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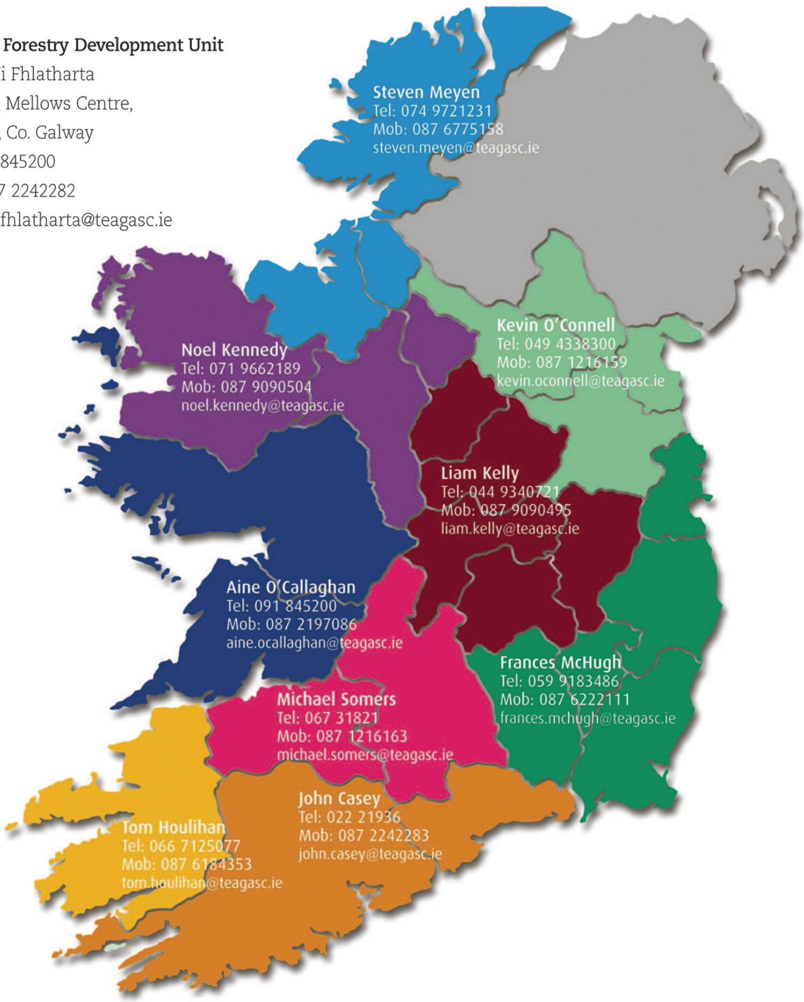

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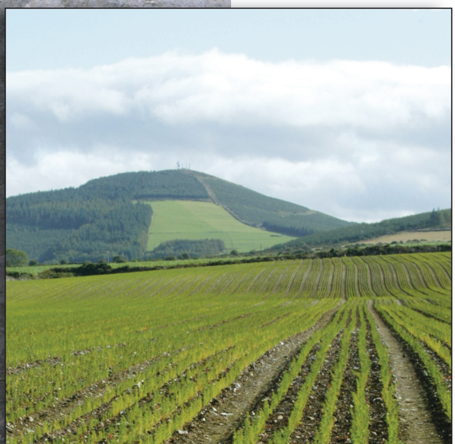


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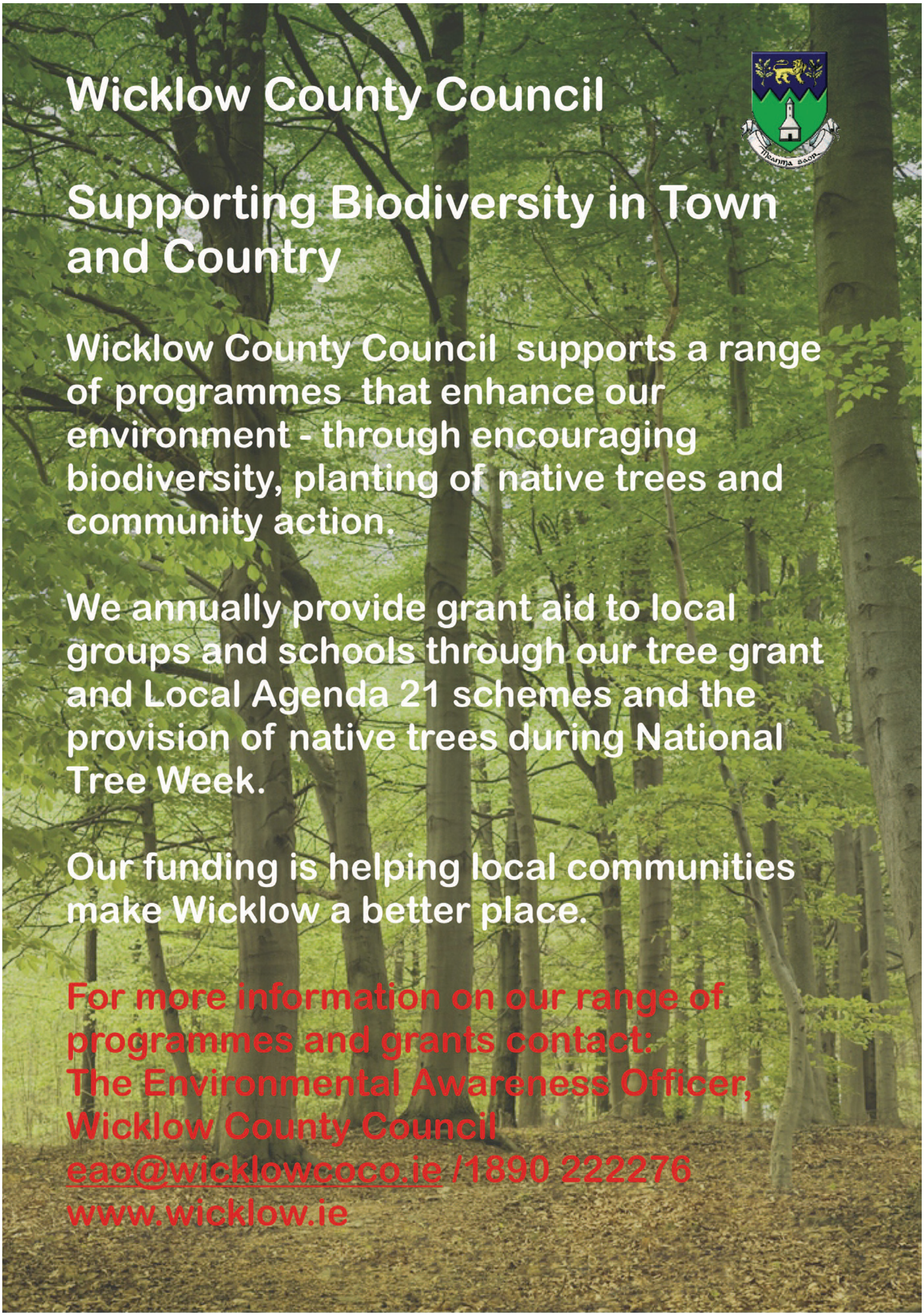
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EDITORIAL

Changing climate

The science of climate change has had a poor press over the past year. Leaked emails from scientists in dispute over climate data sets, allied to the continuing and predictable outpourings of the fossil fuel lobby, have raised the level of scepticism among the public. Is all this talk about climate change being down to energy use and western lifestyle just a coterie of scaremongering scientists, lobbying for more research funding?

No, a large majority of scientists have concluded that climate change is real, and is caused by greenhouse gas emissions arising from human activity. That is not to say that there is small probability that climate change is cased by underlying long-term trends outside of human influence. Science does not deal in certainty: ideas and hypotheses are tested and proved or disproved based on probability. As Karl Popper pointed out, science is based on the precept that all hypotheses must be capable of being falsified. In other words, what we say must be capable of being tested and then accepted or rejected. However, equivocal scientific language such as 'very likely' has been used by vested interests as evidence that climate change is uncertain, and by implication no action is needed.

The public perception of climate change has not been helped by the failure of the Intergovernmental Panel on Climate Change - the body charged with collecting and assessing scientific evidence for the cause and impact of global warming - to properly rebut mischievous and self-serving comments. It has been too slow to maintain and build broad public acceptance of the need for action.

All of this is of relevance to forest policy and practice. Afforestation and forest management have strong roles in mitigating greenhouse gas levels in the atmosphere. Climate change will impinge upon species and provenance suitability for afforestation, and on the growth and productivity of existing forests. A number of papers in this issue address these themes. Plantation forests planted today will experience a changed climate over their lifetimes – how they respond will depend on species/provenance composition, and the level of change in rainfall, temperature and wind patterns. Natural forests will also be impacted by climate change, depending on their extent and level of connectivity. All forests are growing in a changing climate, assessing impacts on health, growth and yield is necessary to develop effective adaptation policies and measures. Continued funding of the National Forest Inventory and research are therefore essential to detect and quantify these effects, and for the forest sector to respond to the challenges of a changing climate.

The PractiSFM multi-resource inventory protocol and Decision Support System A model to address the private forest resource information gap in Ireland

Frank Barrett[a], Maarten Nieuwenhuis[b] and Marie Doyle[b]

Abstract

During the last 20 years, the size of the forest estate in Ireland has increased dramatically. Inventory and management information on the (FSC-certified) publicly-owned forest is widely available, however details on the rapidly expanding private estate, both in terms of inventory data and management objectives, are missing. The PractiSFM inventory protocol and Decision Support System (DSS) comprises Microsoft Excel™ based modules that allow forest managers to analyse multi-resource inventory data and to project the development of a forest under a range of management alternatives. After each simulation, reports in tabular, graphic and map format are produced on a wide range of variables. Visual tools (i.e. an interactive map interface and a goal analysis module) have been incorporated into the program to refine alternatives and to facilitate choice amongst alternatives. It is suggested that use of the PractiSFM inventory and decision support model will allow for the reporting of essential information on the state, development and management of the private forest estate to the State forest authorities. These standardised data can then form the basis for a multi-resource forest inventory and timber (and non-timber) production forecast for the private forests, complementing the already available information on the publicly-owned forest and the results of the low-resolution national forest inventory (NFI) that has recently been completed.

Keywords

Multi-resource forest inventory, forest planning, decision support, inventory reporting, sustainable forest management

Introduction

As a result of the introduction of government and EU incentives, private afforestation as a proportion of total afforestation in Ireland has increased significantly in recent years. Large areas of the private woodlands planted in the 1980s and early 1990s are now approaching the age of first thinning and as the forest estate matures it is estimated that the timber supply from private owners will rise steadily from 0.24 million m^3 at present (Knaggs and O'Driscoll 2008) to over 1 million m^3 by the year 2015, representing some 20% of the total potential national roundwood supply (Gallagher and O'Carroll 2001). However, much of the information concerning private forest holdings is at present either non-existent, confidential or scattered amongst various organisations (Ní Dhubháin and Wall 1998, Gallagher and O'Carroll 2001). In contrast, timber or non-timber inventory information on the publicly owned FSC-

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certified forest, managed by the State Forest Board, Coillte Teoranta, is maintained as an up-to-date, stand-level forest inventory database (Quinn 1996).

While national forest inventory and monitoring initiatives have been ongoing in Ireland for a number of years (Purcell 1979, Fogarty et al. 2000), several authors have drawn attention to the problems of the reliability and correctness of the data that has been collected in these programs (Department of Agriculture Food and Forestry 1996, Gallagher and O'Carroll 2001, Bacon and Associates 2004). The National Forest Inventory (NFI), recently completed by the Forest Service, is a detailed forest inventory using systematic sampling based on a 2 x 2 km grid covering the entire country, with approximately 1800 inventory plots to be assessed on a 5-year cycle (Forest Service 2007a). The inventory produced forest resource information for national policy and international reporting purposes and will go some way to address the lack of current, relevant forest inventory data at a national level. However, the data collected will not serve the data needs of private woodland owners and managers in the implementation, assessment and monitoring of sustainable forest management at a local forest or stand level. The need for further information on economic, silvicultural, environmental and social aspects of private forest holdings, projected timber and non-timber forecasts and management planning in the private sector will also not be addressed by the NFI alone (Figure 1).

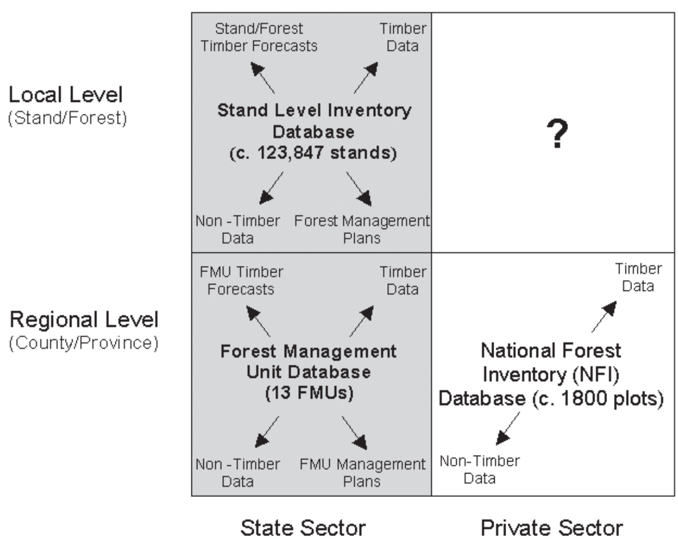

Figure 1: *State and private sector forest inventory, management planning and forecasting protocols, at local and regional levels.*

Following the publication of the Irish National Forest Standard in 2000 (Forest Service 2000), private forest owners are encouraged to evaluate and manage forests for sustainability through the quantification and qualification of multiple forest resources. The preparation of forest management plans is now a prerequisite for the grant payments made in support of afforestation in Ireland (Forest Service 2003). Currently, the two mandatory, paper-based plans, spanning the years 4-10 and 10-20 respectively, include only very basic statements on the management objectives, environmental objectives, and work plans during the planning period. While accurate information is available regarding the area and location of new plantations as a result of the afforestation approval process, these management plans do not provide detailed information on the silvicultural and management practices, nor on the resulting timber and non-timber production potential of the afforested area. A number of reports and submissions to government have emphasised the need for management and database software to support management planning and decision making for private growers and to allow standardised reporting of inventory data to the forest authorities (Ní Dhubháin and Wall 1998, Hennessy and Lawlor 2000, Gallagher and O'Carroll 2001, Whelan 2004, Phillips 2008).

Integrated multi-resource inventory and decision support systems (DSS) for sustainable forest management offer forest owners and managers new and more robust methods for conducting inventories and simulating, analysing and evaluating forest management activities, resulting in a practically attractive, more transparent and higher quality planning process (Rauscher et al. 2000, Reynolds 2005). The development of 'user-friendly' decision support tools, does not seek to replace the need for expert assessment, rather it facilitates the non-specialist or small business users constrained by resources, by integrating and resolving multiple, and often conflicting issues (Ray et al. 2003). In addition, through the use of a DSS, the way the decision maker arrived at the decision is automatically documented and, thus, the process facilitates decisions that are reproducible and as rational as possible (Vacik and Lexer 2001). As a result, these systems have become increasingly important in gaining support from the public for forest related management activities, in attaining planning approval from forest regulatory authorities and in achieving accreditation from forest certification bodies for sustainable forest management (Johnson et al. 2007).

While DSSs for forest management have been used extensively internationally in recent years (Schuster et al. 1993, Akabua et al. 2000, Pyatt et al. 2001, Reynolds 2001, Ray et al. 2003), their use in Ireland has mostly been limited to Coillte Teoranta (Williamson and Nieuwenhuis1991, Tiernan and Nieuwenhuis 2005) or in academic research (Nieuwenhuis and Nugent 1999, Nieuwenhuis and Tiernan 2005). It is only relatively recently that the power of computers has been brought to bare in decision making in areas such as yield modelling (GROWFOR (COFORD 2007a)) and windthrow (Irish Windthrow Risk Model (COFORD 2007b)). This paper describes the development and application of the PractiSFM DSS, designed to function as a user-friendly, integrated multi-resource inventory data management and stand-level based forest planning tool. The development, design and structure of the DSS are described briefly. The inventory, management planning and forecast outputs produced by the DSS are also described. The paper identifies and highlights the importance of the three outputs provided by the PractiSFM DSS: 1) multi-resource inventory data; 2) forest management plans and; 3) timber and non-timber forecasts. The potential for the spatially explicit, high resolution inventory and management planning data outputs from the system to supplement existing Forest Service management information requirements and to complement low resolution information from the recently completed national forest inventory (NFI) is discussed.

The development of the PractiSFM system

The PractiSFM DSS was designed as a low/no cost, flexible, user-friendly decision support tool to aid forest owners and managers in the implementation of SFM. A review process coupled with feedback from forest managers, forest management consultancy companies and the Forest Service, facilitated the design and implementation of an effective and efficient multi-resource inventory protocol (Barrett and Nieuwenhuis 2006) and permitted the identification of the following key functionality requirements in the PractiSFM DSS:

- the capability for the processing, analysis, storage and reporting of stand-level multi-resource (timber and non-timber) forest inventory data;
- the facilitation of stand-level timber and non-timber forecasting for the planning horizon;
- the generation of a range of forest management scenarios over the planning horizon to determine the effects of stand management decisions on a range of timber and non-timber (environmental, economic, social) parameters of relevance in SFM;
- the production of appropriate user-friendly interactive, tabular, graphic and map based tools and outputs to facilitate decision-making;
- the compatibility with the needs of the Forest Service for multi-resource inventory and planning data to complement the National Forest Inventory, assist in the monitoring of SFM and facilitate strategic planning of the forest sector.

PractiSFM was developed in incremental stages within Microsoft Excel using the Visual Basic for Applications (VBA) integrated development environment (IDE). VBA offers the advantages of fast performance, tight integration with the host application, and the ability to build solutions without the use of additional programming tools. Microsoft Excel's familiarity to the end user group (Hennessy and Lawlor 2000), its widespread availability, its user-friendliness and its relatively low cost compared with other proprietary systems were also considered advantages. The PractiSFM DSS comprises three main program modules (Figure 2), which control the functionality of the application, including the production of inventory data entry forms, validation of inventory data, production of stand timber and non-timber forecasts, generation of reports and control of interactive mapping and goal analysis functions. Data requirements for the program are provided in the form of keyboard input through forms and dialogs, and data stored in lookup tables as part of the application. Figure 2 also illustrates the potential linkages of the outputs from PractiSFM with the NFI.

Inventory reporting
The primary source of input data for the PractiSFM DSS is the PractiSFM multi-resource inventory, developed in conjunction with the PractiSFM DSS as a standard set of procedures for observing, assessing and recording multi-resource forest inventory data at a stand-level scale (Barrett and Nieuwenhuis 2006). The multi-resource inventory has been developed in accordance with the criteria and indicators (C&I) as identified in the Irish National Forest Standard (Forest Service 2000) and comprises a total of 27 different timber (e.g. dbh, top height) and non-timber (e.g. vegetation class, landscape sensitivity, soils type etc.) components, with each component comprising one or more variables (Barrett et al. 2007). The multi-resource procedures adopted were incorporated in a field sheet, including key information (e.g. description of types of evidence demonstrating specific wildlife activity, descriptions of tree canopy density classes/foliage discolouration classes), and field sheet guidance notes for each of the components. In addition, documentation listing the steps taken to arrive at the final set of methodologies was created. This was provided to explain the reasoning behind and justification for the various multi-resource inventory procedures and to show the relevance and importance of each of the parameters measured against C&I in the National Standard. The PractiSFM field sheet has been set up on a hand-held data logger.

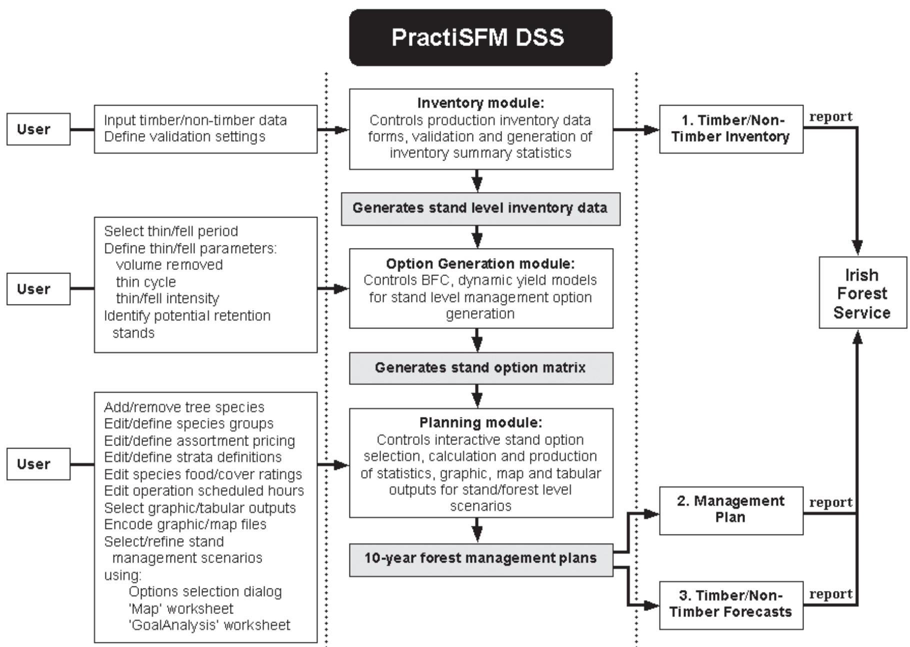

Figure 2: *Structure of the PractiSFM DSS showing the relationship between user inputs, the DSS application modules and output linkages to the NFI.*

Quantitative continuous data (e.g. length of hedgerows, adjacency to streams), quantitative categorical data (e.g. deadwood, natural regeneration) and qualitative categorical data (e.g. internal and external landscape sensitivity) are stored, processed and summarised by the PractiSFM DSS. These data allow the forest owner to form a more holistic picture of the current state of the forest ecosystem, establish a sound knowledge base upon which to make more informed forest planning and management decisions and, thorough monitoring using additional data from future inventories, will assist in the assessment of the progress towards or away from SFM (Barrett et al. 2007). Summary statistics and estimates of timber and non-timber parameters are generated on an aggregated plot, per species, per hectare and stand level. Inventory plot data are checked and validated when the program is initiated to ensure they are in the correct domain and user defined ranges. Timber and non-timber inventory statistics (e.g. amenity, landscape sensitivity, vegetation classification, terrain classification) describing the current state of the forest are outputted from the program in a standard format, grouped by stand and species (Table 1).

Validation of the multi-resource inventory

Subsequent testing and validation of the PractiSFM inventory protocol was carried out by an independent assessor on eight sites in addition to the main test site at Ballycurry, Co. Wicklow. The additional test sites were selected so as to be typical of the physical, environmental and characteristics of privately owned forests in Ireland. This further testing permitted the: 1) analysis of whether the results of the inventory were representative of the different sites; 2) assessment of the time and resources required; 3) evaluation of the effectiveness and completeness of the documented protocol; and 4) correction and revision of the assessment protocols and associated documentation where problems occurred in the interpretation of the methodology. A plot-based, timber inventory and the PractiSFM multi-resource inventory were carried out for each of the stands at eight test sites. Where forest mapping data were not available, stand boundaries and other physical and environmental features were mapped using a GPS.

