- *Forests provide economic, ecological and social services, including wood production, biodiversity and carbon storage, and recreation.*
- *Responsible forest management and conservation measures underpin the lasting delivery of these services.*
- *Challenges and threats to forest condition include climate change, emissions and deposition of air-borne pollutants and land use change.*
- *These challenges and threats are addressed through a range of forest and climate related environmental policies. Policy makers rely on long term, up-to-date, comparable and validated information on the condition and development of processes occurring within forest ecosystems.*
- *These data are used to understand changes in forest biodiversity, cycling and storage of carbon in forests as well as the productive capacity of forests to provide wood, other products and services.*
- *The role of forest monitoring is to gather relevant, robust long-term information to understand changing processes occurring within the forests of Europe and beyond. These data facilitate and support informed decision-making on the future management of European forests.*
- *The FutMon project represents the evolution of 20 years of forest monitoring addressing current issues of policy concern in the forests of Europe.*

COFORD
Department of Agriculture, Food and the Marine, Agriculture House,
Kildare Street, Dublin 2, Ireland
Telephone: +353 1 607 2487
Email: info@coford.ie
http://www.coford.ie

A new vision of forest monitoring in Ireland and Europe

The FutMon project

Fiona Harrington[1]***, Pat Neville, Thomas Cummins, Ted Farrell***

History of Irish forest monitoring

Ireland has been collecting data and reporting on the condition of Irish forests for over 20 years through its involvement in one of the world's largest forest monitoring networks. This pan-European network (EU/ICP Forests) was established in the mid 1980s across Europe (and in Ireland) in response to concerns raised over the health of forests, evident from an observed deterioration in the condition of trees across many regions of Europe. It has evolved to address other issues of concern including forest biodiversity and climate change issues.

In tandem, several forest health and vitality processes have been initiated, most significantly the Ministerial Conference on the Protection of Forests in Europe (MCPFE), the Convention on Long-range Transboundary Air Pollution (CLRTAP).

Ireland has made a commitment at Ministerial level, along with other Member States and signatory nations, to supply annual forest data from the Irish forest monitoring network, to the European Union and the United Nations to fulfil its reporting obligations under these processes.

Forest monitoring site at Dromahaire, Co Leitrim.

[1] *Fiona Harrington, FutMon Project Manager, Coillte Research & Development, Newtownmountkennedy, Co Wicklow. Email: fiona.harrington@coillte.ie*

From the beginning, the monitoring programme has been co-funded by the Forest Service, Department of Agriculture, Fisheries and Food, with support from the EU through European regulations Reg. (EEC) 3528/86 (1986-2002) and Reg. (EC) 2152/2003 (Forest Focus 2003-2006), and more recently through LIFE+ funding, known as the FutMon project (2009-2010). The monitoring programme has been implemented in Ireland through a unique partnership between the Forest Service, Coillte (The Irish Forestry Board) and University College Dublin (Forest Ecosystem Research Group).

The FutMon Project (LIFE07 ENV/D/000218) marks a new phase in Irish and European forest monitoring. The project aims to develop new forest monitoring tools and to fully harmonise existing processes to provide better information about the interactive effects of climate change and air pollution on forest ecosystems across Europe.

