intermediate in response (Ray et al,. 2008).

1.2.3. Disturbances and extreme events

Windthrow
Endemic windthrow is common on forest sites with high winter water tables due to imperfectly or poorly drained soils. Most of the soils in Ireland are characterised by high winter water tables. In waterlogged soil, oxygen is quickly depleted, leading to anaerobic conditions (characterised by gleying) which prevents plant root respiration, and leads to the death of waterlogged roots and a reduction in tree stability (Ray and Nicoll, 1998). The predicted change in the seasonality of rainfall, with a 20% increase in the winter months is likely to exacerbate problems of shallow rooting. There is therefore an increased likelihood of increased endemic windthrow on wet soils, and, coupled with the predicted increase in frequency of intense storms, an increase in the likelihood of catastrophic windthrow (Nisbet, 2002).

1.3. Impact monitoring

1.3.1. Monitoring systems and networks

There are numerous national and European monitoring programmes related to various aspect of Irish forestry:

- The International Phenological Gardens (IPG) network (see section 1.1.2.1)
- The International Cooperative Programme Forests (ICP Forests) and Futmon (section 1.1.2.3)
- The National Forest inventory (NFI) was first established in 2004 and completed in 2007. It was based on a randomised systematic grid sample design, at a grid density of 2 x 2 km to provide the number of plots needed to estimate total standing volume with a precision of ±5%, at the 95% confidence level. The grid generated 17,423 intersections, each representing 400 ha. A land use classification of each intersection point was undertaken to identify afforested areas using photo-interpretation of OSi aerial photographs, aided by supplementary databases such as the Coillte and the iFORIS datasets. This resulted in the classification of 1,742 points as forest land. At each point permanent sample plots, representing 500 m^2, were set up. Data are collected to monitor the following forest characteristics:
  - Standing volume and timber production
  - Afforestation, deforestation and reforestation
  - Land use change
  - Carbon stock changes
  - Forest health
  - Biodiversity
  - Management and silvicultural trends

  It is envisaged that the NFI is to be repeated every 5 years. There are also efforts to harmonise and integrate the NFI and Futmon, so that forest monitoring can be scaled up to the national level.
- CARBiFOR and FOREST SOIL C projects are primarily concerned with carbon mitigation studies. However certain aspects of these project have long term monitoring aspects, these include
  - Eddy covariance and climatic recording since 2002 in two forest types. One of these sites is now a Level 1 Futmon site and we plan to upgrade this to level 2 in Futmon II so that forest health and mitigation monitoring in integrated.
  - National soils databases based on 60 permanent NFI sample points. These soils will be resampled every 5 to 10 years to monitor forest soil carbon stock changes.

1.4. Impact management

There are national limited resources allocated to the management of catastrophic disturbance events. Impact management is largely the responsibility of the forest owner/companies.

Windthrow risk: Wind throw risk models have been developed for Irish forestry (Ni Dhubhain, 1998), based on probability of wind throw risk using a number of stand and site variables. These are available to the public via the COFORD website. However, these models are not used by forest managers in Ireland where estimates of wind throw risk are made on a subjective basis.
Reconstitution grants: The Forest Service does offer a reconstitution grant for reforestation of damaged forest areas due to wild fires

2. Adaptation

Decision support tools are urgently required to guide strategic policy, for example, to guide woodland grant incentives to maintain a robust and sustainable forest policy response to climate change. Tools are also required to support the operational response, for example, to identify potential site and climate related problems, to identify well-adapted species, provenance and silvicultural systems. Current work within the CLIMIT programme will provide these tools in the COFORD funded project CLIMADAPT.

2.1. General adaptation strategy and policy

The national climate change strategy 2007-2012 follows on the form of the first strategy published in 2002. The purpose of the strategy is to:

- Show clearly the measures by which Ireland will meet its 2008-2012 Kyoto commitments
- Show how these measures position us for the post 2102
- Identify potential future impact and develop adaptive strategies

Flood relief management strategy is a national priority and these policies are being developed by the OPW and other state agencies.
Ireland has also engaged in an exchange of information on impact and adaptation activities through the British Irish Council.