Completeness and representativeness of multi-resource inventory

The multi-resource inventory protocol was capable of accommodating the wide array of biological, physical, cultural and social characteristics encountered. The testing and validation process permitted the revision of the protocol where inadequacies had been identified. These revisions included: a methodology for recording and mapping within-stand open spaces (excluding roads); a revision of deadwood volume classes; a record of forest wind-zone (Miller 1985); a record of the forest soil type (Horgan et al. 2003); and a record of any proposed statutory or non statutory designations within and/or adjacent to the forest being assessed. Assessment of landscape sensitivity proved most difficult to finalise and apply in practice. A combination of expert knowledge and additional information describing landscape quality and type, sourced from county landscape character maps (Department of the Environment and Local Government 2000) and/or county development plans facilitated the allocation of internal and external landscape sensitivity scores.

Table 1: *A sample of inventory statistics produced by the PractiSFM DSS.*

Timber parameters	Non timber parameters
Timber Plot Area (ha)	Great soil group
Species Present	Severity of soil damage
Age of Species (yr)	Soil damage as a prop. of stand area
Avg. No. stems per plot > 7 cm	Adjacency of stand to major rivers (m)
Avg. No. stems per plot < 7 cm	Adjacency of stand to minor rivers (m)
Total No. stems per plot	Stems (per ha) of natural regeneration
Basal Area per plot (m^2)	Invasive species as a prop. of stand area
Volume in the per plot (m^3)	Presence/absence of feeding by wildlife
Mean diameter breast height (cm)	Deadwood volume class
Mean Basal Area per tree (m^2)	Internal landscape sensitivity class
Mean Volume per tree (m^3)	External landscape sensitivity class
Mean Top Height	Amenity sensitivity class
General Yield Class	Stand terrain classification

Precision and accuracy of multi-resource methodologies

Multiple resource inventories and associated variables and measurement techniques should match individual informational needs, resources, budgets, data-processing capabilities, forms of analysis to be employed, and tabulations to be reported (Whyte 1999). In the PractiSFM multi-resource inventory protocols, a trade-off is achieved between the investment in sampling and the level of accuracy and precision obtained. The system was designed to facilitate collection of timber data according to point, line and plot sampling strategies typically used in Irish forestry (Purser 2000), facilitating statistical analysis and error estimation. The timber inventory provides an opportunity for reconnaissance and a rapid visual assessment of various non-timber (multi-resource) attributes of the stand. Where appropriate, additional time is spent gathering more detailed information on specific multi-resource stand attributes.

Quantitative continuous data, quantitative categorical data and qualitative categorical data are collected as part of the protocols. The quantitative continuous data provide an opportunity for statistical analysis and trend analysis. The quantitative categorical data allow trend analysis as the classes are clearly defined (Lund 1998). However, appropriate training should be given in the measurement of these categorical data. For example, a tendency exists to assess smaller vegetation coverages as larger (e.g. percentage cover grass/herb, lichen, shrub) and larger coverages as smaller than they are in reality (Jukola-Solunen and Salemaa 1985). Further research is needed to try to quantify and objectify the (subjective) qualitative categorical landscape sensitivity data.

Planning and forecasting

The objectives of Irish private forest owners for their forests are typically multiple-use rather than singular; however almost all owners consider the production of timber for sale as a prime objective (Ní Dhubháin and Wall 1998). Thus, to achieve the owner's objectives, active management occurs primarily through decisions to thin, fell, regenerate, underplant, restock or retain stands beyond the normal financial rotation age. The harvest simulation or timber forecasting tools built into the PractiSFM option generation module (Figure 2) are based on the Forestry Commission Yield Class system (Edwards and Christie 1981) and the Irish Dynamic Yield Models developed for Sitka spruce, Douglas fir and Norway spruce (Broad and Lynch 2006). Estimated thinning and felled timber harvest volumes associated with particular silvicultural treatments may also be entered manually into the DSS, in cases where (Irish) forest growth projection models have yet to be developed (e.g. for Continuous Cover Forest systems (CCF) and for broadleaf species). The option generation module is used to create an option matrix, which represents a series of 10-year harvest (thin, clearfell, CCF felling, retention) schedules and replanting/underplanting treatments for each stand in the forest. The option generation module incorporates interactive dialogs and uses stand stocking, basal area, yield class, average growing stock, user defined thinning parameters and other calculated stand summary statistics as inputs to guide the creation of realistic stand management option sets. Non-timber data for each option is also included in the option matrix.

The planning module (Figure 2) uses the values in the option matrix generated by the option generation module to create: 1) alternative forest management planning scenarios (management plans); 2) forecasts of timber (e.g. future species age, composition, diversity statistics, log volume assortments); and 3) non-timber variables (e.g. deer habitat suitability ratings, retention area, ending deadwood volume) for the 10-year planning horizon. The planning module generates a series of interactive dialogs, a map-based interface and a goal analysis worksheet to assist the user in selecting specific stand management options from the option matrix. The capabilities for scenario visualisation and the creation of maps incorporated into the PractiSFM DSS mean that the important consequences of proposed management alternatives, in both time and space, can be effectively communicated in a visually intuitive graphic form. For example, the PractiSFM DSS allows the comparison of alternative landscape designs or harvest strategies relative to the other parameters of interest such as the revenue from timber sales, landscape sensitivity, amenity sensitivity, stands adjacent to water bodies, terrain classification, stonewall length, and forest safety or hazard indices.

The goal analysis worksheet produced by the planning module allows the decision maker to set satisfactory levels of achievement for specific parameters or indicators of SFM (e.g. volume harvested, discounted revenue). The interactive dialogs initiated by the goal analysis worksheet facilitate the decision maker in the selection of management options which direct or move the simulation towards these desirable goals or aspirations. The goal analysis worksheet slider bars are used to visualise the minimum, current and maximum possible values of a range of timber and non-timber variables, including harvest volume, discounted revenue, area of retention, amenity sensitivity, average deadwood per hectare, area of broadleaf restocking, deer food/cover habitat weightings.

Tabular and graphic output produced by the PractiSFM DSS 10-year plans or simulations include, among others, timber volume assortments forecasts and associated revenues, species composition, age class distributions, landscape sensitivity statistics, estimated deadwood volume production and estimates of scheduled operation hours (Table 2). The starting condition of the output variables (at the start of the 10-year planning horizon, based on the multi-resource inventory data) is produced with each of the scenario outputs, which allows the decision maker to compare whether any of the alternative scenarios improved on the current condition of the variables being assessed. This body of information may then be used to select an alternative for implementation or refine an existing scenario. Multiple scenarios or alternatives can also be retained for comparison.

Table 2: *Summary management planning outputs produce by the PractiSFM DSS*

Harvest (thinning/clearfell) volume (m^3) per period[1] per species group or by stand[2]
Harvest (thinning/clearfell) value (€) per period per species group
Harvest volume/value/discounted value per period
Starting/ending/normal conifer age class strata area and species
Starting/ending/normal broadleaf age class strata area and species
Starting/ending species/mixture totals (ha)
Starting/ending species stand types (ha)
Aquatic area/adjacency outputs for minor and major streams
Cumulative retention area (ha) per stand type
Internal landscape sensitivity of stands (ha) scheduled for harvesting operations
External landscape sensitivity of stands (ha) scheduled for harvesting operations
Terrain classification for stands (ha) scheduled for harvesting
Terrain classification for stands (ha) scheduled for clearfell/thinning
Starting/ending deadwood by conifer/broadleaf strata (m^3)/by stand
Scheduled hours for planting/thinning/clearfell operations/by stand/forest
Starting/ending deer habitat – food
Starting/ending deer habitat – cover
Amenity/aquatic/forest safety/landscape sensitivity map-based outputs

[1] The 10-year simulated planning horizon is divided into five 2-year periods.
[2] Outputs are also generated by species by stand.

The PractiSFM system, the NFI and stand level multi-resource information

Current, accurate and reliable multi-resource data form the basis for a (sustainable) forest management decision-making process. An understanding and application of the relevant multi-resource, management planning and forecast data can help forest owners and managers to evaluate the current status of forest resources, identify objectives that are sustainable, evaluate the effects of proposed management strategies and reconcile competing objectives and values. The paucity of standardised inventory, management planning and forecast data for privately owned forests in Ireland makes it very difficult for the State forest authority to comprehensively evaluate the extent, type, distribution and use of potential resource outputs from privately owned forests. Basic silvicultural management information and data regarding the owners' intentions for their forests are also missing. These information deficits also cause potential difficulties when formulating relevant and focused national policies and new forest schemes directed towards encouraging active management of the private estate.

The Private Stand Level Inventory proposed by the Forest Service in 2007 will go some way towards addressing the lack of inventory data for the private estate (Forest Service 2007b). However, the inventory will be confined to a sub-set of the private forest estate established during the 1980s and will be directed towards the collection of data for timber related parameters only (stand area, top height, basal area, stand age etc.), with no attention given to either the owners objectives or the collection of data for non-timber parameters such as visual amenity, wildlife or biodiversity. Furthermore, unlike the NFI, there are no plans to periodically update the stand level inventory, resulting in an inability to monitor change and leading to potential information deficits in future years, if no other inventory standards or provisions for the collection of timber and non-timber parameters for the private estate are put in place.

A number of COFORD and IRCSET (Irish Research Council for Science, Engineering and Technology) funded research projects also focus on providing resource information related to the private forest estate (e.g. CLUSTER, FORECAST, FORESTSCAN, REMOTEINV). However, these research programs are not yet fully operational and face the same short-term project duration, funding and institutional/ government support issues as all research programmes not operated on a permanent footing. In addition, their scope and scale all vary, some projects addressing only specific forests or regions or taking a top down approach to forest resource analysis and forecasting. A bottom-up approach has been identified as the "ideal situation" in terms of the private estate information question (Phillips 2008). Such a bottom-up approach should consider the owners' preferences and management regimes, which should be collected together with reliable stocking and growth information. This information would then form the basis of forecasts using reliable and flexible growth models. The forest owner centric approach to the resource question would also facilitate more realistic national and catchment based forecasting, as well as scenario modelling.

Although the PractiSFM system was primarily developed to assist forest owners and managers to develop, present and compare alternative forest management regimes and ultimately to manage a range of forest values in a more sustainable and holistic manner, the system could potentially function as a model to facilitate automated, standardised reporting of detailed, spatially explicit, stand and forest level multi-resource inventory data. Many of the data types collected and summarised using the PractiSFM multi-resource inventory and DSS are similar to those collected in the

National Forest Inventory (NFI) recently completed (Barrett et al. 2007, Forest Service 2007a). The compatibility of PractiSFM with the NFI could facilitate local, regional and national analysis and reporting of timber and non-timber resource data when the datasets are combined. However, the issues of standards, objectivity and transparency in the data collection procedures initiated by forest owners and their agents will need to be considered carefully and resolved before inventory and management information can be incorporated into any Forest Service data base.

The Forest Service is currently developing a complete online version of the corporate iFORIS, (integrated Forest Information System) which supports the administration of state supported afforestation and premium schemes. Such an online system would strongly benefit from the capacity to receive electronically the inventory and management planning information currently required by applicants in receipt of afforestation premium payments. Provided that the information can be sent in a standardised electronic form, PractiSFM DSS outputs could be modified as required to serve this niche. The 1946 Forestry Act, currently being reviewed for submission to the Irish Government later this year, will potentially include new provisions related to the requirement for forest management planning documentation in support of felling activities on privately owned forest lands. The new Forest Act also represents an opportunity to incorporate, from a regulatory control point of view, the same bottom-up approach to the collection of multi-resource inventory and other information as incorporated into the PractiSFM system.

Timber production forecasting

The management plan information produced by the PractiSFM DSS can provide the Forest Service with a detailed record of forest operations and work plans for the planning period. A standardised, digital work plan produced by PractiSFM could facilitate forest owners and forest managers in receiving pre-approval for forest operations. To date, such management planning is submitted in hard copy or paper format. The current lack of timber and non-timber (amenity value, recreation, wildlife habitat value) inventories and forecasts for many private forest properties undermines significantly the technical and scientific credibility of forest resource management plans, and stymies strategic planning for the forest industry chain at the regional and national level. Successful planning for the future development of the processing sector cannot occur without accurate spatial and temporal information on future supply. It is of critical importance that the processing industry is provided with reliable supply forecasts so that the processing capacity can be installed at the right time and in the right locations to handle the increasing amount of roundwood coming from private forests (Gallagher and O'Carroll 2001).

Information derived from the PractiSFM DSS inventory, management and forecast output could also be used to facilitate policy makers and researchers in assessing the existing and future needs of the sector for financial support, planning, training and education. The results from the test sites showed that the owners' objectives had a significant effect on timber and non-timber production, so that when viewed in isolation from the owners' objectives, the multi-resource inventory alone is not sufficient to determine the future output of products and services. Full consideration of the relevant multi-resource inventory, management and forecast data can help to improve the forestry sector's decision and policy making processes by providing an understanding of the natural and human systems and their interactions. For example, a more complete picture of woodland owners' intentions with regard to thinning and felling would allow the sustainable development of policies or support mechanisms to ensure that harvest operations are occurring at optimal stages of the forest rotation or are planned at a landscape or regional level to facilitate the development of industry, and to ensure that the productive, amenity, habitat, carbon sequestration, environmental, landscape and aesthetic potential of particular regions are maintained or enhanced (Hummel 2005, Pajuoja et al. 2005).

A feature of the privately owned forest estate in Ireland is that a relatively small number of forest management companies (approximately five) have established (and in some cases still manage) the majority of the privately owned forests. Thus, the inventory, management planning and reporting linkages provided by PractiSFM could be implemented easily and efficiently, representing a potentially large proportion of forest owners, if only a small number of forest management companies adopted such a system to facilitate management of the recently established private estate. Several of the forest management companies involved in this study have acknowledged the potential benefits of PractiSFM as an inventory and management planning tool and have also seen the usefulness of this type of software for reporting to the Forest Service and facilitating their day-to-day business in areas such as grant applications, felling licence approval and record keeping. A new research project, PractiSFM II, has recently been initiated in cooperation with COFORD and three forest management companies, to investigate the potential of the PractiSFM DSS to: 1) facilitate the standardisation of management plan reporting by private forest owners/managers to the Forest Service; 2) investigate the synergies between the multi-resource inventory data derived from PractiSFM DSS outputs and data recorded in the National Forest Inventory and the Integrated Forest Information System (iFORIS); and 3) determine the role of PractiSFM DSS outputs in facilitating regional and national timber forecasting and strategic planning for the forest industry. The project will involve the implementation and testing of PractiSFM in an operational environment within the three companies, and the development of an optimisation module to facilitate owners/managers in the proper weighing of the objectives and in obtaining optimal solutions.

Conclusions

Until relatively recently, forest management practices in private forests in the Republic of Ireland have been directed solely towards timber production. Little, if any, consideration was given to the physical, social and biological forest resources, their status and condition, as well as their significance in developing sustainable forest management plans. The PractiSFM multi-resource inventory and decision support software offers a practical, user-focused approach to stand-level, multi-resource forest inventory and decision support for private forest owners and managers, using Criteria and Indicators identified in the Irish National Forest Standard. The system has the potential to facilitate the exchange of inventory, management planning and forecast information between forest owners/managers and the Forest Service in a standardised format. Thus, the PractiSFM system can provide the missing link in the forest information chain between the forest owner and the Forest Service and, in combination with National Forest Inventory data and information from the State managed forests, complete the picture of the current and future state of the national forest estate (Figure 3).

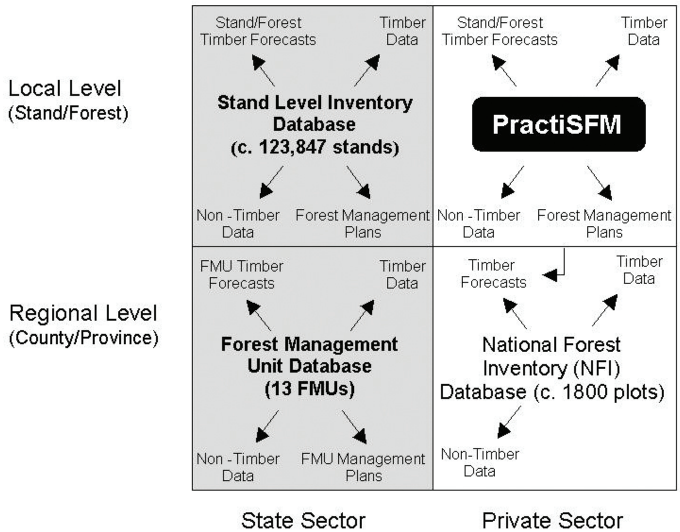

Figure 3: *The place of PractiSFM in state and private sector forest inventory, management planning and forecasting protocols.*

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The use of site factors and site classification methods for the assessment of site quality and forest productivity in Ireland

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Abstract
Site classification methods have been traditionally used in forestry to determine the most appropriate tree species to plant and to assess their potential yields on various sites. Recently the role of site classification systems has been expanded to fulfil a wider range of multifunctional forestry objectives: silvicultural practice, sustainable forest management, climate change, carbon sequestration and environmental issues. Site classification systems used in forestry, with examples of single and multifactor systems are reviewed. Forest site quality is a composite of climatic, topography and soil factors at any one location. The determination of site quality using an approach similar to that used in Canada, the United States and Britain is advocated. This approach, based on scientific principles, can be calibrated for Irish conditions, offering potential to develop a model to aid decision making on tree species selection and the assessment of forest productivity on various sites in Ireland.

Introduction
Site classification has long been used in forestry as a means of determining species suitability (Cajander 1926, Anderson 1961, Krajina 1969, Ellenburg 1998, Pyatt et al. 2001). Anderson (1950) commented that the role of a site classification was to … *strive to provide what still seems to be lacking – some relatively objective practical means of distinguishing and classifying plantable site-types, which will serve, not only to aid in the choice of tree-species to be grown, but as a basis upon which a sound silvicultural practice can be built*.

This concept, that site classification can be the basis upon which sound silvicultural practice can be built, has received renewed interest in recent years. This includes the use of site classification methods to cover silvicultural practice and aspects of forest management and planning in British Columbia (Pojar et al. 1987, Meidinger and Pojar 1991, Green and Klinka, 1994) and in Britain (Pyatt et al. 2001, Ray 2001). The idea that silvicultural decision-making requires knowledge of the growth of tree species on specific sites provides an ecological foundation for silvicultural practices. A good understanding of specific-species variability and the interactions between species and site conditions is one of the prerequisites for the development of sustainable management practices, which include timber production (Klinka and Chen 2003). Furthermore, the forest ecosystem and its protection and enhancement is vital if forestry is to be practised in a sustainable way, which will allow for long term monitoring of changes in ecological site factors caused by forest management

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and external environmental drivers (Moffat 2003). Anderson (1950) stated that the only safe basis for the choice of species is the purely ecological one, and that for a given planting area the process consists broadly of two stages. First, an analytical or inductive process or an assessment of the locality factors, and second a synthetic or deductive process or a selection of those species whose requirements through life are likely to be satisfied by the site in question. When a site was capable of supporting two or more species, he indicated that the final choice may then be based on the expected value, not volume production of the various species. The characteristics of forest sites, readily identifiable as soil, vegetation or topographic factors, can be used as the basis of prescribing silvicultural operations, such as thinning or for the prescription of ground preparation for the establishment of new forests (Zehetmayer 1954 & 1960, OCarroll 1962, Wills et al. 2001). Site classification methods have widely been used in the USA and Canada to estimate site productivity and for quantifying forest yield potential (Carmean 1975, Wang et al. 1994, Kayahara et al. 1996, Chen et al. 2002, Klinka and Chen 2003, Chen and Klinka 2003).

The classification of forest sites, in the context of site quality assessment, has also been used as a basis for fertilisation prescriptions for forest crops (OCarroll 1975, Farrell 1985, Schaible 1992, Taylor and Tabbush 1990). The challenge of climate change and greenhouse gas mitigation has increased the need for information about the forest ecosystem, and in particular increased knowledge of the relationship between forest soils, climate and productivity. Furthermore, it should be possible to estimate the amount of dry matter that is allocated to above- and below-ground components of the forest, which can in turn be used to calculate the amount of carbon sequestered in the forest. New standards of environmental protection have also increased the need for information about forest sites.

Overall, site classifications, particularly soil classifications, have received renewed interest in recent years. A major driver for this interest is the need to develop methods for monitoring soils, especially with a view to the development of sound soil conservation strategies and in assessing the effects of silvicultural practices on soil quality (Moffat 2003, Powers et al. 2005, Hopmans et al. 2005, Fisher at al. 2005).
The need for information concerning species site interactions, species performance and the correct matching of species to site (which is likely to minimise forest establishment problems) has been the catalyst for this review. In addition, the use of classification systems which evaluate forest site quality could also be used as an aid to determine the growth and yield potential of species on different site types

Site classification methods

Site classification for forestry falls broadly into two groups: single factor or multifactor methods (Savill 1983). Single factor classification systems rely on one factor to describe a forest site, such as soil or climate, whereas multifactor classifications are based on interrelationships between climate, physiography, soil (and related edaphic factors) and vegetation. Classifications based on soil characteristics are the most common single factor systems used in forestry, mainly due to the abundance of soil survey information. Soil classification methods have been used extensively for quantifying potential timber yields in the United States (Carmean 1961, Ralston 1964, Carmean,

1975) and for determining the suitability of sites for afforestation in Ireland (Dittrich 1955, Ryan 1960, Bulfin 1987 & 1990, Carey et al. 1985). Soil classification (or soil type) is often seen as a proxy for soil quality, and good relationships have been found between soil type and yield in specific geographic areas in the Republic of Ireland (National Soil Survey of Ireland, 1963-2003, O'Flanagan and Bulfin 1970, Bulfin et al. 1973, OCarroll and Farrell 1993, Bulfin 1988, Conry and Clinch 1989).