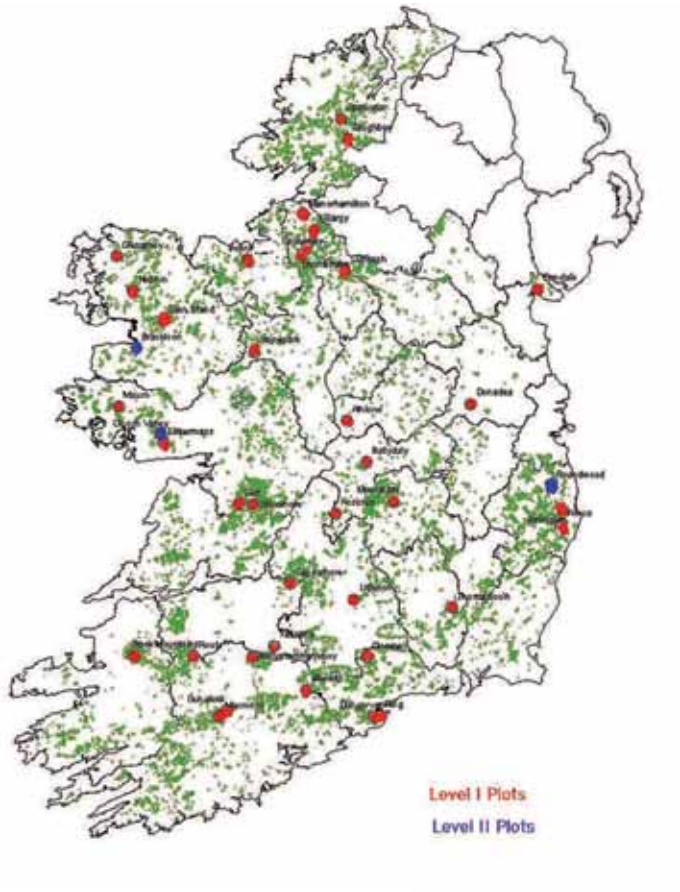

Figure 1: FutMon plots in Ireland.

FutMon forest monitoring network

The European forest monitoring network, FutMon, works at two levels:

- a large scale survey known as the Level I network (6,000 forest plots);
- a detailed intensive survey known as the Level II network (900 forest plots).

FutMon Level I Network: Large scale forest monitoring

The Level I network of forest plots provides information on the current status and changes taking place in forests across Europe. Central to this work is the annual *Crown Condition Survey*. This survey gathers information annually on tree crown density and uses these data as a measure of forest responses to environmental stress. Forest monitoring plots in the Level I network were selected using a systematic grid of 16 x 16 km covering Ireland and Europe. Of the 6,000 Level I plots in the pan-European network, 37 are located and surveyed each year in Ireland (Figure 1).

Trees are assessed on the basis of defoliation and discolouration observed in the tree crown, and tree mortality and causes of damage are recorded and investigated. More recently a full inventory of soil information and components of forest biodiversity has been recorded at the Level I plots (known as the BioSoil project[1]). Data from Ireland and 38 participating countries are submitted to EU/ICP forests annually. Results from this extensive monitoring work are published annually in *The Condition of Forests in Europe* – an Executive Report of the European Commission and ICP Forests. The most recent report is the 2010 Executive Report[2].

FutMon Level II Network: Intensive forest monitoring

Intensive forest monitoring plots are designed to investigate in detail ecological processes occurring within forests. Level II plots are selected across Europe as a representation of the most important forest ecosystems of each country. While these plots are central to the detection of changes in forest processes, they also provide the means to understand and explain the changes observed at the Level I plots.

The European network consists of 900 plots, three of which are located in Ireland. Ballinastoe (Co Wicklow) and Cloosh (Co Galway) are intensively monitored plots located within Sitka spruce plantations while the Brackloon plot (Co Mayo) is located in a semi-natural oakwood.

Data are collected at each plot on a weekly basis from a range of different surveys (Table 1). Results and trends observed

Table 1: List of measurements and timing frequencies made on FutMon Level II Intensively Monitored plots.

Measurement	Frequency
Tree growth	Weekly and every 5 years
Crown condition	Annually
Foliar chemistry	Every 2 years
Soil (chemistry and description)	Every 10 years
Litterfall	Monthly
Deposition	Weekly
Air quality	Monthly
Soil solution	Every 2 weeks
Meteorology	Daily
Phenology	Weekly
Ground vegetation	Every 3 years
Biodiversity	Every 5 years
Leaf Area Index	Annually
Reconciling monitoring networks	One off event

across Europe over the Level II network are published annually in *Forest Condition in Europe*, a Technical Report of the European Commission and ICP Forests - the most recent being the 2010 Technical Report [3].

Key FutMon objectives

Today, under the FutMon project, the main aim of the monitoring programme is the collection of forest data which enables scientists and key policy makers to:

- Understand the fate of **atmospheric pollutants** in a range of forest ecosystems, i.e. their accumulation, distribution and release to the environment;
- Identify **cause-effect relationships** and the extent to which air pollution and other abiotic stress factors (storm events, fires, carbon stocks) and biotic factors (invasive species, newly emerging diseases) are responsible for observed changes in forest condition;
- Review the likely **impact of future scenarios** of climate change, air pollution, abiotic and biotic stress factors on forest ecosystems;
- Contribute to understanding of **net carbon sequestration** in Irish and other European forests and changes in the global carbon balance;
- Determine **critical levels and loads** of atmospheric pollutants for forests under current and predicted climate conditions;
- Develop and test **indicators** that can be used to assess the changes in forest biodiversity and the long-term sustainability of forest ecosystems.