2.2. Forest adaptation measures

2.2.1. Political level

The Irish Government has committed to expanding ‘Kyoto forests’ that will contribute towards the countries emissions reduction targets as outlined in the National Climate Change Strategy (NCCS) 2007-2012. It has also been recognised (Malone, 2008, Black, 2008) that to ensure forests continue to play a role in greenhouse gas emissions reductions, a programme of forest expansion of 7,500 to 10,000 $ha.yr^{-1}$ will be required over the next 20-30 years. To achieve this target a range of stakeholders, including environmental and conservation agencies, public, business and of course landowners must be persuaded that forest expansion is essential. However in addition to effective incentives to encourage expansion, the policy standards of sustainable forest management (SFM) must be implemented. Guidance on species choice in Ireland has been published (Horgan et al. 2004), and recommendations for the selection and silviculture of broadleaved trees is also available (Joyce et al. 1998).
COFORD, the national research and development funding agency supports research for the development and of sustainable forestry in Ireland under 13 broad themes including forests and climate change, reproductive material, silviculture, planning and management, forest economics and policy, forest health, wood products and energy, biodiversity and forests and water. Most of the climate change policy is related to mitigation options.

FOREST SERVICE
There is at present no formal forestry adaptation policy. However, the Forest service has published an Indicative Forestry Statement (IFS) is to provide high-level, national guidance in relation to the suitability of land for afforestation (http://www.agriculture.gov.ie/media/migration/forestry/IFSDoc_Dec08.pdf). One of the key aspects of delivering a balanced programme is to ensure, as far as possible, that new forests integrate, enhance and reflect the diversity and local distinctiveness of the landscape in which they are set. It is also fundamentally important to provide the public and the forest

industry with the earliest indication of the areas where potentially sensitive issues may arise in relation to, for example, landscape, water quality, archaeology and biodiversity.
Other guidelines include

- Code of Best Forest Practice – Ireland (2000)
- Irish National Forest Standard (2000)
- Forest Biodiversity Guidelines (2000)
- Forestry and Water Quality Guidelines (2000)
- Forest Harvesting and the Environment Guidelines (2000)
- Forestry and Archaeology Guidelines (2000)
- Forestry and the Landscape Guidelines (2000)
- Forestry and Aerial Fertilisation Guidelines (2001)
- Forest Protection Guidelines (2002)
- Forestry Schemes Manual (2003)
- A review and appraisal of Irelands Forestry Development Strategy (2004)
- Forest Recreation in Ireland (2006)

2.2.2. Management level

Site classification has an important role in this regard as it will encourage improved species choice, and more importantly it should demonstrate the evolving recommendations on climate change adaptation (Ray, 2008a; Ray 2008b; Ray et al, in press). Forests planted now will grow and mature through a period of unprecedented climate change. Therefore the new challenge of site classification systems is to recommend robust species choice and silvicultural systems to minimise the negative effects of climate change to forests, forest ecosystems, as well as other services that forests provide to society.
Major guidelines include:

1. Selection of new provenances or species for warmer climates (see section on ESC).
2. Although our oceanic climate is not associated with the occurrence of water deficits, future planting policies need to take water availability into account. It has been shown that the establishment of Sitka spruce, under current planting conditions, is susceptible to water deficits. Also, broadleaves may be become a better choice for planting in drier regions because they intercept less rainfall and are not as susceptible to water deficits as Sitka spruce and other conifer species.
3. Rotation length may need to be reduced to take higher growth rates into account.
4. An assessment of windthrow risk is required to account for the higher frequency of cyclones and increased wind speed on stand stability.
5. An assessment of the effects of climate change of carbon cycling and sequestration potential of out national forest estate is also required.

3. Mitigation

Land use and land-use change contribute substantially to global greenhouse gas emissions, but they also offer significant potential to reduce emissions. The authors of the forestry chapter of the IPCC Fourth Assessment identified the following key mitigation technologies and practices in the forestry sector:

- afforestation/reforestation
- forest management
- reduced deforestation
- increased use of wood products
- use of forestry products for bioenergy to replace fossil fuel use.