Indicator plants or plant communities have also been used for the basis of site classification (Cajander 1929, Anderson 1961, Krajina 1969, Ellenburg 1988, Klinka et al. 1989, Pyatt et al. 2001, Wilson et al. 1998, 2001 & 2005). The characteristics of the vegetation can be used as an indicator of the fertility and moisture status of a forest site. The classification of site fertility based on indicator plants and plant associations is highly developed in British Columbia, Canada, where it is used to quantify the soil moisture and soil nutrient regime of forest sites (Green and Klinka 1994). A strong relationship between the inherent soil nutrient status and vegetation type and abundance has been found in recent research carried out in Scotland (Wilson et al. 2001 & 2005) and this has formed the basis for the indirect assessment of soil nutrient and moisture regimes soil in the Ecological Site Classification (ESC) system developed for Britain. Vegetation characteristics have also been used to assess the inherent fertility of blanket peat soils in Ireland (Dickson and Savill 1974, Savill and Dickson 1975). In this system, four nutrient classes are recognised: (1) dystrophic, (2) oligotrophic, (3) mesotrophic and (4) eutrophic. Potential yields in Sitka spruce increase from the dystrophic to the eutrophic class. OCarroll (1975) used information from Ordnance Survey 6 inch: 1mile (1:10560) maps to classify potential forest sites into four fertility classes: (A) Fields and ornamental ground, (B) Furze or Whins, (C) Rough Pasture with or without outcropping rock, and (X) Woodland. He used this classification as the basis for fertiliser prescriptions for forestry land. The system is still in widespread use in Ireland by the Forest Service and Coillte. It has been used as a basis for the unenclosed/enclosed assessment of land quality for the determination of grant payment rates for afforestation by the Forest Service in the Republic of Ireland (OCarroll 1975 & 2008, Joyce and OCarroll 2002).

Multifactor site classifications are based on interrelationships between climate, physiography, soils and vegetation. An example of a multifactor classification is provided by Anderson (1961), who developed a classification based on the abundance of certain plant communities on a site. Fertility classes A to F reflect decreasing fertility levels and increasing degrees of wetness, from Dry to Wet with Peat. For each combination of fertility and moisture class, Anderson recommended selection of tree species based on their nutritional and moisture requirements. This was based on his extensive experience as a forestry practitioner in Britain and Ireland. Condon (1961) devised a multifactor classification for blanket peats, based on vegetation, topography, and peat characteristics. The five classifications, in decreasing order of site quality were: (1) Molinia Basins and Flushes, (2) Eriophorum flats and slopes, (3) Calluna slopes, (4) Calluna Knolls and (5) Tricophorum knolls.

In recent years multifactor classifications have achieved prominence in forestry as they focus on ecological site quality and its relation to the ecosystem. These systems are considered more robust, so are expected to provide a sound basis for the sustainable production of wood and the provision of other forest benefits (Pojar et al. 1987, Green and Klinka 1994, Pyatt 1995). The biogeoclimatic ecosystem classification (BEC) developed in British Columbia is a good example. It uses regional and local information about climate, vegetation communities, soil moisture and soil nutrients and has been widely used to estimate site productivity (Wang et al. 1994, Kayahara et al. 1998, Chen and Klinka 2002, Chen et al. 2002) and to cover aspects of forest management and planning in an ecological sustainable manner (Klinka et al. 1984, Pojar et al. 1987, Meidinger and Pojar 1991, Pyatt et al. 2001). The ecological site classification (ESC) currently in use in Britain is a modification of the BEC. Both systems use indicators of soil quality, notably soil moisture and soil nutrient regime, based on local site-level assessment. This system, similar to Anderson's site classification, uses a matrix of eight categories of soil moisture regime, ranging from *very wet* to *very dry*; and five categories of soil nutrient availability, ranging from *very poor* to *carbonate*. Indices of soil moisture and nutrient regime can be estimated directly from soil analysis or they can be inferred indirectly from vegetation, or site characteristics. An example of the soil quality grid of the BEC is provided in Table 1, which includes the vegetation characteristics as used in ESC (Pyatt et al. 2001).

Table 1: *An example of the soil quality grid used in the BEC with some examples of indicator plants used for indirect methods of soil quality assessment in ESC (after Wilson 1998, Pyatt et al. 2001).*

Soil moisture regime	*Soil nutrient regime*					
	Very poor	*Poor*	*Medium*	*Rich*	*Very rich*	*Carbonate*
Very dry						
Moderately dry						
Slightly dry			Wood sage			
Fresh	Cowberry	Bracken		Bluebell	Elder	
Moist	Heather	Wood sorrel			Stinging nettle	
Very moist			Lady fern			
Wet				Meadow-sweet		
Very wet	Bog myrtle					

The components of the forest site

The term site describes an abstract concept which combines a multitude of environmental factors affecting tree growth into a unified classification. Although there are biological and management factors that influence species suitability and productivity, those most likely to influence growth are climate, topography and soil (Anderson 1961, Ralston 1964, Carmean 1975, Pyatt 1995, Pyatt et al. 2001, Horgan et al. 2003, Klinka and Chen 2003) (Figure 1). All three factors are interdependent at varying degrees and scales and combine in one climatic region to create the *forest site*. Site factors have the greatest and often longest-lasting effect on the productivity of indigenous and plantation forests.

The composition of the vegetation growing on a site may provide valuable information about the site factors that are likely to have the greatest impact on tree growth (Anderson 1961). The role of climatic, topographic and edaphic site factors in explaining differences in forest growth and productivity on various sites are examined in the following sections.

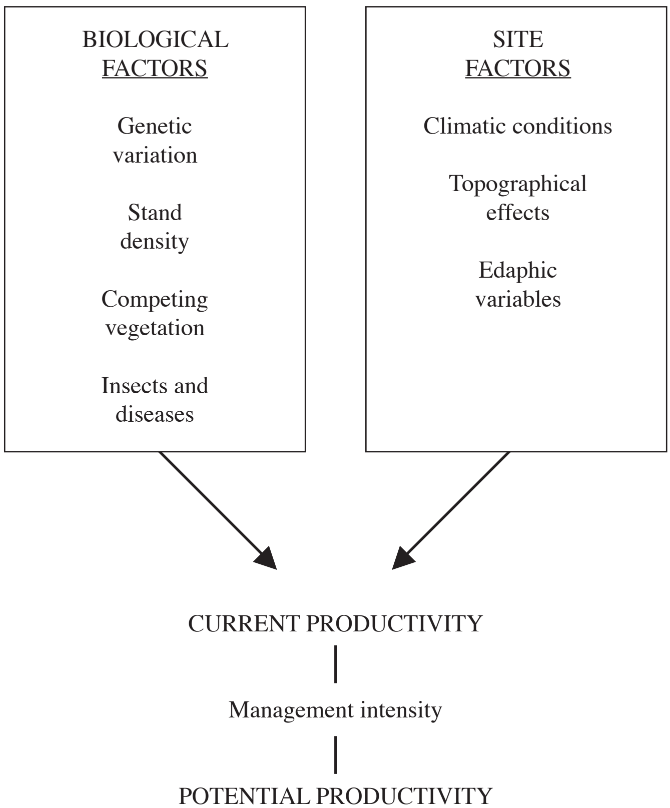

Figure 1: *The major factors regulating forest growth and productivity (after Ralston 1964).*

Climate factors and their influence on forest growth

A review of literature on forest growth and yield studies indicates that a number of key climatic factors play a role in tree growth and in forest productivity (Table 2). It is widely known that temperature or growing season warmth affects the growth rate of trees (Pyatt et al. 2001). Annual heat sums or day degrees may be particularly useful, often providing a measure of the heat available for tree growth in any year or growing season. Degree days have been shown to be highly correlated with productivity (Farr and Harris 1979, Worrell 1987, Worrell and Malcolm, Waring 2000).

Table 2: *Climate variables used to assess tree growth and productivity, with associated authors.*

Climate variable	*Author(s)*
Degree days	Farr and Harris 1979, Christie and Lines 1979, Worrell, 1987, Tyler et al. 1996
Winter rainfall	Blyth and MacLeod 1981,Tyler et al. 1996
Spring rainfall	Tyler et al. 1996
Summer rainfall	Tyler et al. 1996
Total rainfall	Tyler et al. 1996
Air temperature growing season	Blyth and MacLeod 1981
Mean spring temperature	Tyler et al. 1996
Mean summer temperature	Tyler et al. 1996
Mean winter temperature	Tyler et al. 1996
Climate zone	Wang et al. 1994, Kayahara and Pearson 1995, Klinka and Chen 2003
Global solar radiation	Waring 2000

In general, photosynthetic activity rates are low or negligible at temperatures below the most commonly used critical base temperatures (usually 5-6ºC) (Christie and Lines 1979), although positive net photosynthetic rates have been recorded at temperatures as low as -5ºC in Sitka spruce (Ludlow and Jarvis 1971, Neilson et al. 1972). The onset of flushing in trees is largely governed by the accumulation of degree days above a critical threshold (Cannell and Smith 1983). Degree days can be calculated by subtracting a base temperature from the mean daily temperature and summing these values over time, usually over a particular developmental period of interest or over a full year. Temperature variations are influenced by topography with a standard lapse rate of 1ºC for every 150 m increase in elevation (0.6ºC per 100m) (MacEntee 1976, Worrell 1987). Degree days can be reduced by as much as 10% per 100 m elevation (Keane and Sheridan 2004).

Low rainfall may limit the growth of tree species (Zehetmayer 1960, Malcolm 1970). Precipitation is highly variable, both spatially and over time. Precipitation in Ireland is characterised by plentiful rainfall, fairly well distributed throughout the year. Annual rainfall in lowland areas varies from 750 mm in parts of the east and northeast to greater than 1200 in the west, northwest and south west. Rainfall is modified by topography. Mountainous areas of Ireland receive more than 1600 mm of rain annually, with a maximum of 3200 mm recorded for Corran Tuthail in

Kerry (Keane and Sheridan 2004). Blyth and Macleod (1981) found that the growth of Sitka spruce was positively correlated with winter temperature sums and annual rainfall in a study in north east Scotland. The effect of water drought or water stress, where evapotranspiration exceeds rainfall, may be a problem on shallow or freely draining soils, which may have insufficient water storage capacity during low rainfall periods, thus limiting tree growth. This has been shown to cause problems for growth of certain tree species (Anderson 1961, MacDonald 1967, Fourt 1968, Toleman and Pyatt 1974, Jarvis and Mullins 1987). Water balance models have shown the negative effect of drought on the growth of tree species in Canada (Klinka and Carter 1990, Wang and Klinka 1996, Kayahara et al. 1997).

Exposure to the wind, results in the lowering of plant temperatures, localised water stress and mechanical damage, resulting in reductions in the leaf water balance and restriction of the rate of photosynthesis (Grace 1977, Tranquillini 1979). The result is windswept trees with branches permanently swept to the leeward side, mainly because buds on the windward side of the trees are killed. Windspeeds greater than 15 ms^{-1} may reduce the growth of conifers, which can lead to the development of trees with poor form and increased taper. Ireland has a windy climate, due to the Atlantic Ocean. Annual windspeeds in Ireland are lowest in the central plain, ranging from just over 3.5 ms^{-1} in the south midland area of Kilkenny, to 8.1 ms^{-1} at Malin Head, Co Donegal in the extreme north west (Met Eireann 2008). At higher elevations mean annual windspeeds can reach up to 12.1 ms^{-1} in Donegal (Haslett and Kelledy 1979). In Britain, tatter flags have been used to estimate windiness levels; the rate at which the flags tatter correlates with wind speed (Rutter 1968, Jack and Savill 1973, Quine and Sharp 1997, Quine 2000). Significant correlations have been found between tatter rate and the productivity of Sitka spruce (Worrell 1987, Worrell and Malcolm 1990). The development of a new wind atlas for the assessment of wind energy, offers significant potential for the assessment of windiness of forest sites in Ireland (SEI 2003).

The occurrence of sporadic severe frosts, usually of short duration, can have a devastating effect on the survival and growth of young trees. Late spring frosts often coincide with the time of flushing, and these can kill new shoots. The extent and intensity of spring frost has a major effect on species selection, especially in midland areas. Frost damage represented over 60% of all accidental damages recorded by the Forest Service in Ireland in the mid 1990s (Horgan et al. 2003, Renou-Wilson 2008). The prediction of the regional occurrence of spring frost may be possible by examining minimum monthly temperatures from long-term averages from climate data. However, local effects due to topography (e.g. frost hollows), can lead to a reduction in temperatures over relatively small distances.

Solar radiation also influences tree growth (Waring 2000). Solar radiation levels associated with changes in topography accounted for nearly half the variation observed in the growth of Sitka spruce on poorer sites in Britain in Waring's study. He states that if solar radiation was converted at maximum efficiency, then 8000 g C m^{-2} a^{-1} could be fixed during photosynthesis. When converted to wood production this is equivalent to a theoretical mean annual increment (MAI) of 70 m^3 ha^{-1} a^{-1}. This is, however, limited as only half of the photosynthate is utilized for growth, the rest is respired as CO_2 and because an increased proportion of growth is directed to root production as the environment becomes more stressful. Most of the variation in solar radiation is associated with topography, particularly slope and aspect (MacEntee 1976, Waring 2000).

Climate data and scales

When considering the impact of climate on the growth and development of trees it is important to consider what climate data are available and how appropriate they are for different spatial scales. In Ireland climate data are available from a range of synoptic meteorological stations chosen to represent mesoscale to macroscale conditions and provide the basis for a general climatology of the surrounding area. Keane (2004) provides a summary of different spatial scales where climate information may be required and their appropriate characteristic distances (Table 3). The general climatic conditions reported at regional level can differ significantly from the local climate, due to effects of elevation and topography, resulting in local climatic variations in rainfall, temperature and wind. For the individual forester or landowner, it is important to consider these *topoclimatic* (or terrain-climate) factors, as these may be as important as the general or regional pattern. Microclimate refers to the scale at which plants and animals live. It differs from mesoclimate, which prevails above the first few metres over ground level, primarily in the intensity of the changes that occur over time and with elevation (Rosenberg et al. 1983).

Data for some climate variables, such as windspeed, potential evapotranspiration and solar radiation, are available from 15 Met Eireann synoptic stations, which indicate regional trends in lowland areas. Rainfall and temperature data are more commonly available for a wider range of recording stations and may represent regional trends in upland areas or topo-scale trends in lowland areas. Climatic data at finer scales, the topo-scale and micro-scales are generally not available, except in situation where data are being collected for research or other monitoring purposes.

Table 3: *Climatic scales and characteristic distances (after Keane 2004).*

Scale	*Lowlands/plains*	*Uplands/mountains*
Regional (county/district)	100 km	10 km
Topo- (farm/field)	10 km	100 m
Micro- (field/crop)	100 m	10 m

Topography

The effect of elevation on the growth of tree species has been examined in many studies. Sitka spruce height growth decreased as elevation increased in studies carried out in Britain (Day 1946, Page 1970, Malcolm and Studholme 1972, Mayhead 1973, Worrell 1987, Worrell and Malcolm 1990). The effect of elevation can be more significant at coastal and northerly locations (Malcolm and Studholme 1972, Worrell 1987, Worrell and Malcolm 1990). It appears that the effects of elevation and associated climatic factors have a small impact on tree growth at lower elevation ranges (0-300 m) (MacMillian 1991, Hassall et al. 1994, Tyler et al. 1994, Dunbar et al. 2002). Elevation is not a causal factor itself but rather may be regarded as a composite indicator of climatic conditions (Blyth and Macleod 1981).

Elevation data are readily attainable from many sources, such as digital elevation models (DEMs), global positioning systems (GPS), altimeters and contour maps, and has widespread potential use in forestry due to ease of data collection.

The degree of shelter provided from the surrounding landscape, providing protection from prevailing winds, is also an important factor when assessing forest site factors. A method to measure the amount of geomorphic shelter provided by the surrounding landscape (Malcolm and Studholm 1972) has been developed. The level of shelter, or exposure, can be estimated from the TOPEX index for a site, which involves summing the angles of inclination to the horizon at the eight cardinal points of the compass. Lower TOPEX scores indicate that the surrounding landscape has relatively little influence on shelter in the proximity of the site. In contrast, higher TOPEX scores suggest that the surrounding landscape, such as mountains and hills, obstruct winds and thus provide greater shelter levels. Higher TOPEX scores have been associated with increased yields (Hassall et al. 1994, Worrell and Malcolm 1990b, Macmillian 1991). The collection of TOPEX measurements in the field is conceptually easily achieved, but views to the horizon may be constrained in forest situations, such as when a mature overstorey crop is present. However recent developments in geographical information systems (GIS) have led to the development of distance limited TOPEX models using digital elevation models, such as those developed for use in Britain (Quine and White 1993) and Ireland (Green 2006).

Some have found that the shape of the slope and contours affects tree growth. Sitka spruce growth was found to respond more favourably to receiving sites, than to shedding sites and this may indicate water stress problems associated with steeper slopes and nutrient accumulation in certain receiving sites (Page 1970, Malcolm 1970, Blyth and Macleod 1981, Jarvis and Mullins 1987). This could be related to the fact that slope shape affects the amount of water that is received or runs off a site. Site aspect has been shown to be significantly linked to growth rates in northern Britain (Worrell 1987, Worrell and Malcolm 1990). The height growth of Sitka spruce on sites with north-easterly aspects was greater on sites sheltered from the prevailing winds in the uplands. Hassall et al. (1994), in a study of Douglas fir, found that forests having similar site characteristics had higher yields when located on steep slopes than on gentler slopes. South-facing aspects in Scotland were more favourable for growth than north facing slopes (Cook et al. 1977, MacMillian 1991). This may be due to the greater levels of solar radiation received on south facing slopes, providing more energy for growth (Jack 1968, Waring 2000). On south facing slopes, the steeper the slopes the greater the amount of radiation that is received (MacEntee 1976). On eastern and western slopes, gentler slopes receive higher radiation levels. On northern slopes, radiation decreases with increasing slope.

Edaphic factors

Edaphic factors refer to the physical and chemical composition of the soil. Soil properties can be used to assess soil quality and may help explain site differences in tree growth. Some of the soil variables that have been found to be most important in previous site/yield studies are presented in Table 4. These include chemical indicators such as pH, total carbon, sulphur, available SO_4 form of S, extractable P, K, Mg and Ca, cation exchange capacity (CEC), exchangeable Ca, Mg and K. Total nitrogen (N), mineralisable N, the two inorganic N components NO_3 and NH_4. Soil pH, NO_3 form of N and calcium are good indicators of potential soil N availability and relate closely to the species composition of the ground vegetation in British forests, according to Wilson et al. (2001). In some infertile soils, the NH_4 form of N or total N may be of greater importance since NO_3 availability is usually low in these soils. The chemical composition of the soil is usually estimated from samples taken from the forest floor or from the soil fraction at a predefined depth, usually 30 cm.

The chemical composition of the parent material may have a marked effect on fertility. Sedimentary rocks, with the exception of some sandstones, as a general rule give rise to more fertile soils than primary or metamorphic rocks. Basic parent materials give more fertile soils than acid parent material and metamorphic rocks. Rocks with high silica or quartz content tend to lead to the most infertile conditions. Various physical characteristics, such as drainage, porosity, gleying and watertable depth, are important soil factors and can be determined from soil profile analysis in the field or from descriptions provided in soil survey bulletins published by the National Soil Survey (An Foras Talúntais, now Teagasc).

Inadequate soil drainage may lead to anaerobic conditions, which reduce root growth and site productivity potential (Blyth and Macleod 1981, Macmillian 1991).
Studies undertaken to examine the effect of edaphic factors on growth and yield are not universally applicable as these studies differ in the range of climatic, site and soil variables chosen. The variable(s) that emerge as the most important in explaining tree growth may reflect specific species interactions with soil factors (Moffat 2003).
Soils can be categorised into similar classes on the basis of the availability of both nutrients and soil moisture. Determination of actual soil nutrient regimes involves removing soil samples from a predefined depth (rooting depth), and then determining the nutrient elements in the soil using laboratory chemical analysis procedures.
Characterisation of soil moisture regime involves determining water table or gleying depth in poorly drained soils, or the calculation of potential water balance using available water capacity of the soil and the balance between potential and actual evapotranspiration for freely drained soils. Under field conditions, it may be more practical to determine soil moisture and soil nutrient regime using field keys based on soil morphological properties and site characteristics (Green and Klinka 1994, Pyatt et al. 2001).

Table 4: *Soil characteristics examined in a selection of site/yield studies.*

Soil property	*Author(s)*
Parent material	*Cook et al. 1977, Blyth and MacLeod 1981, Dunbar et al. 2002*
Soil group/type	Malcolm and Studholme 1972, Cook et al. 1977, Blyth and MacLeod 1981, Worrell 1987, Macmillian 1991, Hassall et al. 1994, Tyler et al. 1996
Soil series	Page 1970, Bulfin 1973, Conry and Clinch 1989
Soil texture	Malcolm and Studholme 1972
Soil drainage	Malcolm and Studholme 1972, Blyth and MacLeod 1981, Macmillian 1991, Hassall et al. 1994, Tyler et al. 1996
Total soil depth	Page 1970, Hassall et al. 1994
Peat depth	Hassall et al. 1994
Depth of raw humus	Day 1946
Hue of soil, chroma value of soil, Munsell colour value of soil	Page 1970
Moisture content % at 15 cm, Moisture content % of the B horizon	Page 1970
Bulk density at 6 inches, bulk density at 30 cm	Page 1970, Blyth and MacLeod 1981
Soil temperature	Blyth and MacLeod 1981
Soil pH	Blyth and MacLeod 1981, OCarroll and Farrell 1993
Total N of organic layer	Blyth and MacLeod 1981
Total P	Blyth and MacLeod 1981
Soil C	OCarroll and Farrell 1993
Soil N	OCarroll and Farrell 1993
Mineralisable N of forest floor and of soil at 30 cm	Klinka and Carter 1990
NO3-N, NH4-N	Wilson et al. 2005
Air porosity	OCarroll and Farrell 1993
Thickness of profile	Blyth and MacLeod 1981
Depth of mottling	Blyth and MacLeod 1981
Stone content	Blyth and MacLeod 1981
Depth of rooting	Malcolm and Studholme 1972, Blyth and MacLeod 1981
Effective rooting depth	Blyth and MacLeod 1981
Free rooting depth	Day 1946
Soil nutrient regime	Wang et al. 1994, Kayahara and Pearson 1995, Klinka and Chen 2003
Soil moisture regime	Wang et al. 1994, Kayahara and Pearson 1995, Klinka and Chen 2003

Vegetation classifications

Various indicator plants or plant communities have been used as a guide to the productive potential of sites. The classifications devised by Cajander (1926), Anderson (1961), Krajina, (1969), Ellenburg, (1988) and Klinka et al. (1989) have all been used as a basis for classifying the fertility and soil moisture status of sites. Plant community assemblages may provide a sound ecological basis for forest species selection and productivity assessment. Anderson (1961) suggested that vegetation is a better and more practicable indication of soil fertility. He says that chemical analysis of the soil may only show the relative proportions of certain nutrients present in the soil, whereas the vegetation cover gives an indication of the extent to which these are available for plant growth. Wilson et al. (1998) used the ground vegetation in British woodlands to examine the relationship between species composition and soil nutrient regime determined from soil chemical analysis. He further indicated that crop yields of Scots pine and Japanese larch appeared to be broadly correlated with soil nutrient regime. In recent years, the use of vegetation to assess soil moisture regime and soil nutrient regime has received widespread acceptance as a means of evaluating soil quality (Klinka et al. 1999, Wilson et al. 2001& 2005). This can form the basis for species selection, and the assessment of site productivity potential. The use of ground vegetation has the potential to assist with soil assessments, producing reliable indications of soil moisture and soil nutrient conditions without the need for laboratory soil analyses (Wilson 2009).