While these are the overall key objectives of the FutMon project, the forest monitoring programme is flexible enough to accommodate different issues as our understanding of forest processes increases and new methods are tested and developed.

FutMon surveys

The key objectives of the FutMon project are delivered through a range of different surveys carried out at the FutMon Level I and Level II plots. Table 1 lists the surveys and the frequency at which they are conducted.

FutMon project surveys

Tree growth: Forests are expected to respond to changes in climate as warming is predicted to increase the length of the growing season for trees. How trees will respond to these changes is unclear at present. FutMon is monitoring and recording tree growth at weekly intervals on a selection of trees at the Level II plots and once every five years for all trees on the FutMon Level I plots.

Crown condition: The health and vitality of trees is partly manifested in the vigour of their crown. Healthy and productive trees express a full and luxuriant crown while trees suffering from stress or disease can have a patchy and damaged appearance in their crown. Records are taken annually of crown condition at all FutMon plots in Ireland; tree mortality and causes of damage are recorded and investigated.

Foliar chemistry: The large surface area of forest canopies means that they collect dust, mist and deposits from atmospheric gases. Trees absorb many of these chemicals through their needles and leaves. Surveys of foliar chemistry help to understand this process and its effects on tree health. In areas of poorer soil quality, where nutrients may be lacking, foliar chemistry recorded at the FutMon Level II plots can be used as a measure of tree nutrition.

Litterfall: Large amounts of needles and leaves falling to the forest floor can be an early indication of stress to a forest ecosystem. Leaf and needle input to the forest floor also plays a vital role in the nutrient cycle of forests, returning nutrients from the trees to the root zone. FutMon records the amount and chemical composition of litterfall at the Level II FutMon plots. Leaf litter chemistry gives an indication of the health of the trees above.

Soil chemistry: Soil plays a key role in the development of a forest ecosystem. Fertile base-rich soils lead to healthy productive forests, but more nutrient-poor and acid forest soils can cause leaching of potentially toxic compounds such as iron and aluminium into surface waters. Leaching of toxic ions is

the result of the interaction of precipitation chemistry, the forest canopy and the soil. A detailed description and inventory of soil nutrient status has been completed at all FutMon plots. Results of this survey are being compared with a previous survey conducted in 1995 to assess long term changes in soil fertility. A national report on Irish forest soils will be published in 2011 based on the FutMon data. Soil carbon data have also been collected.

Soil solution chemistry: Changes in soil processes can be difficult to detect and may occur over long time periods. To understand these processes in greater detail, twice-monthly measures of soil solution chemistry are recorded at the FutMon level II plots. These records are used to predict future changes in soil fertility and sustainability and can give a key understanding of other processes observed at the FutMon forest plots. Concentrations of ions measured in soil solution are also evaluated against the amounts recorded in the rainfall deposition survey on the FutMon plots to understand the interaction of the forest canopy in the nutrient cycling process.

Deposition: The amount of rain that falls on the forest, and its chemical composition, are recorded weekly at the FutMon Level II plots. This information is critical in understanding the roles that forests play in trapping substances from the air. The forest canopy intercepts airbourne gaseous and particulate matter, cleaning the air but consequently concentrating pollutants in the throughfall. Relatively high deposition of acidifying ions can result in accelerated acidification of sensitive soils. Understanding the maximum safe amounts, or critical loads, of nutrients that forests can safely absorb, is a major aim of FutMon.

Air quality: The FutMon project also records other aspects of air quality at the FutMon Level II plots on a monthly basis. Measures of nitrogen in the form of ammonium and nitrogen dioxide are recorded, as is sulphur dioxide. Amounts of ozone in the air are also measured at the FutMon plots as ozone at ground level is known to be potentially damaging to both plant and human health. In addition, an assessment of vegetation is conducted to examine plants for signs and symptoms characteristic of ozone damage.

Meteorology: Automated weather stations located at the three FutMon Level II plots collect detailed information on rainfall, air temperature, relative humidity, wind speed and direction, and solar radiation. These records are used in conjunction with other surveys, for example phenology to measure the length of the tree growing season in Ireland and also to serve as a permanent record of climate data for Irish forests. The data may also be used to validate climate change models for Ireland.

Phenology: Phenology is a measure of key seasonal tree growth phases in the forest. The occurrence of major growth events such as bud burst and flowering in the forest canopy along with leaf fall in deciduous trees are recorded at the FutMon level II plots. Long term records give an indication of changes in length of the growing season in Ireland in response to predictions of climate change. How trees and forest ecosystems may react to such changes is unclear, but this kind of data may be used to validate growth and climate models.