All the measures identified in the IPCC Fourth Assessment report are of direct relevance to forest policy and practice in Ireland. However, in order to develop and implement policy, baseline and forecast forest sink data are needed. Good quality data for the forest sector in Ireland are now available from the national forest inventory completed in 2007, the COFORD-funded CARBWARE[1] project, and statistical information on wood harvest and wood product use in Ireland.[2]

3.1. Carbon accounts

3.1.1. Kyoto Protocol and Irish position

Based on the EU burden sharing agreement, Ireland's target is +13% of its 1990 emissions. Annex A to the protocol sets out the greenhouse gases and sectors which Parties include in their annual inventory report.

Articles 3.3 and 3.4 of the protocol deal with forestry. Article 3.3 sets out the overall framework for the mandatory accounting of carbon stock changes arising from afforestation and deforestation activities since 1990, over the commitment period 2008-2012. Article 3.4 encompasses four land use activities:

- cropland management
- forest management
- grazing land management and
- revegetation.

Selection of the activities to be included in carbon accounting is voluntary. Forest management covers carbon stock changes in forests that were in existence prior to 1990. Countries had to choose, by the end of 2006, whether to account for Article 3.4 activities. Ireland chose not to account for any of the activities, mainly due to data uncertainties. The recent completion of the first National Forest Inventory, however, places the country in a

[1] CARBWARE is the national forest carbon reporting system and associated software. It is also the name of the COFORD funded project that develops the system and provides annual forest carbon stocks and stock change in Irish forests to the UNFCCC forest carbon stocks and stock changes in Irish forests. The project also carries out projections of the national forest sink on behalf of the EPA, as well as scenario analysis for the Forest Service, government departments and other agencies. Data inputs are provided by the EPA, Forest Service, Coillte and other agencies, as well as other COFORD-funded projects such as CARBiFOR and FORESTSOILC. CARBWARE work also extends to the development of forest growth models, and ascertaining levels of uncertainty associated with estimates. COFORD-funded climate change research is coordinated under the CLIMIT programme.

[2] The Joint Forest Sector Questionnaire (EUROSTAT/FAO/ITTO), compiled annually by COFORD.

stronger position to include forest management in accounting for carbon stock changes post 2012.

Article 3.3 of the protocol requires the reporting and accounting of carbon stock changes associated land-use, land-use change and forestry (LULUCF). Newly planted forests (post-1990), in particular, offer the potential to offset CO_2 emissions in other sectors by taking up and storing carbon in forest biomass and soils. The sequestration potential of these forest sinks has been substantially enhanced by the establishment of more than 250,000 ha since 1990, following the introduction of afforestation grant schemes (Figure 1). Assuming a business as usual scenario, it is estimated that the contribution of national forests, under Article 3.3, may offset ca. 16 % of the required GHG emissions for the first commitment period (2008-2012, Black and Farrell 2006).

3.1.2. Irish carbon account

The total carbon reservoir or store in Irish forests[3] currently exceeds one billion tonnes of carbon dioxide. By comparison, Ireland's total emissions of greenhouse gases in 2006 was 69.8 million tonnes of carbon dioxide equivalent, or less than 7% of the amount stored in forests.

Looking at the Irish forest estate as a whole, over 90% of the total amount of carbon is stored in the soil and litter pools (Figure 9). One of the main reasons for the high level of soil carbon is that many Irish forests have been established on peat soils, which have very high levels of carbon to begin with. However the Irish situation is not unique - similar levels of soil carbon are found in many forests at the higher northern latitudes, where it builds up slowly over hundreds of years from leaf and needle decomposition.

Figure 9: Proportionate carbon dioxide store in different pools in Irish forests in 2006.

In contrast to soil carbon, biomass carbon can accumulate rapidly in newly established forests, and will continue to do so for many decades and indeed centuries if left undisturbed. Conifer forests rapidly accumulate carbon once they are established; broadleaves do so at a slower rate, but over time will accumulate close to the same total amount of carbon in their biomass on a unit area basis. The biomass pool in Irish forests in 2006 was estimated by the National Forest Inventory as 111 million tonnes of carbon dioxide (10% of the total).

Calculating forest carbon stock change at the national level is based on common reporting formats provided by the UNFCCC and on the Good Practice Guidance for Land Use, Land-

[3] For reporting purposes forests are defined as land units with a minimum area of 0.1 hectare, a minimum width of 20 m, trees higher than 5 m and a canopy cover of more than 20%, within a forest boundary, or trees should be able to reach these thresholds (as defined in National Forest Inventory NFI).