Discussion

Good silvicultural decision-making and planning require knowledge of the growth of tree species across the full range forest site types in Ireland. The term site describes a complex phenomenon, a composite for the expression or combination of climatic, topographic and edaphic factors. For example, peaty podzol soils form mainly where the underlying parent material is inherently acid. These soils tend to be found most commonly on high elevation sites (especially where the slopes are steep). The higher amounts of rainfall received and the type of vegetation found at high elevations promote podzolisation. The nutrient and moisture status of such soils are generally less favourable for tree growth. Since these sites are most commonly found at higher elevations, the prevailing climatic conditions tend to limit tree growth there.

The main climatic factors deemed important for forestry have been well documented and include temperature (e.g. degree days). Climatic variables, such as annual or seasonal rainfall, provide information about moisture availability; low availability limits tree growth. The moisture balance method (difference between potential evapotranspiration and precipitation) may be used to indicate areas where drought is likely to reduce growth, which might be expected on soils with limited water storage capacity. Windspeed information is a very useful indicator of the inherent exposure of forest sites. These could be very useful in the west and north-west of Ireland and at coastal locations where windspeed and frequency of wind storms are likely to be particularly limiting factors for growth. For other sites, especially those in the midlands of Ireland, climate variables such as minimum temperatures, which could indicate frost risk, might be considered. Some of these data are available from Met Eireann synoptic stations, and are suitable for use at a regional scale.

For specific sites, location, elevation, proximity to the coast and slope will affect the micro- or topo-climate. Appropriate lapse factors need to be used in any site assessment model. To obtain specific climate data for particular studies, on-site data collection may be necessary. The role of topography is also important. The use of scoring systems, such as TOPEX, will give an indication of the amount of shelter provided by the surrounding landscape. The slope and aspect of sites may be important, especially as it affects solar radiation levels. The topographical position and slope shape influence both water and nutrient availability. Lower or concave slopes are likely to retain more water (in some cases nutrient-carrying water flushes) than areas on higher, steeper slopes. The development of soils is closely associated with topography, which makes it difficult to separate the effects of topography from changes in associated soil factors. For example, it is well known that yields decrease as elevation increases. However, this effect is more dramatically expressed at higher elevations than at lower elevations. It is likely that elevation is really a proxy for climate; the more severe climates tend to be associated with higher elevation sites. Degree days and site information on windiness and/or exposure might better explain declines in productivity with elevation. The use of soil chemical analysis and soil physical attributes may also be useful in site assessment, but these can be time consuming and expensive to carry out. The use of soil classification systems to assess soil quality has potential, especially where the soils are grouped into homogenous units based on moisture or nutrient status.

The advantages of single factor analyses of data derived from soil, vegetation or fertility classifications are their ease of use and simplicity. The fertility and moisture status of soils can be readily determined from many soil attributes. The classification systems developed in other countries to assess forest site productivity potential, such as the biogeoclimatic ecosystem classification (Canada) and the ecological site classification (Britain) could perhaps be modified for use in Ireland.

The provision of data on actual soil moisture and soil nutrient regimes from soil profile data and soil chemical analysis data may provide additional important information. Plant communities have been successfully used as indicators of soil nutrient status in the ESC system used in Scotland, so it is likely that a similar relationship will be found for sites in Ireland. Once established, soil quality indicators can then form the basis for the development of a method for assessing species suitability and the assessment of potential productivity of sites.

Conclusion

A range of variables is suitable for use in determining species suitability and productivity and for site classification in Ireland. Single factor classifications, such as one based on soil or vegetation, can provide good guidance on species suitability for a given site and on potential yields. Soil, vegetation and climate data, may however be combined to provide a more robust assessment of site productivity potential, especially in the context of sustainability issues. Site classification methods, such as the multifactor systems currently operated in Canada and Britain might be modified for use in Irish forestry.

While the factors which best describe site quality and its implications for tree growth are well known, there is less information available about how tree species grow on different site types in Ireland. Many questions remain to be answered, such as the reason why some broadleaved species such as oak and ash species frequently perform poorly on land which had been devoted to agriculture for several generations. Scientifically based understanding of species-specific site-soil relationships is needed to complement ongoing research work in other areas and to keep pace with advances being made in tree improvement. It is clear that the knowledge-based approach to species selection, based largely on experience of forestry practitioners, can help formulate hypotheses about species/site relations, but lacks the basis for understanding the causal mechanisms that affect the growth and performance of tree species. The expert research approach (based on scientific evaluation of tree species in relation to their environment or the sum of all the components of site), such as that undertaken in Canada by Klinka (2008) and the United States is an excellent model to providing a solid scientific basis for the selection of tree species and assessing site productivity in Ireland. A new model of this type would provide foresters with the opportunity to confidently recommend tree species to landowners for different conditions. It will also give state organisations and landowners confidence that their investment is underpinned by solid research and will yield the best returns for all involved. To this end, the establishment of temporary research plots (0.04 ha size) in forest stands, to determine species specific site interactions for the major tree species in Ireland is proposed. When this is complete, the ecological amplitude, nutritional requirements and productivity of tree species in Ireland on various sites types can be compared.

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Reflections on the biogeoclimatic approach to ecosystem classification of forested landscape

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Abstract
The biogeoclimatic approach to ecosystem classification is unique in that it defines, albeit arbitrarily, an ecosystem, and draws from several of the European and North American schools of vegetation and environment classifications. Undisputedly, the classification has provided a predictive tool for foresters in British Columbia and has given impetus for developing similar classifications elsewhere. The aim of this classification system is to organize forest ecosystems according to relationships in climate, vegetation, site quality, and time. The system is vegetation driven and features three independent, but connected classifications: zonal, vegetation, and site. Site classification is a primary tool used for identifying quality of forest sites; furthermore, it provides a framework for accumulated, site-specific knowledge about ecological characteristics of plant species, sites, and ecosystems. As a result, the site classification supports a variety of stand- and forest-level decisions as well as forest productivity research.

Keywords
Ecosystem classification, biogeoclimatic, British Columbia, climate, vegetation, site quality, management decisions

Introduction

Among many classifications of forest landscapes devised in the last hundred years (e.g., Carmean 1975, Klijn, F. (ed.) 1994, Sims et al. 1996) only a few seem serving as a basis for management decisions. Even some of those classifications have not been successful in increasing ecological awareness among foresters and/or in improving management practices, because the users play a passive role in applying the classification (Jahn 1982, Kimmins 1977). In short, there is not an effective, common tool for understanding the ecosystems under management and predicting the consequences of management decisions. Some of the following factors may be responsible:

1. the object(s) of classification is undefined,
2. classification is based on either an environmental or vegetation approach,
3. the complex methodology involved limits the use of classification to experts, and
4. classification schemes are unable to account for a wide variety of ecological settings.

In our opinion, the biogeoclimatic ecosystem classification is one of few which survived the test of time and has been well serving forestry communities in British

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Columbia for over 30 years. The objective of this article is to highlight and outline some of the characteristics that lead to success, and to draw attention to some outstanding issues.

Wali (1988) summarized ecosystem studies carried out from 1950 to 1975 by Krajina and his students in British Columbia. Using these studies, Krajina (1969) presented not only a classification, i.e., biogeoclimatic ecosystem classification (BEC), but also a great deal of information on vegetation-environment relationships. Similar methodologies of data analysis facilitated synthesis of the results at the trans-regional (provincial) level. Next, new information was collected and interpreted by the Forest Service Ecological Program Staff and made available to foresters using the revised framework of the original classification given by Pojar et al. (1987). Since that time there have been only minor improvements in the concepts and system of the classification. A new approximation addressing the system and developing new interpretations are desired, in particular concerning stand dynamics.

The classification system

If the number and variation of ecosystems in a forest is large, we assemble individual ecosystems that are alike with selected characteristics. Classification produces classes of similar ecosystems through characterization and assigning names to the framed classes. All classifications require that the concept of what is to be studied (classified) be defined as different concepts (definitions) would result in different classifications (and confusion). Krajina (1965) adopted Sukachev's biogeocoenose (Sukachev and Dylis 1964) as a **local** ecosystem that is considered to be a landscape segment relatively uniform in climate, soil, vegetation, animals, and microorganisms. The physical environment (site, ecotope, or habitat) of an ecosystem is represented by climate and soil (including topography); the biotic community is represented by vegetation, animals, and microorganisms. Vegetation and soils form as a result of the integrated effects of climate, topography, parent materials, organisms, and time (Jenny 1941, Major 1951). As vegetation and soil are the principally studied ecosystem components they form the basis for the classification. A group of similar local ecosystems influenced by a particular regional climate represents a **regional** ecosystem.

Understanding forest ecosystems means understanding vegetation-environment relationships and vegetation succession. Therefore, a good classification should organize ecosystems in ways that show the greatest number of relationships in the most important properties. As ideas on organizing things or thoughts vary from one person to another, a good classification should display intellectual economy of thoughts. This means by using all available knowledge on the things studied, it classifies them in a way that is easily retained in memory and is easy to convey through instructions. These two pivotal tenets guided the development of the BEC system.

To show relationships among ecosystems in form, space, and time, the system organizes ecosystems at local, regional, and chronological levels of integration. As a result of the analysis and synthesis of vegetation and environment data, the system includes three independent but connected hierarchical classifications: vegetation, zonal (climatic) and site.

The purpose of the local integration level is to organize ecosystems according to similarities in the form (composition and structure) of vegetation and sites features. This task is accomplished in vegetation and site classification, respectively. The purpose of the regional integration level is to organize ecosystems according to similarities in their distribution in a climatic space. This task is accomplished in zonal classification. Using units of the vegetation and site classifications, the purpose of the chronological integration level is to organize ecosystems into site-specific chronosequences according to the type of disturbance and time.

Vegetation classification

Using modifications of the Braun-Blanquet approach (e.g., Mueller-Dombios and Ellenberg 1974, Whittaker 1980), vegetation classification organises local ecosystems according to similarities in the composition of plant species. Although floristic properties are used as differentiating characteristics, an implicit consideration is given to site characteristics to frame floristically as well as environmentally consistent units. Delineated vegetation units are arranged into a hierarchy based on the plant association and diagnostic combination of species (Table 1). The major departure from the Braun-Blanquet approach includes (i) a simplified nomenclature and (ii) no requirement for character-species, i.e., for the species that differentiate in an absolute sense among plant associations and higher units. In consequence, differentiation is relative and based on the criteria adopted for differential species that are associated with more than one vegetation unit in a hierarchy, with presence class >III (>41%) and at least two presence classes greater than in other units of the same category and circumscription (Pojar et al. 1987).

Table 1: *Example of vegetation classification for forested landscape of coastal British Columbia using the order category and simplified Latin nomenclature. The seven orders are arranged more or less according to ascending soil moisture and nutrients. Orders are most suitable for general instructions. Each order includes all ecosystems dominated by a shade-tolerant tree species capable of self-regeneration, except Populus trichocarpa order; coastal Pinus contorta is a non-serotinous species.*

1. Quercus garryana
2. Pseudotsuga menziesii – Mahonia nervosa
3. Tsuga heterophylla – Rhytidiadelphus loreus
4. Tsuga mertensiana
5. Thuja plicata – Tiarella trifoliata
6. Populus trichocarpa
7. Pinus contorta

Although it is advantageous for the development of a stable classification to sample and study undisturbed, old-seral plant communities, where they are absent, the system can be developed for areas with disturbed vegetation, albeit with uncertainties about endpoints of vegetation succession. The study of disturbed ecosystems is necessary for understanding succession and the development of site-specific chronosequences, and vegetation management.

Climatic classification

Using the zonal ecosystems as defined by Pojar et al. (1987), zonal (climatic) classification identifies regional ecosystems and organizes them according to the distribution in the climatic space. The resulting zonal units summarize relationships between ecosystems and regional climate. The climatic space is chosen because climate is the most fundamental determinant of the nature of terrestrial ecosystems (Major 1951, 1963). Where possible, zonal plant associations are identified within the vegetation classification, thus forming a bridge between vegetation and climate and defining subzones. Each subzone has a characteristic pattern of ecosystems in a vegetation-inferred climatic space. Subzones may be differentiated into variants and aggregated into zones, regions, and formations (Table 2).

Table 2: *Example of zonal classification using the zone category. Each of the 14 zones of British Columbia has a distinctive climate. The zones are arranged around descending elevation, continentality, and temperature.*

Name	*Climatic type*
1. Alpine Tundra	alpine tundra
2. Spruce-Willow-Birch	cold continental subalpine boreal
3. Mountain Hemlock	maritime subalpine boreal
4. Engelmann Spruce – Subalpine Fir	cool continental subalpine boreal
5. Montane Spruce	mild continental subalpine boreal
6. Boreal White and Black Spruce	cold continental montane boreal
7. Sub-boreal Pine – Spruce	cool continental montane boreal
8. Sub-boreal Spruce	dry cold continental montane boreal
9. Bunchgrass	continental cool semiarid
10. Ponderosa Pine	dry continental cool temperate
11. Interior Douglas-fir	moist continental cool temperate
12. Interior Western Hemlock	wet continental cool temperate
13. Coastal Douglas-fir	dry mesothermal
14. Coastal Western Hemlock	wet mesothermal

The zonal concept occurs in the traditional ecological literature; although, without explicit and satisfactory definition. In areas with a long history of vegetation disturbance and scarcely occurring zonal sites, examination of topographic sequences or landscape pattern of ecosystems in tentative subzones could be used for differentiation (e.g., Damman 1979). Zonal classification can also be based on climatic data providing their availability for a large area in conjunction with vegetation criteria. Pyatt et al. (2001) used this approach in developing the ecological site classification in Great Britain.

Like the zonal concept, regional climate also evades an explicit definition. The resulting difficulties in differentiating between regional and local climates (i.e., in delineating subzones) typically in the areas of climatic localism, such as in subalpine-boreal (snowy) climates or between north- and south-facing slopes in cold or hot climates. The corollary problem concerns specification of the minimum area of a zonal unit.

Site classification

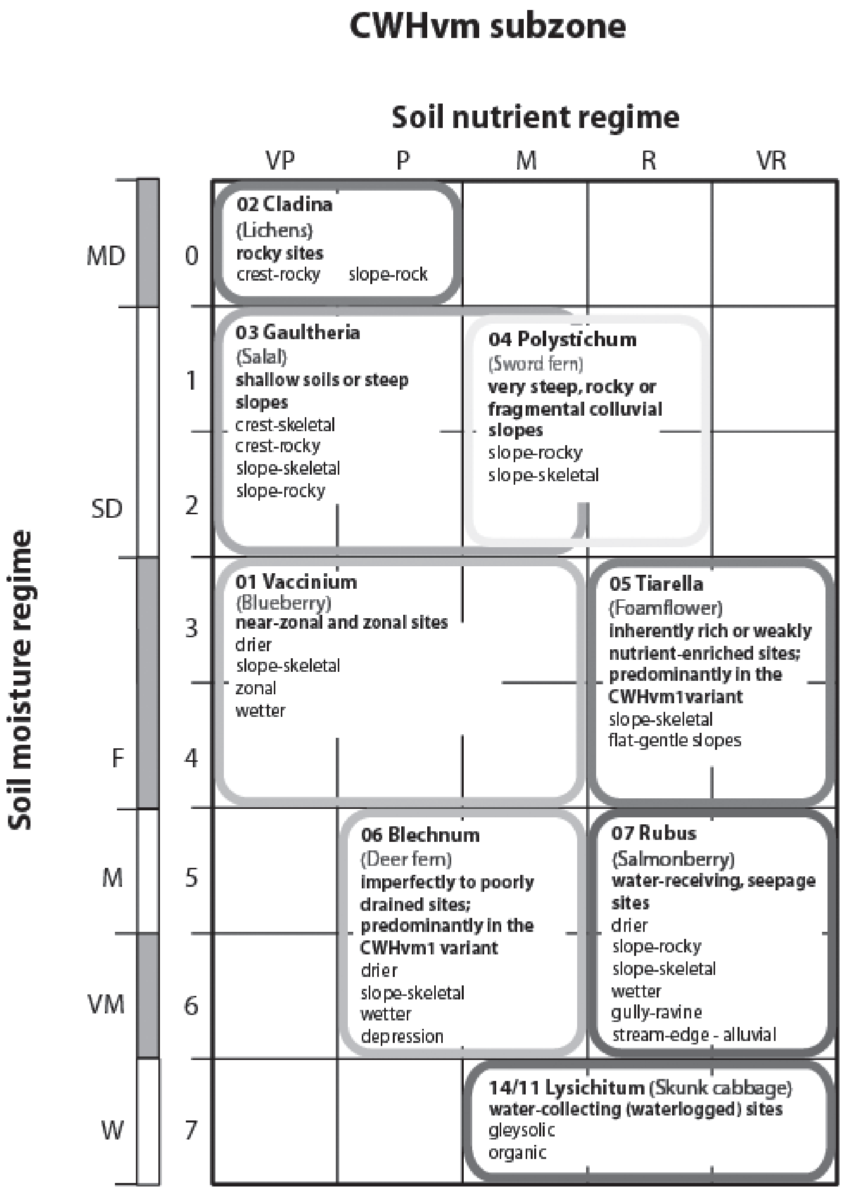
Both climate and soil are expressions of the combined effect of many individual environmental factors each, indirectly or directly, influencing vascular plants. Plants are dependent on light and heat (climate), soil moisture, soil nutrients, and soil temperature, which are all site factors with a direct influence on plants (Pogrebnyak 1930, Major 1963, Bakuzis 1969). Ecologically-equivalent sites are those that have similar site quality or the same combination of direct environmental factors.

Local ecosystems are organized according to similarities in site quality using climate, soil moisture, and soil nutrients as differentiating characteristics, regardless of the vegetation present on the site. A combination of these environmental properties defines the quality of a site. Site associations, as basic units, may be differentiated into site series and phases and aggregated into site groups. Independence from vegetation is the major cause for site units to be selected for ecosystem identification and many management interpretations.

When the vegetation and zonal classifications are developed, the plant associations that are ecologically equivalent, i.e., that have similar site quality, vegetation, and productivity potentials (Cajander 1926, Bakuzis 1969) are used to delineate each site association. This transformation of one or more plant associations into a single site association is possible owing to available environmental data for each plant association. The site association is conceptually similar to the forest type of several European classifications (e.g., Jahn 1982) and to the habitat type of Daubenmire (1968).

The essential part of site classification is the edatopic grid (Pogrebnyak 1930) – a two-dimensional ordination of selected soil gradients. Instead of gradients, the BEC system uses two ordinal classes: soil moisture regimes (SMRs) and soil nutrient regimes (SNRs). A variety of grid designs have been used by ecologists to display relations among plant species or plant communities to chosen environmental gradients (e.g., Bakuzis 1969, Krajina 1969, Mayer 1977, Arbeitskreis Standortskartierung 1978, Whittaker 1978, Ellenberg 1988, Pyatt et al. 2001, Klinka et al. 2002) (Table 3).

Table 3: *Example of site classification showing an edatopic grid for the very wet maritime (vm) subzone of the Coastal Western Hemlock (CWH) zone using the site series category and simplified Latin nomenclature (generic common names are in parentheses). The grid displays eight forested site series sites occurring within the UBC Malcolm Knapp Research Forest in relation to soil moisture and nutrient regimes. Edaphic adjectives listed for each site series designate phases indicating encountered topographic and soil variations.*



Adopting Hills's (1952) suggestion in addressing problems of climatic localism, three edatopic grids could be considered for many subzones instead of one main grid. The first grid would portray the ecosystems influenced by 'normal' local climate; the second grid, the ecosystems influenced by 'cooler' than normal climate; and the third grid, the ecosystems influenced by 'warmer' than normal climate.

Soil moisture regime, defined as the average amount of soil water annually available for evapotranspiration by vascular plants over several years, is used in relative and actual sense. Krajina (1969) used nine relative SMR classes and applied them consistently in different climates to show variations of forest productivity of major tree species in relation to the pattern of vegetation units. A subjective synthesis of soil properties and indicator plants has been used to infer the nine relative SMRs of forest sites; however, in arid and humid climates this number may be excessive and may not reflect real soil moisture patterns. Most importantly, relative SMRs do not inform about actual soil moisture conditions as the relationship between relative and actual SMRs varies with climate.

Klinka et al. (1984) proposed a quantitative classification of actual SMRs based on annual water balance (Thornthwaite 1948) and vascular plant activity (Major 1963, 1977). They used the occurrence and duration of phases of water use, complemented by the ratio between actual and potential evapotranspiration (AET/PET), and the occurrence, depth, and dynamics of the water table, to differentiae among nine actual SMRs. As a result, it was possible to establish relations between relative and actual SMRs in any climate. However, further studies of vegetation-soil moisture relationships in different regions are necessary to account for the ecological significance of soil water in relation to soil temperature, aeration, and nutrient availability.

Soil nutrient regime, defined as the amount of essential soil nutrients that are available to vascular plants over a period of several years, is also used in both relative and absolute sense. Krajina (1969) used six SNR classes and applied them in different climates and for different soil moisture conditions. A subjective synthesis of soil properties and indicator plants was used to infer the actual SNR of forest sites. However, similar to relative SMRs, there were inconsistencies in identifying relative SNRs in areas with different soil parent materials; for example, rich sites in granitic landscapes were deemed poorer than those in volcanic landscapes.

Several studies attempting to quantify SNRs across British Columbia (Courtin et al. 1988, Kabzems and Klinka 1987a & b, Klinka et al. 1994, Chen et al. 1998, Splechtna and Klinka 2001) showed that mineralizable-N in the upper mineral soil layer is the most useful measure of easily available plant nitrogen and in characterizing SNRs. These studies, however, did not account for nutrient availability in non-glaciated, residual soils, such as calcareous, alkaline, and saline soils. Intricate relationships among climate, topography, soil, and organisms complicate evaluations of SNRs and as a result the quantitative characterization of SNRs remains inadequately developed. Some of the uncertainties include (i) appropriate analytical methods for determining the amounts of available soil nutrients, (ii) determining external input of nutrients by laterally moving ground water, and (iii) quantifying the nutrient uptake facilitated by mycorrhizal fungi (Courtin et al. 1988).

Site-specific stand dynamics

Any plant community that develops in a particular site depends on its characteristics, disturbance type, chance, and time (Chen and Popadiouk 2002). Consequently, a number of different plant communities may occur through time on the same site. To show the relationship among ecosystems in time, site-specific chronosequences of plant associations are construed to describe vegetation succession (dynamics) for a particular site unit. This is done by assigning the plant associations with the same equivalent site quality to a particular site association which in turn provides a site-specific framework for arranging plant associations according to disturbance and/or treatment, and succession status along the chronosequence. With minor exceptions (Klinka et al. 1985, Hamilton 1988), site-specific chronosequences have not been yet developed in British Columbia.

Relations of the classification to management

Due to management activities manipulating ecosystems, an ecosystem-specific approach is suggested as a best practice. In turn, a forest that consists of many different ecosystems needs to be stratified into ecologically uniform segments. When it is stratified, management of the forest can be simplified while at the same time providing a sound ecological foundation. A consistent and ecologically meaningful stratification requires an appropriate classification system.