Ground vegetation: The composition of the ground vegetation has been recorded at all FutMon plots in Ireland. The ground vegetation community responds to environmental and man-made changes much sooner than the forest trees. As a result the

Deep soil water samplers.

Humus soil water sample collector.

Ambient air quality passive samplers.

forest floor plant species composition may be an early indicator of environmental stressors such as elevated nitrogen deposition. The plant species of the forest are also a key component of the overall biodiversity and data gathered can be used as a baseline to understand future changes and the impact, for example, of the spread of alien species on native flora.

Biodiversity: Forests are considered to be the richest terrestrial ecosystems for biodiversity. In Ireland and across Europe, forests provide food, shelter and a habitat for many species of plants, animals and fungi. Recently, the European Commission and the Member States have become increasingly concerned about the loss of biodiversity in Europe and 2010 has been labelled as the International Year of Biodiversity. In addition, Ireland is a signatory nation to the Convention on Biological Diversity, an international treaty to sustain the diversity of life on earth. The FutMon project, through the international network of forest monitoring plots both at Level I and Level II, provides an ideal framework for harmonised assessments of European forest biodiversity to build on successful earlier initiatives such as the BioSoil project[1].

Key phenological bud flushing stage in Sitka spruce.

Leaf area index: Leaf area index (LAI) is a new survey to the FutMon project in Ireland. LAI represents the amount of leaf/needle material in an ecosystem relative to ground area. Monitoring changes of LAI is important for assessing growth and vigour of trees. The amount of leaf material on trees has an effect on fundamental processes such as photosynthesis, respiration, transpiration and rain interception. Measurements are recorded annually using hemi-spherical photography to give a pictorial record of tree crown structure. These photographs can be digitally evaluated and used to reconcile with the data collected under the FutMon crown condition survey. Changes in tree crown structure again provide an early warning of processes occurring within the forest ecosystem.

Reconciling monitoring networks in Ireland: The FutMon plot design is based on a historical and long term network established in the 1980s. More recently, however, through the Forest Service, Ireland has established a permanent network of National Forest Inventory (NFI) monitoring plots. The FutMon project now samples 27 NFI plots as part of the FutMon Level I network and employs the common, standardised FutMon methodology on this subset of the national plots. This allows the possibility of linking data collected at the Level I plots with other NFIs across Europe. In addition, data collected from the intensive surveys at the FutMon level II plots may now be used to interpret trends observed across the Irish NFI plots.

Typical woodland flora.

Diverse ground flora at Brackloon - an intensively monitored plot in Co Mayo.

FutMon results

Forests across Europe: Results collected in 2008 classify 21% of assessed trees in Europe as damaged, down from peak levels a few percent higher in 2004-2005. Of the species monitored, the deciduous oaks (*Quercus robur* and *Q. petraea*) have consistently shown the highest levels of damage, with the evergreens generally in better condition than deciduous trees. Beech which had been significantly damaged by extreme heat and drought occurring in central Europe in 2003, has shown a recovery in subsequent years. There has also been a slight overall improvement in the condition of Scots pine and Norway spruce since the late 1990s across Europe. Insects pests, fungi, drought, snow and storms are among the most frequent causes of direct tree damage recorded. This damage can be exacerbated by air pollution and changes in climate[2].

Forests in Ireland: In Ireland, levels of damage are low. During 2008, Norway spruce showed the highest level of damage (15.7%) followed by lodgepole pine (13%) and Sitka spruce (6.9%). These levels do not vary significantly from those recorded in 2006 and 2007. Exposure and abiotic damage from wind events continued to be the greatest single cause of damage to trees in the Irish environment[3].

Long term trends measured at the FutMon plots: Data gathered from almost 20 years of forest monitoring in Ireland show clear and unequivocal reductions in atmospheric depositions of non-marine sulphur to forest ecosystems[4]. These data were presented recently at a COFORD and FutMon sponsored workshop on forest monitoring in Ireland[5]. This follows the successful implementation of clean air policies in Ireland and across Europe (Figure 2).