Use Change and Forestry published by the Intergovernmental Panel on Climate Change (IPCC). COFORD has developed a national carbon reporting and projection system (CARBWARE), based on the UNFCCC and IPCC formats.

- For 2008 the forestry sink (gross uptake of Irish forests) is estimated to be 6.2 million tonnes of carbon dioxide, or
- 3.6 million tonnes net of wood harvest and deforestation,
- of the 3.6 million tonnes, some 2 million sequestered in Article 3.3 (Kyoto) forests,
- with the balance of 1.6 million tonnes being stored in the non-Kyoto forests (Figure 10).

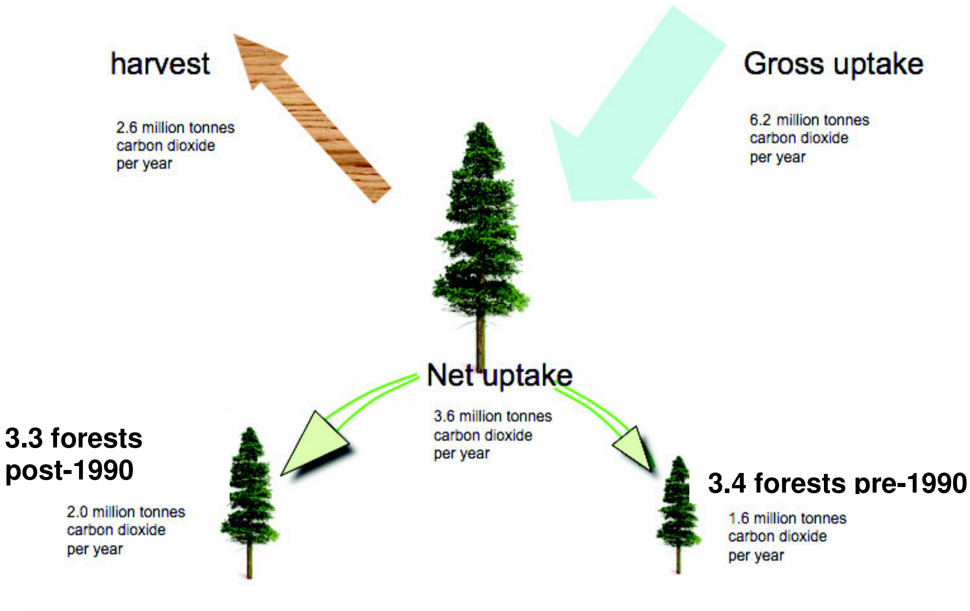

Figure 10: Simplified carbon balance of Ireland's forests in 2008 (Taken from Hendrick and Black 2009).

3.2. Political processes, instruments and strategies for mitigation

The National Climate Change Strategy sets out a series of measures that are designed to meet Ireland's greenhouse gas emission target over the period to the end of 2012. Forest sinks (afforestation since 1990 – the Kyoto forest) is by far the largest measure identified. The contribution is estimated at 2.08 million tonnes of carbon dioxide in 2008. More recent projections provided by COFORD to the EPA estimate that the average annual sink between 2008 and 2012 will be 2.2 million tonnes of carbon dioxide. Looking to the period beyond 2012, it is expected that the sink will increase on an annual basis to reach over 4 million tonnes of carbon dioxide by 2020 (Figure 11).