We consider the biogeoclimatic ecosystem classification to be a right tool for ecosystem-specific management and ecosystem studies. It serves as a predictive tool to support a variety of stand- and forest-level decisions. The stand-level decisions are related to specific vegetation, zonal, or site unit; the forest-level decisions are based on a matrix applicable to the units over the whole region. The ways in which the classification is adapted for, and used by, resource managers were described by MacKinnon et al. (1992).

The classification provides for portability of experience and research by integrating our contemporary understanding of vegetation-environment relationships and forest succession. Portability is based on the presumption that similar ecosystems will respond in the similar way to the same disturbance or treatment. Predictions are based on the presumption that each plant species is adapted to a certain range of environmental conditions, and each species will grow and respond in ways that depend on the sites or ecosystems in which it grows. Fortunately, much information about the ecological characteristics of plant species, sites, and ecosystems has come from ecosystem studies used to develop the classification.

One of the most important keys to a successful application of the classification is the user's ability to identify in a consistent manner the quality of forest sites, i.e., site units. Identification is based on a synthesis of topographic, soil, and plant indicator species data. A variety of aids for site identification are provided in field guides, all sharing edatopic grids of site series for a particular subzone. Field guides also contain selected predictions and interpretations concerning silviculture (e.g., brush hazard, site preparation including sensitivity to fire, tree species selection, stock type, stocking standards, stand tending such as tree species- and site-specific fertilisation decision-making, and reproduction methods), range, recreation, and wildlife.

The major contributions to site identification and silvicultural decision-making are: (i) identifying plant species that could be used as indicators of climate, soil moisture, soil nutrients, ground surface materials, or special edaphic conditions (Klinka et al. 1989), (ii) devising humus form classification (Green et al. 1992), and (iii) proposing criteria for tree species selection (Klinka and Feller 1984).

Relations of the classification to forest productivity research

The site classification is also used as framework for forest productivity studies. The most important research focus was on was quantifying forest productivity-site quality relationships. The paradigm adopted for this work came from recognizing the environmental determinants of forest productivity and knowledge of the importance of productivity itself.

Height growth and site index models were developed for several crop tree species for which there were no local data, only imported models from outside the province. The models for Douglas fir (Carter and Klinka 1990, Klinka and Carter 1990); Pacific silver fir (Splechtna and Klinka 2001); subalpine fir, Engelmann spruce, and lodgepole pine (Chen and Klinka 2000, Klinka and Chen 2003); western larch (Brisco et al. 2002); trembling aspen (Chen et al. 1998, Chen et al. 2002; Nigh et al. 2002); western hemlock (Kayahara et al. 1994, Kayahara and Schroff 1997); white spruce (Wang et al. 1994, Wang and Klinka 1995); and black spruce (Nigh et al. 2002) provided the means for more accurately predicting potential forest productivity and growth and yield of natural and managed stands in the provincial forest.

Potential application of the biogeoclimatic approach to forested landscapes of Ireland

It may appear to the reader that the biogeoclimatic approach has no or limited application to Ireland which features ecosystems with a long history of disturbance and plantations of non-native tree species. It is our firm belief the approach can be applied, albeit with some modifications as done by Pyatt et al. (2001), who developed the ecological site classification for forestry in similarly disturbed landscapes of Great Britain.

Instead of vegetation, the classification approach in Ireland is to be environmentally driven. A preliminary stratification of climate, soil, and vegetation is developed through field reconnaissance and review of pertinent resource information (e.g., climate data, forest cover maps, geology, landform, and soil reports).

Zonal classification could be derived from multivariate analysis of long-term climatic records, corroborated by examination of topographic sequences, in conjunction with soil data and floristic records as suggested by Damman (1979).

On each sample plot, vegetation and environment data are collected; however, the emphasis of data collection and analysis is placed on developing soil moisture and nutrient regime classifications in order to conceptually simplify the physical environment (site) of each local ecosystem into three main elements: climate, soil moisture, and soil nutrients. As a result, local ecosystems will be organized in site classification according to similarities in site quality using climate, soil moisture, and soil nutrients as differentiating characteristics regardless of the vegetation present on the site.

Conclusions

The application of biogeoclimatic ecosystem classification in British Columbia over the past 30 years has resulted in an increased ecological awareness among foresters and improved forest management practices. Foresters now have an effective tool for understanding the ecosystems they manage and are able to predict the consequences of their decisions. Using the framework provided by the classification, results of research and operational trials can be successfully extrapolated to other areas.

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The distribution and productivity of Sitka spruce (Picea sitchensis) in Ireland in relation to site, soil and climatic factors

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Abstract

An analysis of the geographic distribution and productivity of Sitka spruce with reference to site, soil and climate characteristics, planted between the years 1924–1991 was conducted. Sitka spruce plantations have been established throughout Ireland from latitude 51° N on Cape Clear Island off the south-west coast of Co Cork, to 55° N on the Inishowen Peninsula in Co Donegal. Climate models were used to characterise the range in rainfall and temperature of sites afforested with Sitka spruce. Annual accumulated temperature above 5°C and growing season potential water balance (deficit or surplus) were used to derive five climate zones. Seventy percent of Sitka spruce stands had annual accumulated temperatures >1200 degree days per year. Only 7% of the area was classified as having a potential growing season water deficit. Sitka spruce has been most commonly planted on Mountain & Hill sites below the 450 m contour, typically on peat, gley and podzol soils. A stratified random sampling scheme was used to assess productivity on different soils, climate zones and elevation classes. Results indicate that the most productive stands occurred on deep, moist, well-aerated soils, of moderate to rich nutrient status. Yields on low and high level blanket peats were significantly lower than on grey-brown podzolics, acid brown earths, brown earths and gley soils. Productivity varied between elevation classes, but was only significantly lower at elevations over 500 m. Significantly lower yields were found in high rainfall areas where rainfall exceeded potential evapotranspiration by more than 150 mm during the growing season, these areas are associated with blanket peat, peaty podzol and lithosol soils. The national average weighted yield class was found to be 17.0 $m^3ha^{-1}a^{-1}$.

Keywords

Sitka spruce, site factors, climate zonation, degree days, moisture availability, productivity, general yield class

Introduction

Sitka spruce (*Picea sitchensis* (Bong.) Carr.) was introduced to Ireland in 1835 as a specimen tree at Curraghmore, Co Waterford. The tree had reached a height of 32 m by the late 19th century, and 55 m by the late 1990s (Twomey et al. 2002).

The earliest plantations were mixtures with larch (*Larix* spp.); the first (with European larch (*Larix decidua* Mill.)) was established at Glenart, Co Wicklow in the mid 1870s, at an elevation of 90 m (Joyce and OCarroll 2002). In 1905, two plots of were established as part of the Avondale (Co Wicklow) forest demonstration plots, in

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50:50 mixture with Japanese larch (*Larix kaempferi* (Lam.) Carr.), at 1.2 m spacing (Carey 2004). A further plantation was established in 1912 at the Lough Eske estate in Co Donegal, as a mixture with western red cedar (*Thuja plicata* **Donn ex D. Don**), European larch and Scots pine (*Pinus sylvestris* L.). Productive growth in those plots established the suitability of Sitka spruce for Irish forestry (Mooney 1956).

The species does not seem to have been planted pure before 1909, but rather, as indicated, in mixture with larch and with Norway spruce (*Picea abies* **(L.) Karst)**, lodgepole pine (*Pinus contorta* **Douglas ex Louden**), and birch (*Betula spp*).

Just over 47 ha of Sitka spruce had been planted prior to the start of World War 1. During the war years, 1914–1918, a further 68 ha were planted. Forbes, writing in 1925 about forestry in Ireland, stated that Sitka spruce was extensively grown on damp soils, and appeared to be the most rapidly growing spruce species.
The influence of the Avondale plots, established by Forbes in the 1920s, led to an increase in planting of the species by the state on wet ground, on exposed grassy areas and generally at elevations in the range 300–550 m (Joyce and OCarroll 2002). By the end of the 1920s Sitka spruce was well established as a plantation species, and over the subsequent two decades or so, from 1929-1948 it accounted for 24% of the afforestation programme. A census of woodlands conducted in 1958 estimated the area of Sitka spruce planted up to 1948 as 8,891 ha.

By the early 1950s the productive potential of Sitka spruce in Irish forestry was being more fully realized. Joyce (1953) reported that the cumulative production (490 $m^3 ha^{-1}$) of a 30-year-old crop of Sitka spruce exceeded that of crop of Norway spruce (290 $m^3 ha^{-1}$) of the same age growing on similar soil in Co Westmeath.

Odekoven (1957) commented that the thrifty growth characteristics of Sitka spruce, giving high yields on relatively short rotations, together with its excellent timber qualities, made it one of the most valuable species in the state.

A notable feature of government policy at the time was that afforestation should proceed only where there was no agricultural use for the land. As result, most afforestation was confined to marginal or sub-marginal agricultural lands. A further consequence was that during the period from the early 1950s until the mid to late 1980s, considerable areas of marginal land unsuitable for agriculture, such as Cloosh Valley in Galway and blanket peat areas of south-west Sligo and west and north-west Mayo, were afforested, mainly with Sitka spruce, lodgepole pine (*Pinus contorta* **Douglas ex Louden**) (O'Gruinneil 1956, Condon 1961). In fact, by 1956 Sitka spruce had become the most widely planted species in the Forestry Division's afforestation programme on blanket peat (O'Gruinneil 1956, White 1956), and on peat covered moorlands (Parkin 1957).

The area of Sitka spruce in 1958 was estimated as 22,471 ha, or 22.5% of the total forest estate (O'Flanagan 1973). By 1977, Sitka spruce had become the most common tree species in Ireland, occupying 110,753 ha, or 45% of the total area of high forest (Purcell 1977). By 1984, Sitka spruce occupied 49% of the forest area (Anon 1985).

In the 1970s and 1980s the range of site types on which the species was planted widened. Lowland agricultural sites were being planted (O'Flanagan and Bulfin 1970, Bulfin 1987 & 1988). In particular, gley soils which were inherently more fertile than peatland, but which suffered from impeded drainage and waterlogging, were beginning to be planted. This pattern continued with the large afforestation schemes of the 1980s and 1990s, with Sitka spruce being planted on a still wider range of sites. Today, Sitka spruce remains the most important tree species in Irish forestry, occupying 52.3% of the total forest estate or 327,000 ha (Forest Service 2007), and 60% (231,744 ha) of the area owned by Coillte (The Irish Forestry Board). Forest Service afforestation data show that Sitka spruce accounted for 61.6% of all private, grant-aided afforestation (114,000 ha) from 1980–2006 (Forest Service 2008).

The purpose of this paper is two-fold: first to describe the characteristics of sites on which Sitka spruce has been planted between 1924–1991; second to describe the derivation of a mean General Yield Class for Sitka spruce in Ireland, and to test what effect, if any, climate regime, elevation class, and soil type have on the productivity of the species.

Materials and methods

Stand selection

All subcompartments containing pure stands of Sitka spruce, which were over 1 ha in area, and were at least 15 years of age, were selected from a database of Coillte-owned forest. In addition, all private stands classed as 'Spruce' or 'Private Grant Aided' (PGA)[a], which were over 1 ha in area, and were at least 15 years of age were identified from the Forest Inventory and Planning System (FIPS) database of the Forest Service, Department of Agriculture, Food and Fisheries (Gallagher et al. 2001). The age constraint of 15 years or greater was based on results from a larger study examining the productivity of Sitka spruce in Ireland, which included only crops which were at least 15 years old in 2006 (planted up to and including 1991). The minimum area requirement of 1 ha was set in order to avoid edge effects. The selection provided 30,275 stands of Sitka spruce, occupying an area of 158,241 ha (Table 1).

Table 1: *Distribution of Sitka spruce stands planted up to and including 1991 by ownership type.*

Ownership	*Number of stands*	*Area ha*	*%*
State	23,590	109,959	69.5
Private	6,706	48,282	31.5
Total	30,296	158,241	100.0

The location of stands is in Table 2 and Figure 1.

a No differentiation at species level is made in the FIPS database, although it was assumed that most stands classified as Spruce and Private Grant Aided which were over 15 years of age would be predominately Sitka spruce, based on studies by Redmond et al. (2003) and Maguire (2009).

Table 2: *Summary location statistics of Sitka spruce stands planted up to and including 1991.*

Location variable	*Unit*	*Mean*	*Range*	*Std dev*
Longitude	Decimal degrees	8.2	6.0 - 10.4	0.95
Latitude	Decimal degrees	53.2	51.4 - 55.3	0.89
Dist. from sea	km	27.2	0.1 - 91.0	19.5

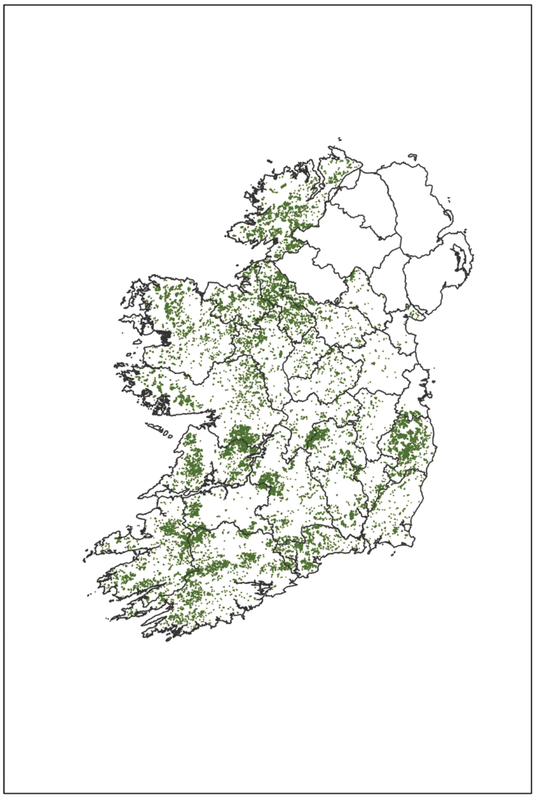

Figure 1: *Distribution of Sitka spruce stands in Ireland.*

In order to characterise sites on which Sitka spruce was planted, stands were classified by elevation class, landscape type, soil association and climate variables in a Geographic Information System (GIS). Elevations were taken from a Digital Elevation Model (DEM), which had a horizontal and vertical resolution of 25 and 1 m, respectively, and which covered the entire land area of the country. Stands were allocated to elevation bands based on 100 m increments, starting at sea level (0 m) to 600 m above sea level.

Based on the General Soil Map of Ireland (Gardiner and Radford 1980) stands were allocated to one of the following landscape types:Mountain & Hill; Hill Land; Rolling Lowland; Drumlin; and Flat to Undulating Terrain. The soil association for each stand was also taken from the General Soil Map of Ireland. A soil association is not a soil classification but is a cartographic unit. It consists of one or more Great Soil Groups, usually formed from the same type of parent material, which are associated in the landscape in a particular pattern. In each association there are principal and associated soils. The principal soil usually comprises about 75% of the association, but this may be as low as 50% or as high as 100% (Gardiner and Radford 1980). The 44 soil associations are grouped according to principal soil type (Table 1, Appendix).

Climate variables

Climate data associated with each stand were derived from 1 x 1 km climate surfaces (raster maps) provided by the Department of Geography, National University of Maynooth (Sweeney and Fealy 2003). The maps were developed from climate models derived from Met Eireann's climatological station data, and based on 30-year averages of annual and mean monthly temperature, annual and monthly precipitation, and monthly potential evapotranspiration covering the period 1961-1990. A map of annual accumulated temperature above 5°C was derived for use in the study and calculated as the sum of monthly accumulated temperature from January to December (Figure 2), where monthly accumulated temperature is:

(Mean monthly temperature – 5°C) x days in month (1)

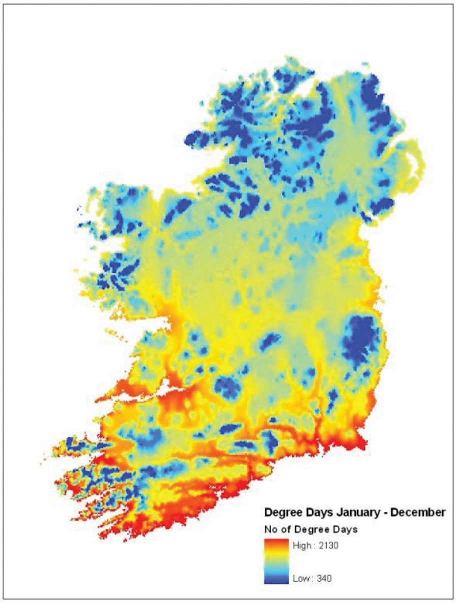

Figure 2: *Annual accumulated temperature above 5°C (degree days) 1961-1990.*

The annual accumulated temperature above 5°C map was used to derive two temperature subzones for Ireland[b], designated Cool and Warm, based on temperature zones defined for Great Britain (Pyatt et al. 2001) (Table 3).

Table 3: *Description of temperature subzones, associated number of degree days and total and proportionate area occupied by each zone.*

Temperature subzone	*Degree days*	*Area km²*	*%*
*Alpine**	< 375	1	0.0
*Sub-alpine**	375 - 575	10	0.0
Cool	575 - 1200	7,668	9.1
Warm	> 1200	76,209	90.8

*Alpine and sub-alpine zones merged with cool subzone for analysis.

Growing season potential water balance was calculated as the difference between monthly precipitation and monthly potential evapotranspiration (PE) and summing months where PE exceeded precipitation. The balance between monthly precipitation and monthly potential evapotranspiration is presented in Table 4. Growing season potential water balance is in Figure 3.

Table 4: *The potential water balance by month (rainfall minus potential evapotranspiration), indicating a surplus (positive values) or deficit (negative values), with the cumulative deficit or surplus for months April-August, 1961-1990.*

Month	*Range of rainfall-potential evapotranspiration values mm*	*Deficit (yes/no)*	*Cumulative deficit mm*	*cumulative surplus mm*
January	61 - 398	no		
February	33 - 270	no		
March	16 - 257	no		
April	-11 - 135	yes	-11	135
May	-36 - 147	yes	-41	282
June	-47 - 116	yes	-89	398
July	-48 - 130	yes	-136	528
August	-13 - 177	yes	-149	705
September	11 - 241	no		
October	37 - 323	no		
November	52 - 331	no		
December	63 - 387	no		

b Although the categorisation resulted in four temperature subzones, the Alpine and Subalpine subzones were amalgamated with the Cool temperature subzone because of the small area each occupied.

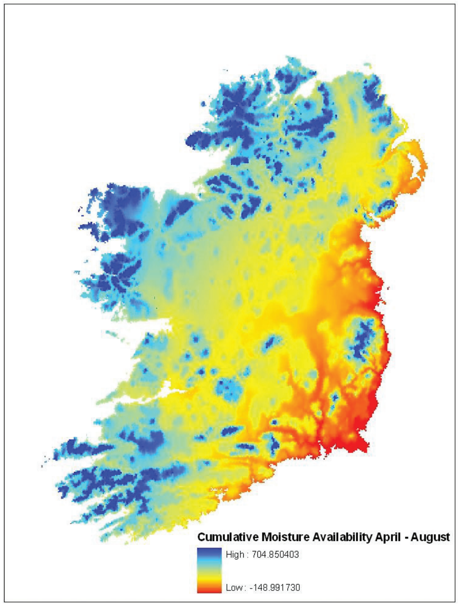

Figure 3: *Potential growing season water balance, April–August, 1961-1990. Low values (negative) are deficits, high values are surpluses.*

Results from previous research have shown that growing season water supply is a key factor influencing the growth of Sitka spruce in Scotland and Douglas fir in Canada (Jarvis and Mullins 1987, Klinka and Carter 1990). For the purposes of evaluating growing season water balance, three growing season potential water balance subzones were derived for Ireland: areas with growing season water deficit, areas with growing season water surplus 0-150 mm, and areas with growing season water surplus >150 mm. Proportionate area breakdowns for the three subzones are in Table 5.

Table 5: *Designation of growing season potential (GSPot) water balance subzones by area in Ireland.*

GSPot water balance subzone	*Water Balance (April – August)*	*Area km^2*	*%*
Deficit	Water deficit occurs (potential evapotranspiration > rainfall)	19,994	23.8
Surplus 0-150 mm	Water surplus (0 – 150mm of rainfall> potential evapotranspiration)	49,754	59.4
Surplus >150 mm	Water surplus (150+mm of rainfall>potential evapotranspiration)	14,140	16.8

Climate zonation

The two temperature subzones, cool and warm (Table 3), and the three growing season water balance subzones (Table 5) were intersected to create five climate zones (Table 6).

Table 6: *Five climatic zones of Ireland based on annual degree days and growing season potential (GSPot) water balance, associated range of annual degree days >5°C, GSPot, annual rainfall, mean elevation and mean annual temperature.*

Climate zone	*Area km²*	*Annual accumulated temp degree days*	*GSPot. water balance mm*	*Annual rainfall mm*	*Mean elevation m*	*Mean annual temp °C*
Warm deficit	19,994	1318 - 2114	-149 - 0	672-1366	75.5	9.3
Warm surplus 0-150 mm	48,563	1200 - 2130	0-150	891-1872	94.6	9.0
Warm surplus > 150 mm	7,652	1200 - 1828	151-318	1320-2310	154.0	8.6
Cool surplus 0-150 mm	1,191	979 - 1200	47 - 150	1169 -1617	285.0	7.5
Cool surplus > 150 mm	6,488	340 - 1200	151 - 705	1317 - 3299	305.3	7

Stands were allocated to one of the five climate zones based on accumulated temperature above 5°C and growing season potential water balance.

Analysis of site, soil and climatic characteristics of Sitka spruce stands

The distribution of the Sitka spruce stands by elevation bands and landscape type, and climate zones was assessed using GIS (as previously described). Soil associations were grouped by principal soil type to aid presentation of results. Missing data were described as unclassified. Summary statistics are presented in Results.

Analysis of potential productivity of Sitka spruce stands

A total of 201 sample plots were established in Sitka spruce stands between October 2006 and April 2009 covering all the major Great Soil Groups across the range of climate zones in Ireland. A two way sampling matrix of principal soil type by climate zone was developed to aid with the selection of samples for field analysis (Table 1, Appendix). In the absence of detailed soil information, the principal soil type within a soil association was used as a guide to locate Great Soil Groups in the field. Stands for field visit were randomly selected from each principal soil type and climate zone combination and were visited in the field, with a target of achieving at least three samples for each Great Soil Group and climate zone combination (stratified random sampling). Within each stand, plots were randomly allocated. Three plot sizes were used, 20 x 20 m, 20 x 10 m and 10 x 10 m (Table 7); smaller plots sizes were allocated in younger crops or where there were time constraints. A soil pit was excavated at the plot centre and the Great Soil Group was described from detailed soil profile analysis (Gardiner and Radford 1980). Elevation bands and climate zones of stands were available from the GIS system described.