Concentrations of aluminium (a known phytotoxin) in deep soil waters have also decreased at the FutMon plots in Ireland, most likely as a decrease in the reduction of acidic deposition in the form of sulphur to the forest soils. However, long term deposition of nitrogen compounds in rainfall to Irish forests remains unchanged and steady. This long term and chronic deposition of nitrogen is known to cause a range of damage to forests of central and eastern Europe once their capacity to absorb nitrogen becomes saturated. It is possible that saturation of Irish forests may occur in the long term and careful monitoring is required to understand these processes. A new report detailing the complete results of 20 years of forest monitoring in Ireland is in preparation[6]. This long term data set will be evaluated in the context of the results collected from the new surveys of the FutMon project to understand the long term viability and sustainability of forestry in Ireland.

Forest biodiversity: The first survey of components of forest biodiversity has been completed at the FutMon Level I plots as part of the BioSoil project. BioSoil has examined structural and compositional aspects of forest biodiversity at more than 4,000 forest plots across Europe. This represents the first harmonised assessment of European biodiversity. Data collected under BioSoil may be used as baseline information to understand changes in the extent and trends of forest biodiversity and is fully in line with the European Commissions 2010 target to halt the loss of biodiversity. Ireland played a leading role in drafting and formulating the approach adopted for the biodiversity element of the BioSoil project. A preliminary report outlining the forest results of both the soil and biodiversity survey conducted under BioSoil has recently been published by the Joint Research Centre of the European Commission[1].

Forest soils: In addition to the biodiversity component of BioSoil a detailed survey of forest soils was conducted at both the FutMon Level I and Level II plots in 2007. A soil pit has been excavated at each plot and detailed chemical analysis conducted of each soil horizon. The results of these assessments will be compared, where possible, with a similar soil survey conducted in 1995 to detect changes in indices of soil sustainability such as soil fertility. A national report on the results of the BioSoil soil survey is in press and due for release at the end of 2010. This national report will integrate the characterisation of the soils at the FutMon plots with that of the NFI plots using the World Reference Base (WRB) and Irish Forest Soil databases. These results may be used for reporting of Irish forest soils under the proposed EU Soils Directive.

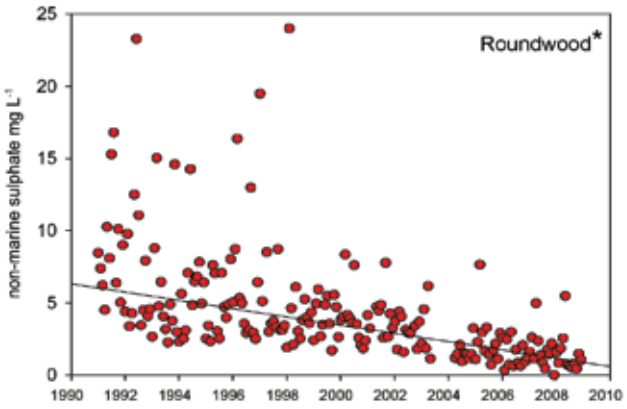

Figure 2: Deposition of non-marine sulphur measured in throughfall (rainfall collected the tree canopy) at the Roundwood and Ballinastoe FutMon plots.

Forests and water: Arising from the implementation of the Water Framework Directive (WFD) in Ireland, there will be an imperative to understand the processes and more importantly quantify the risks of how forests in Ireland can contribute to the acidification of sensitive waters. The results to date from the Intensively Monitored Plot Network demonstrate that under certain seasonal weather conditions (i.e. easterly winds in December to February), upland Irish forests can capture anthropogenic pollution, resulting in acidic pulses in base poor streams. That said, due to international pollution control protocols, such as Kyoto etc, and changes in economic conditions in Europe, ambient air quality has improved significantly since the late 1980s, particularly in regard to sulphur and to a lesser extent nitrogen containing pollutants. Further decreases are expected over the short to medium term and it is important to capture these changes through the intensively monitored FutMon plots, linked to other nationally funded water research projects, such as HYDROFOR[10].

By endeavouring to understand and track the continuous flux of cause and effect in a changing climatic and pollution environment, we can readily demonstrate that under regulated conditions, Irish forests are sustainable and indeed further enhance the aquatic and terrestrial environment in comparison to alternate land uses. Such work is crucial if the ambitious goals of the WFD are to be met, particularly in regard to the forest sector.

We are at a crucial stage in this whole process and any disruptions to continuous monitoring at the Intensively Monitored Plots will leave us with a story half told (i.e. the transition from a high to low pollution environment).