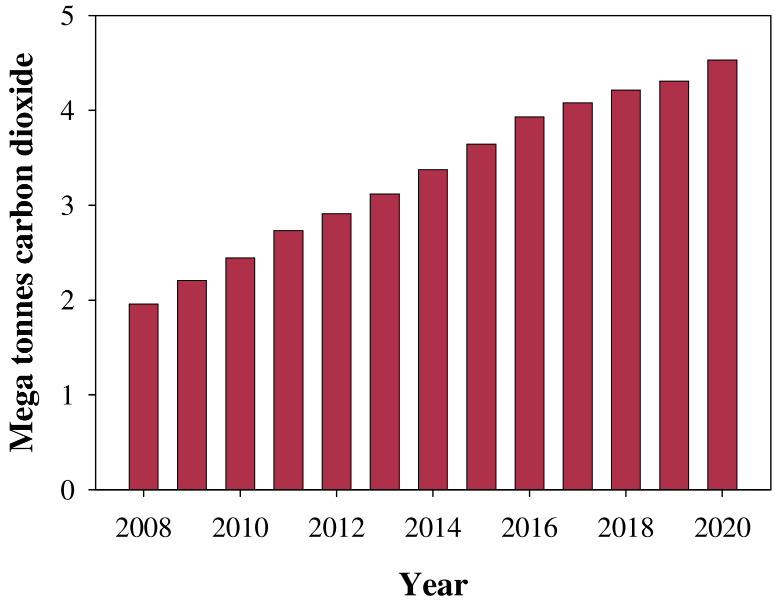

Figure 11: *Ireland's annual projected forest sink to 2020 under Article 3.3 of the Kyoto Protocol.* (Taken from Hendrick and Black 2009).

Based on a price of €20 per tonne of carbon dioxide, the forest sink is likely to save the Exchequer an average of €44 million per year between now and the end of 2012, or €220 million in total. Actual savings will be higher or lower depending on a number of factors, including the price of carbon, and levels of afforestation, harvest and deforestation.

While forestry in Ireland will make a significant contribution towards emission reductions and compliance with the national Kyoto target over the next decade, it needs to be considered over a far longer time frame, given the fact that emissions from the deforestation of the past two centuries are contributing to today's climate change problems. Forestry is a long term business and needs a consistent and far seeking policy framework for it to be a cost effective and efficient climate change mitigation tool. Two factors are key to providing long term climate change mitigation from forests:

- a balanced age structure to deliver an even stream of goods and services over time and
- maintaining forest once it is established.

Forests in Ireland are generally worked on rotation periods (between planting and harvest) of 40-50 years. When the forest is felled at the end of, say, 50 years most of the carbon is removed in the harvest. If, at the national level, there is an even age structure of forests following on (more or less the same area of forest in each age class from 1-50 years), then the overall level of carbon stored, and being stored, will not diminish (provided all felled areas are regenerated to the same carbon stock). If there is less forest following on, then it will be unable to fully replenish the carbon removed in harvest.

What has happened in Ireland is that since 1985 there has been a rapid expansion in private sector afforestation until 4-5 years ago, when it began to tail off (Figure 1). If this downward trend continues, forests that come under Article 3.3 will, at the national level, become a net source of emissions (due to harvest and associated disturbance).

COFORD has carried out an analysis of the afforestation trend and the implications it will have for the future climate change contribution of forests that come under the Article 3.3 umbrella. It shows that if afforestation falls to around the 7,500 ha per annum level (the recent rate), then, by 2035 or so these forests will become a net source of greenhouse gas emissions, under current rules (Figure 12). Not only will the carbon sink turn negative, but the level of wood energy supply will also fall off as the forests mature and produce larger tree sizes, destined for higher value markets than fuel.

The second key factor is that climate change mitigation by forests depends above all else on maintaining the land use as forest - if not the carbon sequestered will be lost back to the atmosphere, and the sustainability of wood energy is called into question. In terms of policy and investment it makes little sense to first establish forest (at considerable cost to the state and the land owner) and then to remove it (at considerable cost to the state in terms of emissions accounted for).

Carbon accounting works on the principle that carbon in the wood harvest is immediately emitted to the atmosphere, and in the absence of replanting it is not replaced. An annual rate of deforestation of 1,000 ha would reduce the allowable sink by close on half a million tonnes of carbon dioxide – or a cost in the region of €10 million.