Table 7: *Number of sample plots by size.*

Plot dimension *m*	*Number of plots*
20 x 20	145
20 x 10	15
10 x 10	41
Total	201

Within each plot the number and dbh (diameter at breast height) of all live stems of 7 cm dbh and greater was recorded. Top height was assessed as the mean height of the four, two or single largest dbh tree(s) per plot, in descending order of plot size. Age was obtained from management records or from ring counts. General Yield Class (GYC) was estimated from Sitka spruce top height/age curves in the Forestry Commission Yield Tables (Edwards and Christie 1981). The maximum GYC is 24 $m^3ha^{-1}a^{-1}$. In a number of stands where the GYC exceeded this value, extrapolation was used by fitting polynomials in top height and age for each yield class (6-24). The coefficients were regressed against yield class to predict the coefficients for yield classes greater than 24. Using the predicted coefficients GYC curves were derived for each yield class greater than 24.

An analysis of variance model was used to test the effects of soil type, elevation class and climate zone on productivity (SAS 2004). A national yield class, and mean yield class for each climate zone and elevation band were derived by weighting productivity values by the proportion of the area occupied by each in the sampling matrix, in order that climate zones or elevations were not over-represented in the sample (Table 1, Appendix). A survey means weighting procedure was performed (SAS 2004).

Results

Distribution of stands by elevation

Sitka spruce plantations were planted predominately below the 450 m contour (Figure 4) - only 68 ha were planted above 600 m.

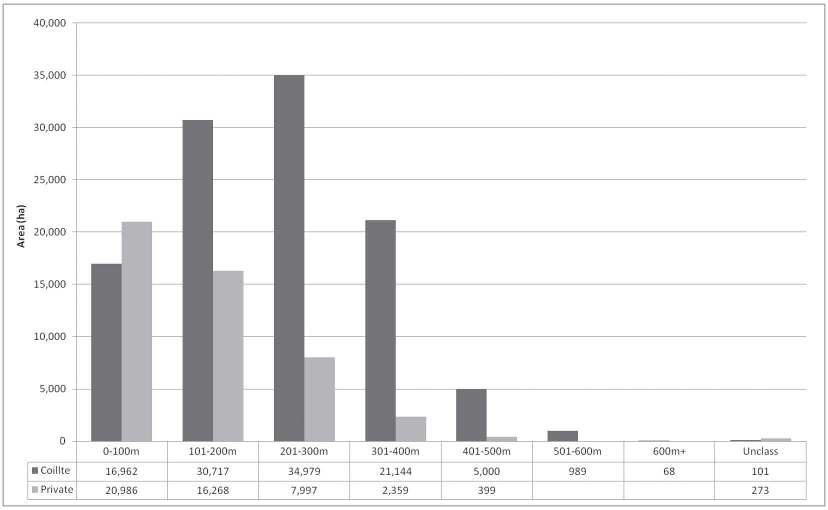

Figure 4: *Distribution of Sitka spruce stands by elevation category and ownership type.*

Privately-owned stands occurred at lower elevations (mean 122 m) than Coillte-owned stands (mean 212 m). The latter were planted over a greater range of elevations, with 25% having been established at elevations over 300 m. High elevation plantations occurred on the leeward slopes of Mount Leinster in Co Carlow, where the stand at the highest elevation was planted up to 651 m. Sitka spruce was planted in the Glenmalure valley in Co Wicklow at over 640 m, while a stand at Temple Hill in the Galtee Mountains in Co Limerick was at just over 600 m. Stands at elevations over 500 m occurred more frequently in the valleys and on mountain sides in Cos Wicklow and Dublin, and Cork on Mullaghanish and Musheramore Mountains near Ballyvourney and Macroom respectively. At these elevations, stands were generally planted on the leeward side of mountains, and in sheltered valleys in the Wicklow Mountains and other areas in the east of the country. To the west of the river Shannon, pure Sitka spruce stands were rarely planted at elevations above 400 m.

Distribution of stands by landscape type and soil association

Sitka spruce was most commonly planted on Mountain & Hill sites, with a total of 71,000 ha planted, representing 7% of the total national land area of Mountain & Hill land (Figure 5). On other landscape types, the proportion of the total area occupied by the species were respectively, Hill land (4%), Rolling Lowland (2%), Drumlin (2%) and flat to undulating lowland (1%). The species was also planted extensively on peats (Table 1, Appendix). Stands on high level and low level blanket peats, soil associations 5 and 24, occupied 38,851 ha and 15,160 ha, respectively. A full breakdown of stands by soil association is provided in Table 1 in the Appendix.

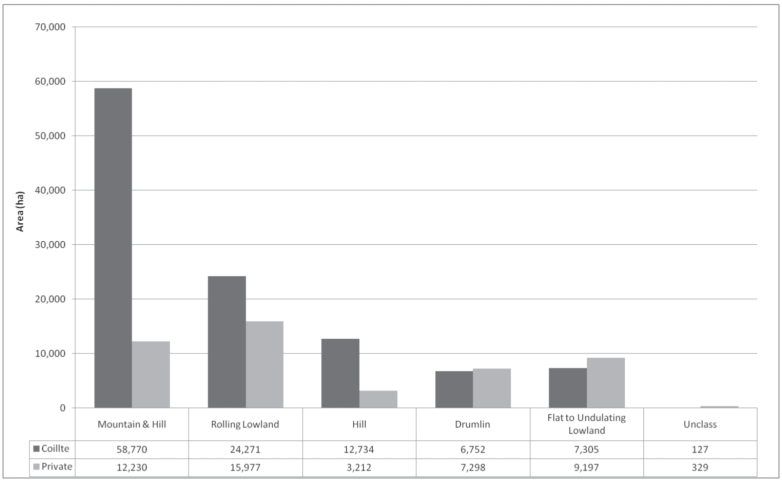

Figure 5: *The distribution of Sitka spruce stands by general landscape type and ownership category.*

Distribution of stands by climatic factors and zones

Annual rainfall where Sitka spruce was planted ranged from 678 mm at the east coast, in Cos Dublin and Louth, to 2946 mm at Molls Gap in Co Kerry, with an mean of 1391 mm. Rainfall was evenly distributed throughout the year, with 11% of the total annual average rainfall falling in January (the wettest month) and 6% falling in April (the driest month), respectively.

The mean temperature of the coldest month, February, was 3.7°C while the mean temperature of warmest month, July, was 15.7°C. The range in mean annual temperature was 4.6°C, at Molls Gap in Co Kerry (546 degree days above 5°C) to 10.7°C (2113 degree days above 5°C), just 46 km from this site at Schull in West Cork. Differences in elevation, increased exposure and lower levels of solar radiation are the main reasons for this difference. The mean annual temperature for all stands was 8.4°C, (1362 degree days above 5°C).

The water balance model predicted that the maximum potential water deficit (147 mm) occurred in Co Wexford, at a stand near Courtown Harbour in that county. The maximum surplus of rainfall over potential evapotranspiration was modelled as having occurred at Molls Gap, Co Kerry. Summary climate statistics for stands are in

Table 8. Seventy percent of Sitka spruce stands were planted in the warm temperature subzone (>1200 degree days per year). Only 7% of the area (10,601 ha) was classified as having a growing season potential water deficit. Sitka spruce was most frequently associated with the warm, surplus (0-150 mm) climate zone (46% of the total area), (Table 1, Appendix).

Table 8: *Values of modelled climate variables associated with Sitka spruce stands.*

Variable	*Mean*	*Range*	*Std dev*
Annual rainfall mm	1391	678-2947	274
Rainfall during wettest month - (January) mm	155	67-354	36
Rainfall during driest month - (April) mm	82	64-169	14
Mean Annual temperature ^oC	8.4	4.6-10.7	1
Mean temperature coldest month (February) ^oC	3.7	-0.5-6.8	1
Mean temperature warmest month (July) ^oC	15.7	10.1-14.0	1
Accumulated Temperature (degree days) >5 ^oC	1362	546-2113	214
Potential Water Surplus mm	120	0-577	80
Potential Water Deficit mm	-35	-147-0	-31

Productivity

Productivity was assessed at each of the 201 sample points. It ranged from 4 to 34 $m^3ha^{-1}a^{-1}$. The weighted mean GYC of Sitka spruce was 17.0 m^3ha^{-1} a-1 (confidence interval +/- 1.8 $m^3\,ha^{-1}a^{-1}$ at the $p <= 0.05$ level). The weighted mean GYC for private sector stands was 21.2 $m^3ha^{-1}a^{-1}$ (confidence interval +/- 3.7 $m^3ha^{-1}a^{-1}$ at the $p <= 0.05$ level.

Sitka spruce productivity in relation to soil type

The highest productivities were found on grey-brown podzolic soils (mean GYC 27.6 $m^3ha^{-1}a^1$), while the lowest were associated with low level blanket peats (mean GYC 14.1 $m^3ha^{-1}a^1$ (Table 9)). General yield class varied significantly with soil type ($p≤0.01$). Grey brown podzolics, acid brown earths, brown earths and gleys had significantly higher productivities than low level and high level blanket peats ($p≤0.05$) (Figure 6). Stands on grey brown podzolics and acid brown earths had significantly higher productivities than those on lithosols, while crops on podzols had significantly lower productivities than those on grey brown podzolics or acid brown earths ($p≤0.05$), (Figure 6).

Table 9: *Sitka spruce sample plots by Great Soil group, elevation and GYC*.

Number of plots	*Great Soil Group*	*Elevation (range) m*	*GYC range $m^3ha^{-1}a^{-1}$*
15	*Acid brown earth*	199 (50-354)	14-30
17	*Basin peat*	65 (41-86)	8-30
40	*Blanket peat high level*	297 (187-516)	4-30
15	*Blanket peat low level*	89 (22-146)	4-24
15	*Brown earth*	45 (9-140)	12-28
14	*Brown podzolic*	243 (31-357)	12-30
46	*Gley*	205 (33-583)	8-34
9	*Grey-brown podzolic*	92 (65-128)	22-32
6	*Lithosol*	231 (131-342)	8-24
22	*Podzol*	278 (116-457)	12-32
2	*Rendzina*	55 (34-75)	16-22

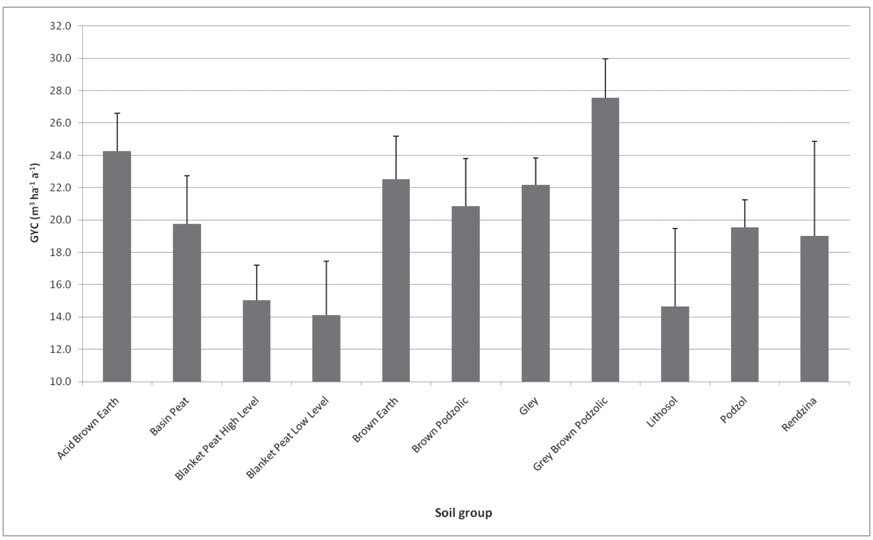

Figure 6: *Mean GYC by soil group (vertical bars are 95% confidence intervals)*.

Sitka spruce productivity in relation to elevation

Productivity (GYC) varied significantly between elevation classes ($p \leq 0.05$). Yield classes were significantly lower ($p \leq 0.05$) in the 501-600 m category compared with the 0-100 m, 101-200 m, 201-300 m and 301-400 m classes ($p \leq 0.05$) (Figure 7).

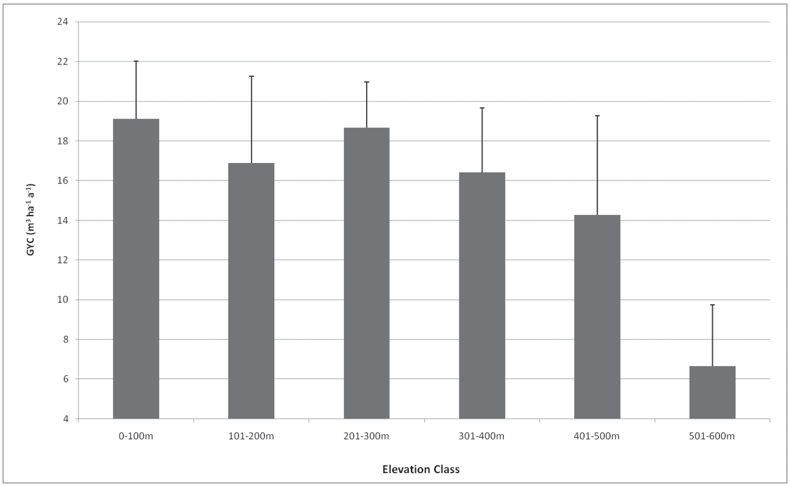

Figure 7: *Relationship between elevation and Sitka spruce productivity (vertical bars are 95% confidence intervals).*

Sitka spruce productivity in relation to climate zone

Productivity (GYC) varied significantly between climate zones ($p \leq 0.05$). The highest yield classes occurred on average in the Warm Deficit, the Warm Surplus 0-150 mm, and the Cool Surplus 0-150 mm climate zones. Productivity was significantly lower ($p \leq 0.05$) in the Cool Surplus >150 mm and the Warm Surplus >150 mm climate zones (Figure 8).

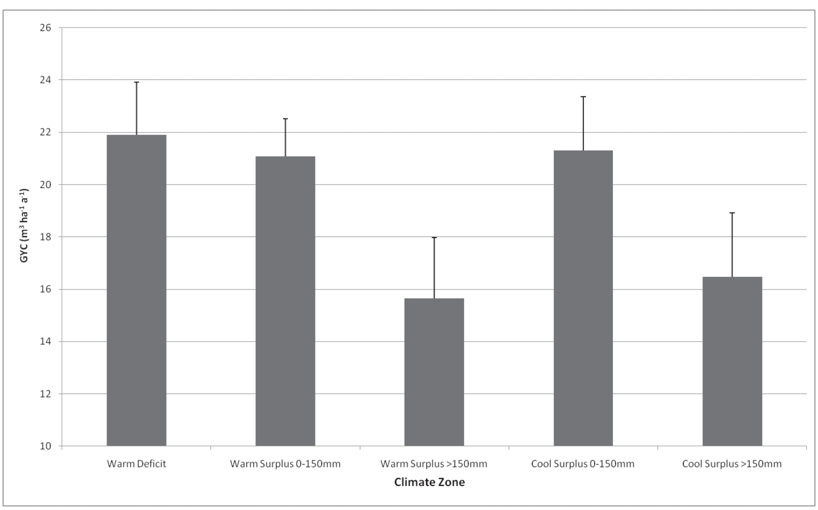

Figure 8: *Relationship between climate zone and Sitka spruce productivity (vertical bars are 95% confidence intervals).*

Discussion

Sitka spruce has been planted on a very wide range of sites in Ireland. Stands planted from 1924-1991 (inclusive) were typically established in upland areas, with 61% of stands (91,953 ha) occurring above 150 m. In those areas the species was found most frequently on high level blanket peats, and soil associations dominated by gleys and peaty podzols. Such soils are characteristic of Mountain and Hill areas (Gardiner and Radford 1980). An artefact of forest policy in Ireland is that Sitka spruce is most commonly associated with Mountain & Hill landscapes (7% of the 1.0 m ha of Mountain & Hill land), and Hill Land (4% of the 0.4 m ha in this category). The species occupies lower levels of the Rolling lowland (2% of the 2.1 m ha) and Drumlin landscapes (2% of the 0.7 m ha). The lowest level of planting has been on the Flat to undulating lowland landscapes (just 1% of the 2.5 m ha) and this mainly a result of planting in the 1980s, reflective of the greater involvement of farmers and institutions in afforestation over that period. In fact, forest policy from the 1980s has targeted better quality land at lower elevations, and a minimum productivity threshold (GYC 14 for Sitka spruce) for grant-aid purposes has been set by the Forest Service since that time. Nevertheless, the very wide range of site types on which Sitka spruce was found to grow above that threshold illustrates the ability of the species to grow successfully across a wide range of sites.

The species has been planted across a similar range of accumulated temperature classes as occurs in its natural range in western North America. At the northern end of its range at Cold Bay in north-east Alaska, annual accumulated temperature above 5°C is 577 degree days (Farr and Harris 1979). Similar accumulated temperatures were found in Ireland, and were associated with increasing elevation and wind exposure. Accumulated temperature rarely exceeded 1200 degree days above the 300 m contour in Ireland, resulting in a similar climate at these elevations as occurs from Cold Bay to Haines in Alaska (where the range in accumulated temperature above 5°C is from 577–1159) (Farr and Harris 1979). The corresponding areas in Ireland - the cool temperature subzone - are also moist even during the growing season, with potential water surpluses ranging from 48–577 mm. Accumulated temperature above 5°C in the central lowland region of the country, and lowland areas of the west and south-west of Ireland rarely exceeded 1700 per year; these areas had accumulated temperatures similar to those of southern Alaska - Ketchikan (1472) and Quotsino (1697), and Vancouver Island in British Columbia (1696). Only in coastal areas of the south and south-west of Ireland does the accumulated temperature above 5°C exceed 1700 degree days. Accumulated temperatures in these areas are similar to southern British Columbia and northern locations in Washington, where accumulated temperatures are 1942 per annum. The few areas that experience accumulated temperature above in excess of 2000 per annum were in the extreme south-west of Co Cork where accumulated temperatures above 5°C reached a maximum (2113) similar to those experienced at Otis, Oregon (2131).

The range in accumulated temperature above 5°C estimated for the Sitka spruce sites is of interest especially for provenance selection in Ireland. Sites above 300 m (25% of the Coillte and 6% of the private sites examined in this study) have less than 1200 degree days per year, and have similar accumulated temperature above

5°C as those experienced in north Alaskan stands (Farr and Harris 1979). The use of more southerly provenances of Sitka spruce from southern British Columbia and Washington below the 300 m contour (where 75% of stands were exposed to accumulated temperatures above 5°C of 1200 or more per annum) in subsequent restocking of sites after clearfell or for afforestation purposes would seem to be a wise decision. Washington provenances may be the most appropriate in the south and potentially Oregon provenances in the extreme south-west of the country. Recent results from Irish Sitka spruce provenance trials seem to support this viewpoint, with recommendations encouraging the planting of Washington provenances of Sitka spruce (Thompson et al. 2005, Pfeifer 2009).

In terms of growing season potential water balance, the model showed that the maximum deficit between April and August occurred in the east and south-east of the country. The danger of drought during the growing season may not be a major concern at present for Sitka spruce, as the species is more commonly planted outside drought prone areas, with only 7% of stands on sites classified as having a growing season potential water deficit (ranging from 146 mm to 0 mm from April to August). In the light of climate change predictions of drier summers, increases in growing season water deficits are likely, resulting in an increase in severity and duration of growing season potential water deficits. For Sitka spruce stands planted after 1991 (outside the study scope), or for new afforestation in these drier areas, water deficits during the growing season may be a concern on soils with low available water capacities. Almost 24% of the land area of Ireland is classed as having some sort of growing season potential water deficit. It must be stressed that the range of climate data used was based on the period 1961–1990.

The most productive Sitka spruce stands, achieving productivity in excess of 27 $m^3ha^{-1}a^{-1}$, were found on free draining grey-brown podzolics. Sitka spruce requires a moderately fertile soil (Miller and Miller 1987). It needs relatively high amounts of available calcium, magnesium and phosphorus, and grows best where soils are derived from parent materials rich in calcium and magnesium (Krajina 1969). Grey-brown podzolics, which are derived from limestone, satisfy the nutrient requirements of the species. Productivities on acid brown earths, brown earths and brown podzolics were also high. These soils, which are moderately fertile, occurred at low to medium elevations: acid brown earths and brown podzolics on lowland to hill areas, with brown earths occurring on lowland areas. These results agree with the findings of Day (1958), who in a study of Sitka spruce in British Columbia, observed that the best development of the species was on deep, moist, well-aerated soils. Average GYC values for gley soils were impressive, with values in excess of 22 $m^3ha^{-1}a^{-1}$. This productivity is similar to those observed by Bulfin et al. (1973) on gley soils in Leitrim. In a later work, Bulfin (1987) indicated that these gleys had a high afforestation potential. The high growth potential of Sitka spruce on moist and nutrient rich sites has been confirmed by measurements of growth rates within its natural range in British Columbia (Green and Klinka 1994, Omule and Krumlik 1987). The productivity of Sitka spruce on cutaway basin peats, GYC 20 $m^3ha^{-1}a^1$, concur with the findings of Carey et al. (1985), and indicate the potential of the species on cutaways, once adequate nutrition is provided at establishment. Podzols and peaty podzols are also very suitable for Sitka spruce with an average productivity in excess of 20 $m^3ha^{-1}a^{-1}$. A surprising result was the higher productivity of stands on high level blanket peat (GYC 16) compared with low level blanket peats (GYC 14). The contributing factor may be poorer drainage on flatter, deeper low level peats. Poor drainage has been shown to contribute to poor growth of Sitka spruce (Odekoven, 1957). On lithosols productivity was relatively low (GYC 14). The poor growth on such sites soils may also be related to their exposed nature.

The effect of elevation on productivity was only significant above the 500 m contour, with no significant differences in growth below that level. These results concur with research carried out in Scotland (Worrell 1987, Worrell and Malcolm 1990), where the effect of elevation in reducing general yield class was more pronounced at higher elevation and northerly locations. This effect is probably explained by the more adverse climatic conditions that are associated with high elevation northerly sites, as elevation may be regarded as a composite indicator of climatic conditions. On high altitude sites, Malcolm and Studholme (1972), Worrell (1987) and Worrell and Malcolm (1990) found that productivity decreased with increasing elevation, by an average of 3.0 to 4.0 $m^3ha^{-1}a^{-1}$ per 100 m. Productivity was also higher at inland or southern sites than at coastal or northern sites. Results from this study indicate that the effect of elevation on productivity resulted in mean GYC declining by on average just over 2 $m^3ha^{-1}a^{-1}$ from 201-300 m to 301-400 m and from 301 to 401-500 m. The decline in yield class was much more pronounced at the higher elevation range, declining by on average 7.6 $m^3ha^{-1}a^{-1}$ for the 501-500 m elevation, class compared with the 401-500 m elevation class (Figure 7).