Critical loads: The deposition data collected at the three intensively monitored plots has been used to calculate Critical Loads for Ireland. Critical loads are amounts of pollutants (such as sulphur and nitrogen) that ecosystems can tolerate before they begin to show signs of damage, such as leaching of nitrate and pollution of ground waters. Deposition data along with the an index of soil sensitivities were used to calculate these loads for Irish ecosystems. Results show a clear deposition gradient from low concentrations in the west of Ireland to much higher in the east. These data have been used in the recent Water Framework Directive programme of measures for forests and waters[9].

Climate change and Irish forests: The effects of climate change on forest ecosystems is gaining increased significance at policy level as reflected in the recent EU Green Paper on Forests[7]. The data collected at the FutMon plots can play a crucial role in understanding how forests will react to changes in climate. For example evidence of increased dissolved organic carbon in soil solution samples may indicate increased rates of decomposition of forest soils due to warmer summers. In contrast, colder winters may lead to snow accumulation and breakage of tree crowns of vulnerable species such as Sitka spruce. Over the winter 2009/2010, 39 trees at the FutMon Level II plot in Ballinastoe (0.25 ha) lost their crown due to snow damage. With predictions of colder winters forecasted, these data are becoming increasingly important.

The new FutMon phenological study is gathering data on the length of the growing season for trees in Ireland. These data may be used for calculations of future estimates of tree growth and timber production but with changing season lengths these estimates become evermore uncertain. The data gathered from the FutMon project can form the basis for future estimates if forest monitoring is continued into the future.

Future forest monitoring

FutMon is a LIFE+ and Forest Service funded project running from 2009 to 2010. The current strategy of the European Commission, elaborated in a recent green paper on Forest Policy[7], is to consider the formation of a new Regulation to embrace forest monitoring in the period following FutMon. It is hoped that Member States actively participating in forest monitoring may make contributions towards this new Regulation. The methods refined and validated in the field during FutMon are foreseen to form the basis of the new forest monitoring Regulation.

Conclusions

Data collected through the FutMon Project are being used by key decision makers to aid forest policy formulation in the areas of clean air, nature conservation, biodiversity, responsible forest management, the protection of freshwaters and soil resources. In addition, the FutMon Project and its predecessors in Ireland are providing valuable and unique data on forest ecosystem services and function in Irish forests. This data set may be used in the future to assess the long term viability and sustainability of productive forests in Ireland.

The FutMon data form a valuable and unique platform on which other studies may build. Recently the FORFLUX project[9] is examining these data and reporting long term trends of nutrient fluxes in Irish forests. In addition, the HYDROFOR project[10] is also using FutMon data to understand catchment effects of forests on waters. The role that forests play in sequestering carbon from the atmosphere is crucial in mitigating the effects of climate change. Forests store carbon as biomass through tree growth and also as organic matter in forest soils. Ongoing monitoring is important to understand any potential changes to these two important forest carbon sinks. The FutMon data may be used from both the forest growth and forest soils surveys to monitor such changes.

The forest monitoring programme has evolved over the past 20 years, moving from the effects of air pollution on forests to cover issues today such as climate change, biodiversity and carbon storage in forests. While the issue of sulphur deposition appears to have been successfully resolved and forest ecosystems are showing clear signs of recovery, the effects of long term chronic deposition of nitrogen on forests persists. Many Irish forests, planted on shallow acid sensitive soils are particularly at risk to continued and long term deposition of nitrogen compounds and may have significant impacts on future sustainability of plantation forests in Ireland.

Long term ecosystem monitoring is crucial to understand forest ecosystem processes in a changing climate and to maintain the protective function that forests play in conserving soils and waters. It is essential therefore, in this regard, that long term forest monitoring should continue both in Ireland and across the European Union.

More information

- EC LIFE Nature Unit: http://ec.europa.eu/life
- Forest Service Department of Agriculture and Food: http://www.agriculture.gov.ie/forestservice/
- Irish Forest Monitoring- www.irishforestmonitoring.ie
- ICP Forests - International Co-operative Programme on Assessment and Monitoring of Air Pollution effects on Forests: http://www.icp-forests.org
- FutMon Project – Further Development and Implementation of an EU-Level Forest Monitoring System LIFE07 ENV/D/000218: http://www.futmon.org
- Coillte Teoranta, The Irish Forestry Board: http://www.coillte.ie
- University College Dublin; Forest Ecosystem Research Group and UCD Soil Science: http://www.ucd.ie/ferg/; email: thomas.cummins@ucd.ie

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