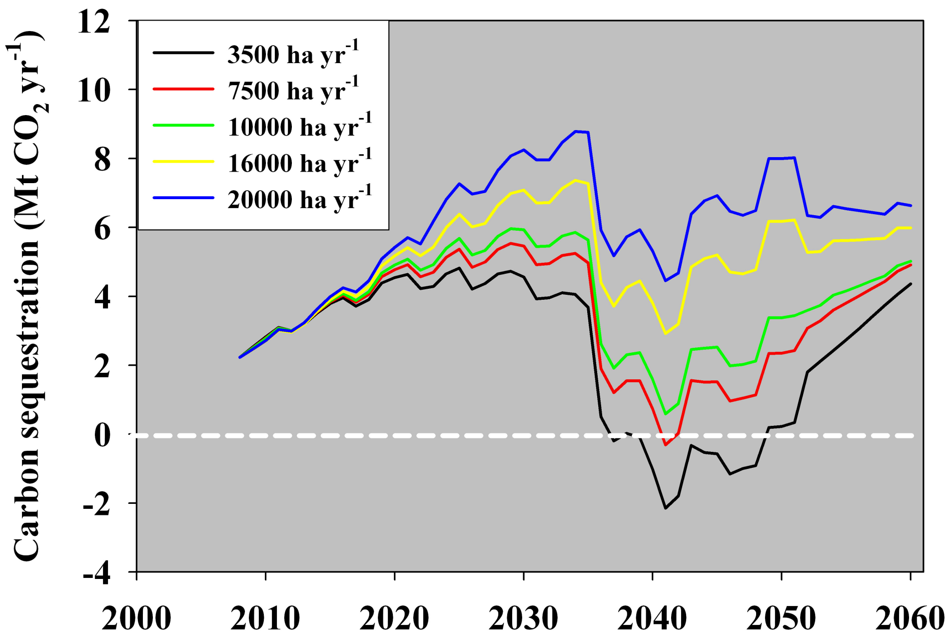

Figure 12: Projected sequestration of carbon dioxide by Kyoto forests to 2060, based on afforestation rate (note negative for 3,000 and 7,500 ha per annum rates).

Afforestation abatement potential and cost curves

Forests currently occupy just 10% of the land cover of Ireland, they are relatively young and productive, and research indicates that a doubling of forest cover is well within technical reach. So, in the future, there is significant scope for adding to the forest reservoir and enhancing the mitigation effort by forestry sinks. The indicative forest strategy suggests that only 15 % on the Irish landscape is unsuitable for forestry (Forest Service, 2008). Potentially, 38% of the Irish landscape is suitable for any type of forestry, with only 10 % of the areas currently afforested. This suggests that the current afforestation target of 15 000 ha per year could substantially increase. Major political and social limitations, such as competing land uses, could substantially reduce the realised potential forest area. However, it would be fair to assume that an additional afforestation rate of 15 000 ha per year up to 2030 is possible above the business as usual scenario. These additional abatement activities could result in an additional 3 M t CO2e per year by 2030, assuming the current species mixtures are planted under current the climate. The abatement cost of these activities, based on the cost of afforestation grants and premiums discounted against the timber revenue returns from a full rotation, is estimated to be in the region of 43 € per tonne of CO_2. Although LUULCF activities are not in the emission trading sector, this compares favourably with other abatement costs (Figure 13) with the 6th highest abatement potential.