This compares with Malcolm and Studholme (1972) who found that in Britain Sitka spruce productivity declined by an average of 6.6 $m^3ha^{-1}a^{-1}$ per 100 m increase in elevation over 450 m. Indications are that the rate of decrease in productivity of Sitka spruce in Ireland may be higher over similar ranges in elevation than in Britain, perhaps the adverse climatic conditions are more severe in Ireland than in Britain for higher elevations with higher average windspeeds. Increasing elevation had no significant impact on productivity at lower elevations. Similar findings have been reported by MacMillian (1991) and Hassall et al. (1994) in Scotland. The former reported average decreases of 0.8 $m^3ha^{-1}a^{-1}$ per 100 m increase in elevation on sites ranging from 15 to 333 m, while the latter study reported average decreases of 1.0 $m^3ha^{-1}a^{-1}$, for sites ranging from 30 to 180 m. Similar results have been found for Douglas fir on sites less than 267 m in elevation in Ireland (Dunbar et al. 2002) and on better quality sites less than 350 m in elevation in Scotland (Tyler et al. 1996). This could be explained by the fact that climatic gradients are lower in lowland areas compared with uplands, and so other limiting factors such as soil fertility play a larger part in influencing crop productivity.

The effect of climate zone on productivity was significant, with lower yields encountered on the cool surplus >150 mm and the warm surplus >150 mm climate zones compared to the other climate zones. The lower yield classes appear to be associated with areas with excess moisture, rather than areas with low accumulated temperatures, as there was no difference between the cool surplus 0-150 mm and the warm surplus 0-150 mm climate zones. The temperature gradient in Ireland is without the extremes of temperature found in continental North America, Europe or even Britain; probably an explanation of why it had did not have a significant effect on productivity. The difference in mean annual temperature, mean February temperature and mean July temperature between the coldest and warmest locations in Ireland is low, at only 6.1, 6.3 and 3.9 ºC respectively (Table 8).

Variability in climate in Ireland is mostly associated with rainfall, with annual values ranging from 678 to 2947 mm, with the highest levels in the west and upland areas of the country. Climate zones with a surplus >150 mm of rainfall over precipitation tend to have poorer soils, predominately blanket peats, lithosols and peaty podzols (Table 1, Appendix). Sitka spruce productivity in the warm deficit climate zone was on average the highest observed, 22.4 $m^3ha^{-1}a^{-1}$. A cross section of all soils were sampled in the warm deficit zone, these soils were acid brown earths, brown podzolics, basin peats and gleys. It seems that the establishment of Sitka spruce plantations has largely has been confined to soils with high available water storage capacities or soils with high seasonal water tables. The maritime climate of Ireland limits the severity of potential growing season water deficit, thus the impacts of water deficits on Sitka spruce productivity is minimal on soils with sufficient water storage capacity.

Conclusion

Sitka spruce has a wide climatic and edaphic amplitude in Ireland, with plantations growing from sea level right up to 650 m, and across a wide range of soils. It has also been successfully established across a range of sites with widely varying accumulated temperature, from 540 to 2000 degree days, showing it is tolerant of low temperature associated with exposure and elevation. Productivity does however decline above 400 m, with sharp reductions over 500 m. The economic planting limit (GYC 14) is likely to be between 400-500 m in sheltered valleys in the east of Ireland, and at a lower elevation, between 300–400 m in the west and northwest.

Bearing in mid the ranges found for climatic variables, the use of southern British Columbia, Washington and indeed Oregon provenances should be further encouraged in Ireland, given the similarity of climate in Ireland (below 300 m) to the areas referred to.

Higher productivity can be achieved by targeting certain soils, which, having been used for pasture and arable crops, offer excellent potential for the species, affording as well the potential for reduced rotation length and a shorter payback on investment. On peats productivity was satisfactory on cutaway basin peats, and to a lesser extent on high level blanket peats. However spring frost may result in poor survival on such sites. Productivity was poorer on low level blanket peats, possibly due to poor drainage and low nutrient levels.

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Appendix

Table 1: *Sampling matrix showing the distribution of Sitka spruce stands by climate zone and soil association (soil associations have been grouped by principal soil types, with percentage of the principal soil within each association in brackets).*

Group	*Soil Assoc(s)*	*Principal Soil Type*	*Associated Soils*	*Principal Soil in Association*
				%
1	*12, 13,14, 16,17,19,29*	*Acid Brown Earth*	*Gleys, Podzols, Grey Brown Podzolics, Peaty Gleys, Brown Podzolics, Interdrumlin Peat, Regosols*	70 – 90
2	*44*	*Basin Peat*		100
3	*5*	*Blanket Peat (High Level)*		100
4	*24*	*Blanket Peat (Low Level)*		100
5	*6, 8, 9, 15, 20*	*Brown Podzolics*	*Gleys, Podzols, Blanket Peats, Acid Brown Earths, Podzols*	60 - 80
6	*10, 28, 30, 31, 32, 34, 35, 36,37,38*	*Grey Brown Podzolics*	*Gleys, Interdrumlin Peats, Peaty Gleys, Brown Earths, Basin Peats, Podzols*	50 - 80
7	*11, 21, 22, 25, 26, 27, 39, 40, 41, 42, 43*	*Gleys*	*Acid Brown Earths, Interdrumlin Peat and Peaty Gleys, Brown Earths, Peats, Brown Earths, Grey Brown Podzolics*	50 - 90
8	*4, 23*	*Lithosols*	*Rock Outcrop and Peats, Blanket Peats, Peaty Podzols*	70 – 80
9	*2*	*Peaty Gleys*	*Blanket Peats, Peaty Podzols*	70
10	*1*	*Peaty Podzols*	*Lithosols, Blanket Peats*	75
11	*18*	*Podzols*	*Gleys and Peats*	70
12	*7*	*Rendzinas + outcropping Rock*	*Lithosols, Shallow Brown Earths*	90
13	*33*	*Shallow Brown Earths and Rendzinas*	*Grey Brown Podzolic , Gleys and Peats*	60
	Unknown			
			Total	

Warm Deficit	*Warm Surplus 0-150 mm*	*Warm Surplus >150 mm*	*Cool Surplus 0-150 mm*	*Cool Surplus >150 mm*	*Unclassified*	*Total*
			ha			
1,712	1,405	83	5	6	44	3,256
1,850	5,447	6	0	0	0	7,302
18	8,857	14,741	515	14,721	0	38,851
0	5,538	8,730	0	877	15	15,620
3,290	11,782	402	2,389	715	42	18,620
1,653	5,340	94	104	18	9	7,219
1,579	24,769	2,952	406	2,649	55	32,406
67	642	761	561	2,351	25	4,406
0	1,690	73	471	380	0	2,615
364	5,210	6,556	4,955	8,458	38	25,581
19	642	188	60	89	0	998
10	356	141	0	44	0	550
26	702	26	0	26	0	780
19	246	19	30	0	182	496
10,601	72,627	34,773	9,496	30,334	410	158,241

The development and validation of a windthrow probability model for Sitka spruce in Ireland

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Abstract
An empirical windthrow probability model for Sitka spruce (*Picea sitchensis*) in Ireland was developed and validated. Data were collected from a range of Sitka spruce stands on different sites. Logistic regression was used to determine which site, stand and silvicultural factors significantly influenced the probability of windthrow. Top height, top height squared, the regional location of the stand, soil type, and altitude significantly influenced the occurrence of windthrow in Sitka spruce. Whether or not the stand had been thinned was also important. A model to predict the probability of windthrow occurring in a forest stand was developed. A validation exercise indicated that only 6% of the stands for which the model predicted the probability of windthrow to be less than 1% actually experienced windthrow.

Keywords
probabilistic model, windthrow, Sitka spruce, thinning

Introduction

Windthrow is a major constraint to economic forestry in Ireland. Over the period 1971 to 1993, 85,000 cubic metres of roundwood were windthrown annually, which represents 9% of the volume sold by the state over the period. Windthrow is therefore a recurring problem in Irish forestry, with serious economic implications. Volume losses to windthrow are expected to increase as much of the afforestation programme (both Coillte and private) approaches a critical height in relation to windthrow.

Among the consequences of windthrow for the forest manager is increased harvesting cost on affected sites. More significantly, windthrow can lead to shortened rotations, resulting in stands being clearfelled well in advance of the economic rotation length.

A range of stand, site and silvicultural factors has been shown to influence the occurrence of windthrow, including soil type, elevation and slope (Savill 1983, Miller 1985). Silvicultural factors, such as ground preparation method (including drainage method), and thinning type, can also influence stand stability (Lynch 1985, Hendrick 1988).

Risk models have been developed in the United Kingdom, where windthrow is also a major constraint to forest management. This work commenced with the development

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of the Forestry Commission's Windthrow Hazard Classification system in 1977 (Booth 1977), with the most recent development being FOREST GALES (Dunham et al. 2000), which calculates the probability of windthrow within a stand, based on a combination of site and stand factors. In Ireland, Hendrick (1988) developed a model to support forest managers in making decisions as to whether it was safe to thin forest stands. However, none of these models is routinely used in forest management in Ireland. Instead, subjective assessment of risk is used to guide decisions regarding thinning and rotation length.

This paper describes the development of a windthrow risk probability model for Sitka spruce in Ireland.

Materials and methods

Work was carried out in two phases.

Phase I

A sample of pure Sitka spruce stands was selected from five Coillte-owned forests. Based on Miller's wind zonation (Figure 1), three were selected in Co Clare, a relatively exposed part of the country (wind zone B), and two in Co Wexford, a relatively sheltered area (wind zone C). Another important factor for the selection of the two counties was that they had been covered under the National Soil survey (Gardiner and Ryan, Finch 1971).

To reduce costs a multi-stage sampling approach was used. Compartments satisfying the following criteria were selected at random from the five forests:

(a) Compartments must have at least two subcompartments comprised of pure Sitka spruce stands.

(b) These two or more subcompartments must be comprised of Sitka spruce stands < 5 years olds (reforestation only) or > 15 years at time of survey.

Stands where the risk of windthrow is very high are often prematurely clearfelled. To ensure that the dataset used in this study included subcompartments with second rotation Sitka spruce stands <5 years old were also surveyed and data (including windthrow history) on the antecedent crop recorded. Stands 15 years or older were chosen as they were approaching the age of first thinning, when susceptibility to windthrow increases (Lynch 1985). Within the selected compartments, all accessible subcompartments satisfying the above criteria were surveyed, yielding 215 subcompartments in Clare and 59 in Wexford.

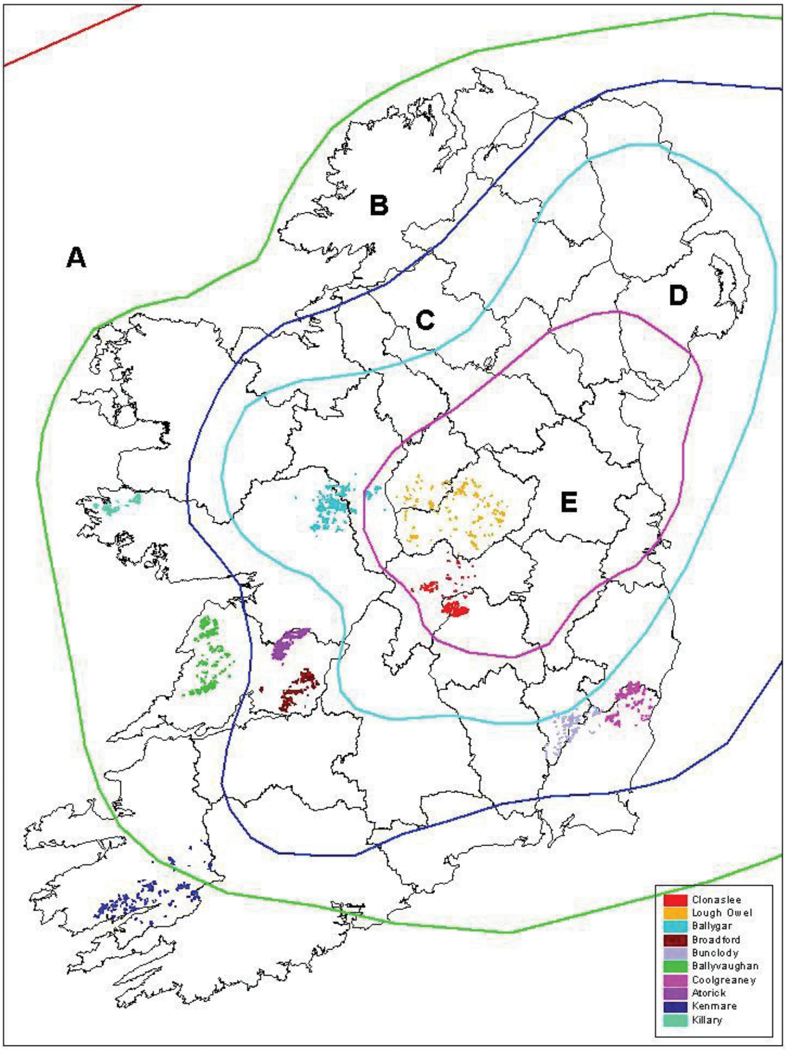

Figure 1: *Location of study forests overlain with Miller's (1986) wind zone map.*

At each subcompartment, a range of site and stand variables was determined (Table 1). Most of the data were collected from site visits and from Coillte's inventory database. The presence of windthrow was determined by site visit. Windthrow was assessed as having occurred where visual assessment indicated at least 3% of the stems were fallen or snapped.

Table 1: *Site and stand variables assessed in the study and their source (Phase 1).*

Site	*Variable*	*Data source*
	Soil cultivation method, direction and bearing	Site visit
	Exposure	Site visit
	Aspect	Ordnance survey 1:50,000 Discovery Series
	Altitude (m)	Ordnance survey 1:50,000 Discovery Series
	Slope (°)	Ordnance survey 1:50,000 Discovery Series
	Wind zone	Miller's wind zone map
	Soil type	Teagasc GIS datasets
	Subcompartment area (ha)	Coillte inventory
	Topex	Ordnance survey 1:50,000 Discovery Series
Stand	Age	Coillte inventory
	Thinning delay	Coillte inventory
	Top height (m)	Site visit
	Presence of windthrow	Site visit
	Percentage windthrow	Site visit
	Thinned	Site visit
	Thinning system	Coillte inventory/site visit
	Thinning intensity	Site visit
	Method of extraction	Coillte inventory/site visit
	Mean height of fallen trees (m)	Site visit
	Initial crop spacing (stems ha^{-1})	Site visit
	Yield class ($m^3ha^{-1}a^{-1}$)	Coillte inventory/site visit

Topographic exposure (topex) was assessed by measuring the angle to the horizon at the eight cardinal compass points. Software tools were developed to derive topex, elevation, aspect and slope from a digital terrain model (DTM) of the sites (Mills and Cory 1998). The DTM was created using Ordnance Survey 1:50,000 (Discovery Series) contour data. It was divided into a 50 x 50 m grid, with aspect, slope, elevation and topex assigned to each grid cell. The DTM was then overlain with a digital subcompartment boundary map of the selected forests. Estimates of topex, elevation and slope for each of the subcompartments were obtained by taking the average of the grid values within a subcompartment. The most commonly occurring aspect for the grid cells within a subcompartment was determined.

A digitised soil map, added as a layer to the GIS database, was overlain with the digitised subcompartment map to determine the soil type which comprised most of the subcompartment. Where the digitised soil map indicated that soil complexes[a] represented most of the subcompartment area, the predominant soil type was assessed during the site visit.

Phase 2

Data were collected from an additional five forests, chosen from parts of the country which had not been covered in Phase 1, namely wind zones A, D and E. In addition, as only one forest from wind zone B had been represented in the original study, a second forest was chosen from this area. The five Coillte forests surveyed were Kenmare (wind zone A), Killary (wind zone B), Ballygar (wind zone D), Lough Owel (wind zone E) and Clonalsee (wind zone E) (Figure 1). In order to reduce costs, Coillte inventory staff collected site and stand variable data during scheduled forest inventory. Within each of the five forests, subcompartments which were 14 years or older were selected for survey (to coincide with the crop age at which Coillte undertakes its inventory), yielding a total of 193 stands.

The number of variables assessed in Phase 2 was less than in Phase 1. The main reason was that preliminary analysis of Phase 1 data indicated that a number of the stand and site variables did not significantly influence the occurrence of windthrow.

For each of the stands surveyed in Phase 2, estimates of topex, elevation, slope and aspect were obtained from DTMs using the method previously outlined. In addition, estimates of mean wind speed for the sites were obtained from Teagasc. These were derived from a combination of two sources. First the Meteorological Service provided mean annual wind speed data for the period 1960-1990 for 14 synoptic stations (Met Éireann 2002). Second, an Electricity Supply Board/Electrical Research Association survey in the 1950s (Golding and Stodhart 1952, Golding 1955, Munro 1953), reported in a paper by Haslett and Kennedy (1979), provided estimated mean annual wind speed for 26 hill-top sites.

In addition to the datasets assembled in Phases 1 and 2, an additional dataset was made available by Teagasc. It had been collected as part of an EU-funded study on the role of private forestry on highly productive sites in agriculturally disadvantaged areas (Bulfin 1987). In the study 1089 stands, on marginal agricultural soils throughout the country were surveyed in 1983-1985, and a range of stand and site variable data was recorded. In addition, the occurrence of windthrow was assessed. By combining these data with those collected in Phases 1 and 2, a larger sample was available for deriving the windthrow probability model.

Adjustments were made to make the three datasets as compatible as possible. Variables assessed in Phases 1 and 2 that were not included in the Teagasc dataset were the compass bearing of the planting lines and the cultivation direction relative to the contour. Topex was also excluded as the approach used by Teagasc to determine

a A soil complex is a mapping unit which represents contiguous soils which can be distinguished in the field, but which are arranged in a pattern that is too complex to represent at the current scale of mapping (Hammond and Brennan 2003, p.29).

it differed from the approach used in Phases 1 and 2. In addition, topex was found not to be a significant variable in explaining windthrow probability in the preliminary analysis (Ni Dhubháin et al. 2001). Although the datasets were collected at different times, it was felt that this would have little impact on the wind climate. Thus, the final dataset comprised data from 1152 stands and included the following variables: stand thinned (yes/no), cultivation method, soil type, top height, altitude, slope, wind zone, aspect and wind speed. Independent data from a further 175 stands were retained for the model validation process.

Statistical analysis

A windthrow probability model was derived from the data using stepwise logistic regression. Initially, all stand and site variables were tested individually to determine which ones significantly influenced (at the 5% level) windthrow probability. An intermediate model was then fitted with all significant variables included; and the impact of the stepwise removal of each variable examined. Only those variables, whose exclusion from the intermediate model was significant, were included in the final model. The final model had the general form:

$$p_i=\exp(ß_0+ ß_1x_1+ ß_2x_2+......+ ß_nx_n)/(1+\exp(ß_0+ ß_1x_1+ß_2x_2+......+ß_nx_n)$$

where

p_i: probability of windthrow in subcompartment i

$x_1, x_2 \ldots x_n$: independent variables

$ß_{0, 1, n}$: parameters estimated.

Results

Six factors were found to influence the probability of windthrow in Sitka spruce: top height, top height squared, soil type, thinning, wind zone, altitude and the interaction between top height and soil type (Table 2).

Table 2: *Logistic regression parameter estimates for variables in Sitka spruce windthrow probability model.*

Variable		*Parameter estimate*	*Standard error*	*t-value*	*Significance*
Intercept		-10.5100	2.2400	-4.69	<0.001
Top height (m)		0.6280	0.2350	2.67	0.008
Top height (m^2)		-0.0156	0.0061	-2.54	0.011
Soil type	*1. Brown earth/ Brown podzolic/Podzol*	0.0000			
	2. Raised bog	-2.6800	1.6900	-1.59	0.112
	3. Blanket peat/Gley	-3.2600	1.2300	-2.66	0.008
Thinned	*0. Not thinned*	0.0000			
	1. Thinned	1.3720	0.2020	6.78	<0.001
Altitude (m)		0.0096	0.0014	7.05	<0.001
Wind zone	*E*	0.0000			
	D/C	1.1190	0.3930	2.85	0.004
	B	2.3920	0.4180	5.72	<0.001
Top height soil type 1*		0.0000			
Top height soil type 2*		0.1680	0.1060	1.58	0.114
Top height soil type 3*		0.2677	0.0742	3.61	<0.001

Windthrow probability increased with top height but the effect was not constant across soil types (Figure 2).

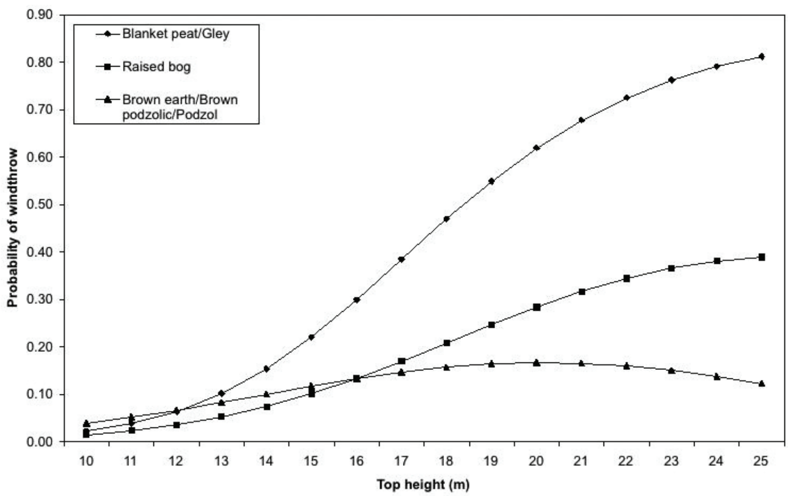

Figure 2: *Effect of top height on the probability of windthrow occurrence in unthinned Sitka spruce stands on a range of soil types (wind zone C; altitude 150 m).*

Following thinning, the probability of windthrow occurring increased on all soil types (Figure 3).

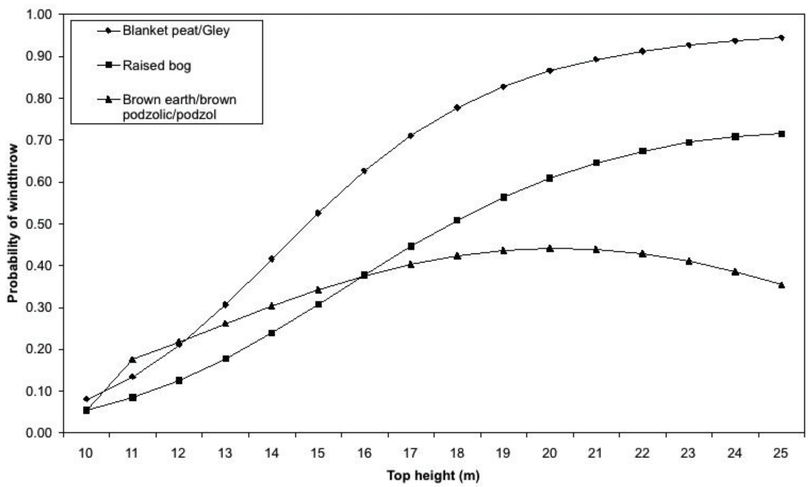

Figure 3: *Effect of top height on the probability of windthrow occurrence in thinned Sitka spruce stands on a range of soil types (wind zone C; altitude 150 m).*

Altitude also had a significant effect on the probability of windthrow occurring in Sitka spruce (Figure 4).