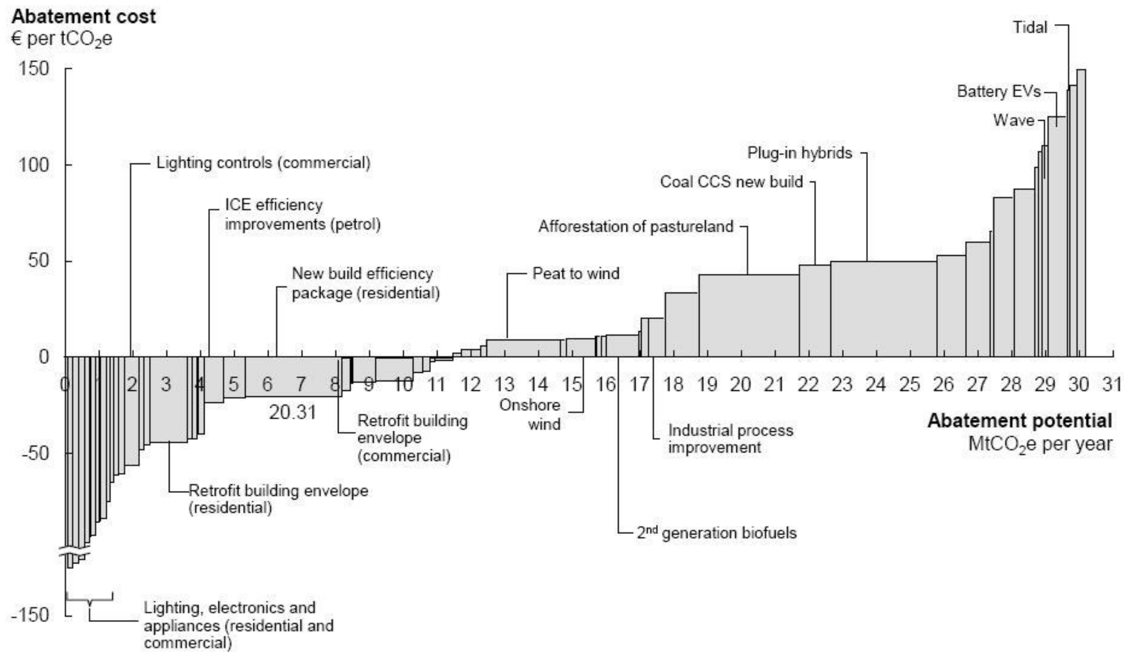

Figure 13: The abatement cost and potential of different options up to 2030. (Source SEI abatement cost curve)

Whilst afforestation offers a good abatement potential, the level of deforestation needs to be considered. For example, the potential introduction of wind farms in many forest areas could easily negate mitigation policy effort. Clearly, there is a need to harmonise renewable energy policy.

3.3. *Forestry as a source of bio-energy*

At the national accounting level, emissions from wood fuel combustion are not included in the energy emissions account, as they have already been accounted for in the forest harvest. This means that it is environmentally sound and economically prudent to use wood biomass for energy production, particularly in applications where there is high energy efficiency.

The wood energy story
At the EU level, the Biomass Action Plan, published at the end of 2005, foresees a doubling of the use of biomass for energy (mostly wood) - to reach 8% of overall energy supply by 2010 (7.7 PJ or 185 million tonnes oil equivalent).

Ireland's most recent policy statements - the Energy White Paper and the Bioenergy Action Plan - place a strong emphasis on wood use for heat, power and combined heat and power (CHP). Sustainable Energy Ireland has estimated that meeting the targets for the three sectors will require a supply of 4.2 million tonnes of wood fuel by 2020.

The latest year for which data are available, 2006, shows wood energy contributing 9 PJ or just over 1% of the Total Primary Energy Requirement of 666 PJ. Since 2006, wind has probably overtaken wood in terms of installed energy generation capacity. Nevertheless, wood energy use is also growing rapidly, in line with schemes administered by SEI, particularly the Renewable Heat Deployment Programme (ReHeat), which has approved the installation of 76 wood fuelled boilers, with an installed capacity of 36 MW_{heat}, delivering emission savings of 47,500 tonnes of CO_2 per year, or around €1 million in terms of emissions savings (Hendrick and Black 2009).

Displacing emissions from fossil fuels by using wood only makes sense if the forests the wood comes from are sustainably managed: the carbon dioxide released from combustion of wood is effectively taken up by the forests as they regrow following harvest. A small proportion of the energy obtained from wood fuel is used in harvesting and transport, but it is generally well below 10%. Forest fuels are one of the most efficient biofuels – little energy is expended in the growing of forests, unlike first generation liquid biofuels such as rape seed oil or ethanol derived from maize, where most of the energy output is cancelled out by energy inputs in the form of fertilisers and pesticides, and other inputs at sowing and harvesting and refining.

Calculating wood energy

- Energy value of wood is usually expressed in Giga Joules (GJ) per tonne or per cubic metre. The average energy value of a fresh green tonne of Sitka spruce is about 6 GJ.

- There are 1 million GJ in a PJ.

- Hence, to generate 9 PJ or 9,000,000 GJ of energy would need a supply of 1.5 million tonnes of fresh Sitka spruce per annum. In practice, the wood energy supply in Ireland comes mainly from board manufacture and sawmilling residues, the recycled wood stream, and a growing contribution from forest-derived energy assortments.

3.4. *Research studies on mitigation*

The COFORD funded CLIMIT programme consists of 4 projects related to mitigation research and reporting

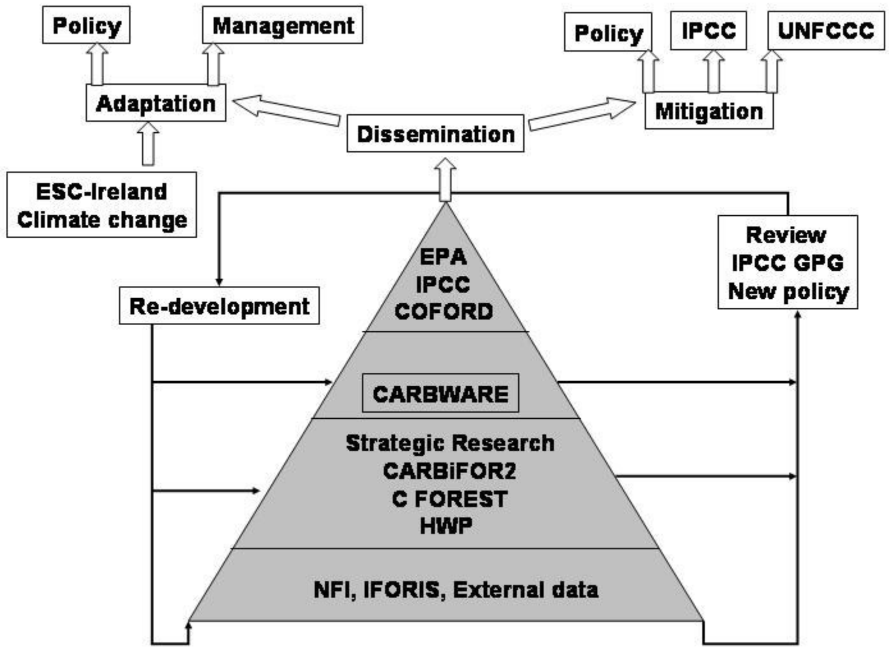

Figure 13: The programme structure outlining the flow of information between external data sources, individual projects and dissemination to stakeholders.

Overall Structure

The programme is broadly divided into two core activities:

1) Assessment of the impact of IPCC climate change scenarios on forest ecosystems, the development of adaptation strategies, as well as the role of forests in overall climate change adaptation. Most of this work will be done under the Ecological site classification and climate change project (ESC-Ireland). However, there will be collaboration with FORESTC, CARBWARE and CARBiFOR projects (see proposals) for adaptation strategies for both future forest and carbon sequestration scenarios (including economic impact).

2) Strategic research and development of a carbon stock change reporting format for all Irish forests (Convention reporting), and for those arising from afforestation and deforestation since 1990 (Kyoto reporting), in the five biomass pools outlined in the Marrakesh accord (Figure 1). CARBWARE will form the focal point for dissemination of all research efforts (CARBiFOR II, FORESTC, HWP-C-stores and ESC-Ireland). <u>The objectives of the research programme are firmly based on the policy requirements in terms of Ireland and Kyoto reporting commitments and government policy. This requires a good knowledge of International and EU Policy, C reporting mechanisms, issues relating to forest C sinks and climate change. Therefore, it is important that the programme is well represented at the policy level.</u>

CARBWARE and ESC-Ireland will be continually updated as new research and external (NFI and IFORIS) information becomes available from both within and outside the proposed programme.

4. Conclusion

The impacts of climate change of forest growth and species distribution remains a key knowledge gap in the Irish forestry context. The relatively short history and rapid expansion of the forestry sector, together with silviculturally related changes in productivity make it difficult to discern any impact of changing climate on forest growth or health. However, limited research information does provide anecdotal evidence of changes in response to global change including climate impacts. The predicted impacts under future global/climate change are even more uncertain and current predictions or changes in species suitability and productivity should be treated with caution. This makes it extremely difficult to develop adaptive strategies without a good knowledge of climate change impacts. Indeed, adaptation policy in Ireland has not been clearly developed and is identifies as a key gap in climate change policy. On the other hand, there has been strong political and industrial support of the mitigation activities, possibly due to greater economic and political incentives.

Climate change research is Irish forestry is relatively new. It is envisaged that stronger adaptive policy could be developed once a better knowledge of climate change impacts is obtained from the research community, particularly form the CLIMIT research programme.

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