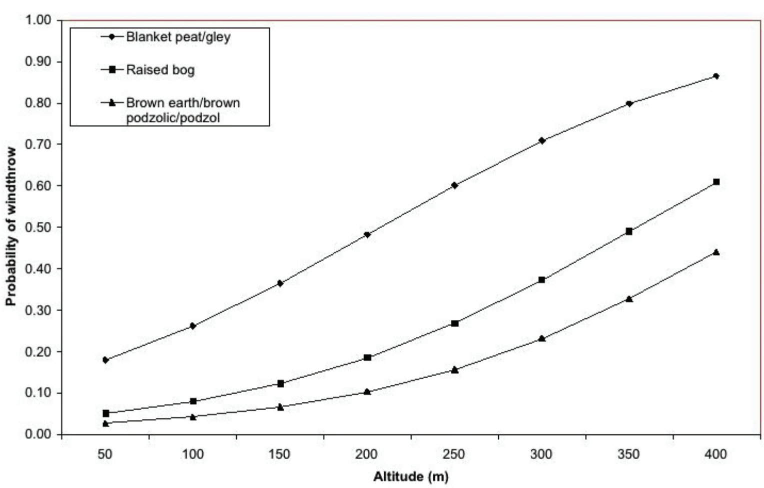

Figure 4: *Effect of altitude on the probability of windthrow occurrence in unthinned Sitka spruce stands on a range of soil types (wind zone C; top height 20 m).*

Model validation
The estimates of windthrow probability provided by the model were tested in a sample of 168 stands. Only 6% of the stands where the model predicted the probability of windthrow to be less than 1% actually experienced windthrow (Table 3). Fifty percent of the stands where the predicted probability of windthrow was greater than 50% had experienced windthrow.

Table 3: *Predicted and actual occurrence of windthrow, using windthrow probability.*

Actual occurrence of windthrow	*Predicted probability of windthrow occurrence*				
	≤ 0.01	0.01-0.05	0.05-0.10	0.10-0.50	>0.50
	Number and percentage of stands				
No	77(94%)	34(65%)	6(35%)	4(44%)	4(50%)
Yes	5(6%)	18(35%)	11(65%)	5(55%)	4(50%)

User-friendly software
In 2007, a user-friendly interface to the model was developed in conjunction with PTR Ltd and placed on www.coford.ie. The interface is linked to yield models, making it possible to examine how windthrow probability changes with increasing top height, once the yield class of the stand is known.

Discussion
Six of the nine site and stand variables examined were shown to contribute significantly to the probability of windthrow: top height, top height squared, soil type, thinning, wind zone and altitude. The relationship between soil type and windthrow probability was not consistent over the range of top heights examined; thus an interaction term (top height x soil type) was included in the model. In Ní Dhubháin et al. (2001) the impact of top height and thinning on windthrow probability was discussed, thus this discussion concentrates on soil type, wind speed and windthrow probability.

Many researchers have identified the key contribution of soil type in determining stand vulnerability to windthrow (Savill 1983, Lynch 1985). This study confirmed that Sitka spruce stands on gleys and peats had the greatest probability of windthrow occurrence. The least probability was associated with brown earths, brown podzolics and podzols. Raised peats had an intermediate probability. These findings generally coincide with those of Miller (1985). However, a greater range of soils was represented in his classification compared with the five in this study.

A number of factors influence the wind load that stands experience. Gusts, the severity of wind speeds and their frequency of occurrence play a major role in determining the risk of windthrow occurring. Unlike the Forestry Commission, where work on this component of windthrow risk has been ongoing for many years, the collection of wind speed data in Ireland has been largely undertaken by Met Éireann. The usefulness of these data in estimating wind speeds in forests is limited.

The Forestry Commission, on the other hand, has a long history and experience of estimating relative exposure using flag tatter. The use of such tatter flags has been limited in Ireland. While the recent interest in establishing wind farms has, and is expected to continue to, provide wind speed data from more remote locations, enquiries made during this study were unable to locate additional data for the study sites. Thus, the wind climate element of the windthrow prediction equation is addressed simply by using Miller's (1986) wind zone map for Ireland. He acknowledges the limited scientific basis of this map, which was based on some tatter flag data from Northern Ireland, which were extrapolated across the whole of Ireland, taking account of regional variation in mean wind speed. Nevertheless the model developed in the study showed the significant difference in the probability of windthrow between stands established in more exposed locations (wind zone B) compared to those in more sheltered locations (wind zone E). Stands located in wind zones C and D were associated with an intermediate probability. The analysis found no difference in the probability of windthrow occurrence in stands in these two wind zones.

The validation exercise indicated that the model worked reasonably well. In 94% of stands where windthrow had not occurred the model estimated the probability of windthrow was less 10%. However, in stands where windthrow had occurred, estimates of windthrow probability were quite varied. The small number of stands with windthrow in this validation dataset (43) may partly explain this finding. Users of the model can use both the validation results, as well as the confidence interval associated with the estimate (see www.coford.ie) to assess whether the precision of the model is acceptable for particular uses. These can vary from assessing the potential impact of thinning on windthrow probability, to estimating its probability over the lifetime of a stand.

Conclusions and recommendations

To gain a fuller understanding of windthrow, site and stand monitoring over time is essential. In this way the progression of windthrow can be examined. Such a process has been ongoing in Britain since 1987, where eight monitoring sites have been established (Quine and Bell 1998). Aerial photography is used to monitor progression. A similar process should be started in a selection of forests in Ireland.

Acknowledgements

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Afforestation of industrial cutaway peatlands in the Irish midlands: site selection and species performance

Florence Renou-Wilson[a], Michael Keane[b] and E.P. Farrell[c]

Abstract
In Ireland, industrial cutaway peatlands account for about 80,000 ha, of which 58,000 ha are currently in production, mainly in the midlands. It is estimated that only 16,000 to 20,000 ha of this area is suitable for commercial forestry. The BOGFOR research programme was initiated in 1998 in an attempt to develop new techniques to successfully establish forests on cutaway peatlands. It established that with good planning and the application of site-specific establishment procedures, satisfactory results could be obtained. It recognised however, the heterogeneity of cutaway peatlands and thus, the difficulties associated with site selection necessitate the use of intensive site evaluation procedures in advance of any decision to plant an area. Norway spruce may be the most suitable commercial forest species for planting on cutaways. Survival and growth results from several field trials, however, show that a range of conifer and broadleaved species can be established successfully. While there is still little information on the long-term performance of most species on such sites, the relatively wide range of suitable species affords the forester the opportunity to create interesting landscapes and the potential for providing other options (e.g. a more diverse range of products for market) at a later stage. The variation in site conditions encountered in any given cutaway peatland means that, not one, but several species might flourish within a given area, thus enhancing the sustainability of these new forests.

Keywords
Afforestation, cutaway peatlands, species selection, species performance, tree establishment, tree nutrition, nurse crops

Introduction
Since the late 1940s, Bord na Móna has been responsible for harvesting vast quantities of peat which was used to fuel power stations and heat homes all over Ireland. Most of the Bord na Móna peatlands are located on raised bogs in the midlands, and once these areas are released from peat production, they are called industrial cutaway peatlands. Ireland has a long experience of peatland afforestation, mainly on blanket peatland in the West and on mountain ranges. Industrial cutaway peatlands, however, are very different in character from blanket bogs and present a series of unique, challenging problems. The peat remaining after harvesting has been buried for several thousand years under the enormous weight of the overlying bog. It has been compacted, and its physical properties have been radically altered by this overlay. When the first milled cutaway raised bogs were released for after-use, foresters were presented with unique

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site characteristics for which conventional forestry techniques had limited applicability and success (Jones et al. 1998).

One of the objectives of the BOGFOR Research Programme, which was established in 1998, was to give practitioners tools with which to better understand the complexity of cutaway peatlands and to successfully establish a forest resource on these site types for which little information was available (Renou-Wilson et al. 2008c). The results from over 200 ha of experimental and demonstration plantations show that the successful afforestation of midland cutaway peatlands is possible but requires (a) a sound plan with specific objectives, (b) careful selection of sites with suitable characteristics and (c) the use of specific operational methods tailored to the site conditions and species requirements. Commercial forest crops have been successfully established on certain cutaway site types, each requiring a combination of actions pertaining to site assessment, site preparation, species choice, tree establishment, fertilisation and vegetation management. This paper reviews some significant findings from the BOGFOR Research project pertaining particularly to the identification of sites best suited for afforestation and the performance potential of various species on these sites.

Site selection

Industrial cutaway peatlands

While large peat resources still remain in the Bord na Móna bogs, they are gradually becoming exhausted for fuel production and thereby transformed into industrial cutaway peatlands (hereinafter called 'cutaways'). About 18% (16,000 ha) of Bord na Móna bogs have so far become cutaway (although varying depths of residual peat remain). This area of cutaway is increasing every year but at a variable rate; it is expected that another 60,000 ha of bogs will become cutaways within the next three decades. They represent a valuable resource with potential for new land-uses (Renou et al. 2006). The BOGFOR research programme has been investigating the forestry potential of these cutaways as a future land-use option.

The process of milled peat production and the variation in peat depth in midland bogs means that the cessation of harvesting varies across the bog and that areas become available for after-use in a piecemeal fashion. Consequently, it may take many years to build up a viable management unit for afforestation. During this time, site properties will have acquired their own heterogeneity as a consequence of the different stages of vegetation development, from almost bare peat, in the sites most recently harvested to broadleaved woodland on the sites which had been harvested for some time. This heterogeneity, superimposed on the inherent variability in peat properties, will require management strategies ranging from the conservation of natural or semi-natural stands of broadleaves to site specific establishment techniques for commercial plantations.

Over the next five years or so, it is anticipated that the annual area becoming available for afforestation will be relatively modest, at about 400-500 ha. It will be post-2020 before larger areas become available. In time, the total area with forestry potential has been estimated by Bord na Móna to be between 16,000 and 20,000 ha. This area obviously excludes all cutaways which are currently being pumped to expel excess water or those which will not be drainable when they are taken out of production. However, even suitable cutaway units contain small areas which will not be suitable for forestry. This is to be expected as pockets of deep peat may be too wet for trees to successfully establish and perhaps might better serve as potential biodiversity, amenity, or wetland areas.

Inherent difficulties

Industrial cutaway peatlands are flat, bare, windswept areas and, at first glance, they appear to offer a uniform and relatively easy medium for afforestation. However, site conditions after peat harvesting has ceased are usually far from optimal for tree growth.

In order to understand these inherent difficulties, the formation of these raised bogs should be examined. As the ice retreated, some 11,000 years ago, the landscape of the midlands was characterised by glacial formations (eskers, drumlins) which impeded drainage and as a consequence, shallow lakes were formed. Most of these lakes became overgrown with aquatic plants over a short period. There was insufficient oxygen in the lake water to allow full decomposition, so partly decomposed plant litter accumulated to form peat. Given the right climate, hydrology and physiography, this basal fen peat (identifiable by the presence of macrofossils of the common reed (*Phragmites australis*) and the saw sedge (*Cladium mariscus*)) and the mosses growing on it, acted as water reservoirs, leading to an increasingly high water table. Over many millennia, peat accumulated in a dome shape above the influence of the inflowing mineral water and was supplied only by rain water. A raised bog was thus formed, dominated by *Sphagnum* moss. Initially, ombrotrophic (rain-fed) peat development was confined to swamp and fen areas, but in time it extended beyond the confines of the enclosed basins and onto the surrounding moraine.

Consequently, a cutaway peatland can display different kinds of peat/sub-peat mineral soil combinations depending on the original development of the bog. In a typical cutaway peat profile in the Irish midlands, the layer of ombrotrophic peat (*Sphagnum* or *Calluna* dominant) is either absent or very shallow, and it overlays minerotrophic peat (*Phragmites* peat or woody fen peat). Lake marl, blue clay or unweathered till are often found underlying the *Phragmites* peat, while silty clay and weathered till are found beneath woody fen peat. Because of the way in which the ice retreated, the sub-peat mineral soil present at the bottom of the peat layer undulates. The horizontal removal (through milling) of peat formed over a rolling terrain means that the remaining peat depth can vary greatly over short distances.

The variety of peat profiles across the 200 ha of the BOGFOR experiments confirms this heterogeneity of cutaways and the complexity of the reclamation process for forestry. The sites investigated have a peat thickness varying from 0 to over 2 m. Shallower and more homogeneous peat depths are found where the sub-peat mineral soil is clay, silt or sand. This is because the surface of glacio-fluvial clay, silt and sand deposits is more even and allows peat to be harvested closer to the surface of the sub-peat mineral soil. On the other hand, glacial drift can contain boulders of varying shape and size which can prevent further milling when exposed at the surface. As a result of this variation in thickness, the peat in which the trees are planted has variable properties over short distances, especially nutrient availability.

At another level, the combination of peat type and sub-peat mineral soil can present drainage difficulties. Following the cessation of peat harvesting, waterlogging will occur on most cutaways. To help ameliorate this situation, two aspects need to be considered: (i) the depth to which the level of the water table needs to be reduced, and (ii) the duration of drain maintenance that will be required. *Sphagnum* peat, particularly humified *Sphagnum* and deep *Phragmites* peat are more likely to be difficult to drain than a woody fen, which has a better pore size distribution and a higher non-capillary pore content and therefore a higher conductivity. As local drainage conditions typically vary within a site, depending on the bottom contour of the cutaway, test pit observations may be used to measure the state and movement of the water at different points. Before planning any new drainage system, input from those with the experience and knowledge of the locality should be sought.

Site suitability for commercial afforestation

Cutaway peatlands are highly spatially variable in terms of peat type, peat depth and hydro-physical properties and consequently in their tree productivity. From the BOGFOR trials, woody fen was found to be the most favourable site types for commercial afforestation, followed by *Phragmites* peat with a deep aerated peat layer. Deep *Sphagnum* peat sites (>1 m) were problematic for the growth of all species except the pines. The nutrient status of both Norway and Sitka spruce stands established in the late 1980s on *Sphagnum* peat, deteriorated over time with trees suffering from P deficiency before reaching 10 years of age (Renou-Wilson and Farrell 2007b). Wherever afforestation was successful, the sites displayed an adequate drainage system (i.e. suitable gradient and outlet leading to low water table all year around). Good drainage signifies an aerated medium. It was clear from the investigation of several sites over long periods that tree growth was positively correlated with the depth of aerated peat (Figure 1). Percentage aeration was measured in the field using the technique of rusting of steel rods (Carnell and Anderson 1986) as well as visual observations. Because a cutaway area will often display several combinations of site factors, the forester needs to assess the general quality of a cutaway site in order to test its suitability for afforestation.

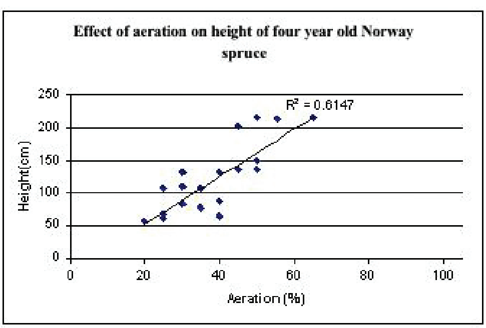

Figure 1: *Effect of percentage of aerated peat (total depth, 1 m) on the height of four year-old Norway spruce on cutaway midland peat.*

Table 1 provides a list of site indicators which can be used to assess the quality of a cutaway peatlands. The more 'good' qualities a site has, the greater is its forestry potential.

Table 1: *Indicators of site quality for the afforestation of cutaway peatland.*

	Quality scale	
Factor	Poor	Good
Drainage system	High water table with waterlogged areas	Low water table and drains cut into mineral soil
Aeration of peat	Orange/brown, anaerobic peat with H^2S smell	Dark brown aerated peat
Peat structure	Massive, dense	Granular
Exposure	Open, windswept land	Presence of wind barrier (e.g. older plantation)
Vegetation	Bare	Grass and shrubs

For site selection purposes, a detailed site survey is required. Soil characteristics (e.g. peat type, peat depth, sub-peat deposits, and permeability), hydrology (e.g. presence of outfall drains), climatic data (e.g. late spring frost frequency tables) and ecological features (e.g. vegetation) should be recorded for each site. Typically, peat depth and peat type should be sampled every 0.25 ha and drainage status should be determined under various weather situations (preferably during the winter). It is important that this database is dynamic, due to the difficulties with the phased timing of the peat fields becoming abandoned within a bog unit. While part of a cutaway may be withdrawn from milled peat production, it may not be available for afforestation for five years or more due to its location within the bog unit. During this time, natural vegetation may start colonising and drain infrastructure may start breaking down, creating waterlogged areas which then become unsuitable for afforestation.

Correct site appraisal is critical to the success of the forest enterprise, as it will provide reliable information which will help in the selection of management options, for example, site preparation and choice of species.

Species performance

While there is still little knowledge of the long-term performance of various species on cutaway peatlands, survival and growth results of a range of species tested in the field (Table 2) indicate that the following species can be generally regarded as suitable: Norway spruce, Sitka spruce (under a nurse crop), Scots pine, Corsican pine, hybrid larch, pedunculate oak, silver and common birch and common alder (see Table 2 for scientific names).

Table 2: *Species tested within the BOGFOR programme.*

Broadleaves	English name	Abbreviation	Latin name		Comments
Alder	Common alder	C. al	*Alnus glutinosa*	Native	Successful
	Italian alder	I. al	*Alnus cordata*		Successful
Ash	Common ash	Ash	*Fraxinus excelsior*	Native	Unsuccessful
Aspen	Aspen	Asp	*Populus tremula*	Native	Unsuccessful
Beech	European beech	Be	*Fagus sylvatica*		Unsuccessful
Birch	Silver birch	S. bir	*Betula pendula*	Native	Successful
	Downy birch	D. bir	*Betula pubescens*	Native	Successful, but not as good as Silver birch
Oak	Pedunculate oak	P. oak	*Quercus robur*	Native	Promising, under nurse crop especially
	Sessile oak	S. oak	*Quercus petraea*	Native	Unsuccessful
Poplar	Poplar	Pop	*Populus Beaupré*		Unsucessful
Maple	Norway maple	Map	*Acer plantanoides*		Unsuccessful
Sycamore	Sycamore	Syc	*Acer pseudoplatanus*		Unsuccessful
Conifers					
Larch	Hybrid larch	HL	*larix x eurolepis*		Successful, on dry sites only
	Japanese larch	HL	*Larix kaempferi*		Promising
Pine	Corsican pine	CP	*Pinus nigra var. maritima*		Successful
	Lodgepole pine	LP	*Pinus contorta*		Successful, but prone to Pine Shoot Moth
	Macedonian pine	PP	*Pinus peuce*		Successful
	Scots pine	SP	*Pinus sylvestris*	Native	Successful
Spruce	Norway spruce	NS	*Picea abies*		Successful
	Sitka spruce	SS	*Picea Sitchensis*		Successful, under nurse crop only
Cedar	Western red cedar	WRC	*Thuja plicata*		Unsuccessful, except in very dry sites
Yew	Irish yew	Y	*Taxus baccata*	Native	Unsuccessful

Field trial results

Since site conditions greatly affect tree growth, species trial results varied greatly across the range of sites investigated within the project. Filling-in was carried out after the first growing season only. Three site types are discussed below.

Site type	*General site description*
1	*Phragmites peat with both deep and shallow areas and good gravity drainage.*
2	*Woody fen peat, with both deep and shallow areas, good drainage and good aeration.*
3	*Sphagnum over Phragmites peat, mostly deep peat, good surface drainage but limited aeration.*

Site type 1 (Blackwater cutaway bog): Phragmites peat with both deep and shallow areas and good gravity drainage

The survival of all the broadleaved species was excellent after the first (>90%) and fourth year (100%) (Figure 2). Silver birch and common alder were the tallest trees after four years and had the greatest growth rate (Figure 2). Silver birch performed better than downy birch at this site. Sessile oak suffered from leader die-back and, like sycamore and ash, growth was disappointing. Aspen was the third fastest growing species after alder and silver birch. All the aspen, birch and alder trees were very healthy.

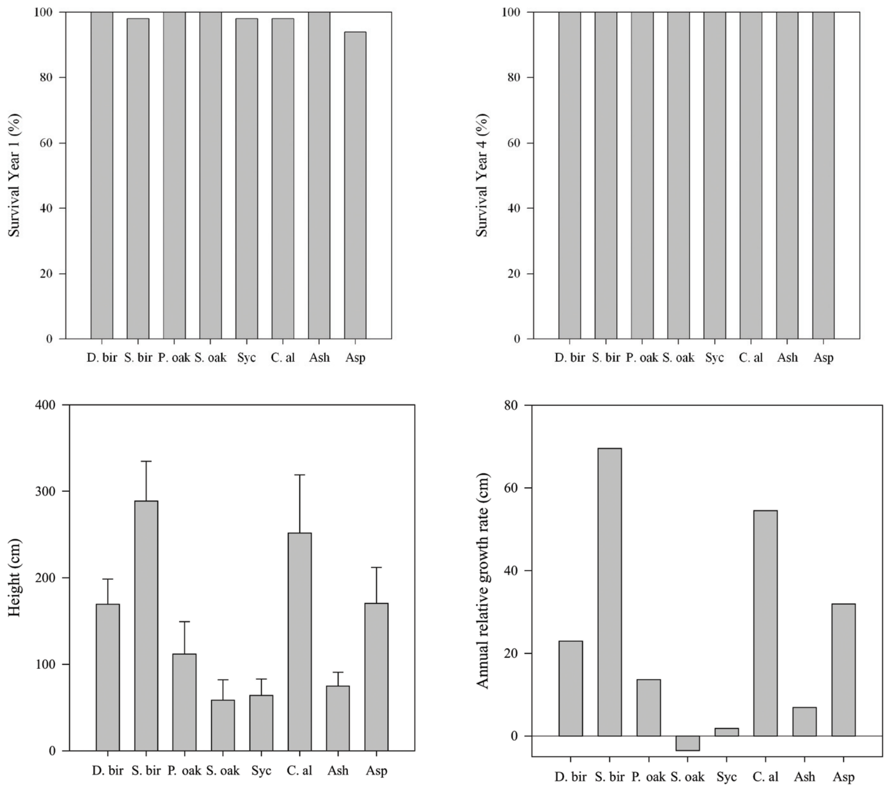

Figure 2: *Survival and height after four growing seasons and annual relative height growth rate of broadleaves at Blackwater cutaway bog (see Table 2 for species abbreviations).*

The survival of all conifer species in this trial was also excellent after one (>80%) and four years (95%) (Figure 3). Hybrid larch and western red cedar were the tallest conifers growing on this site (Figure 3) after four years. Of the pine species, Corsican and Scots pine displayed remarkable growth and were very healthy. Yew survived well, and is still growing, but all trees are in very poor condition.

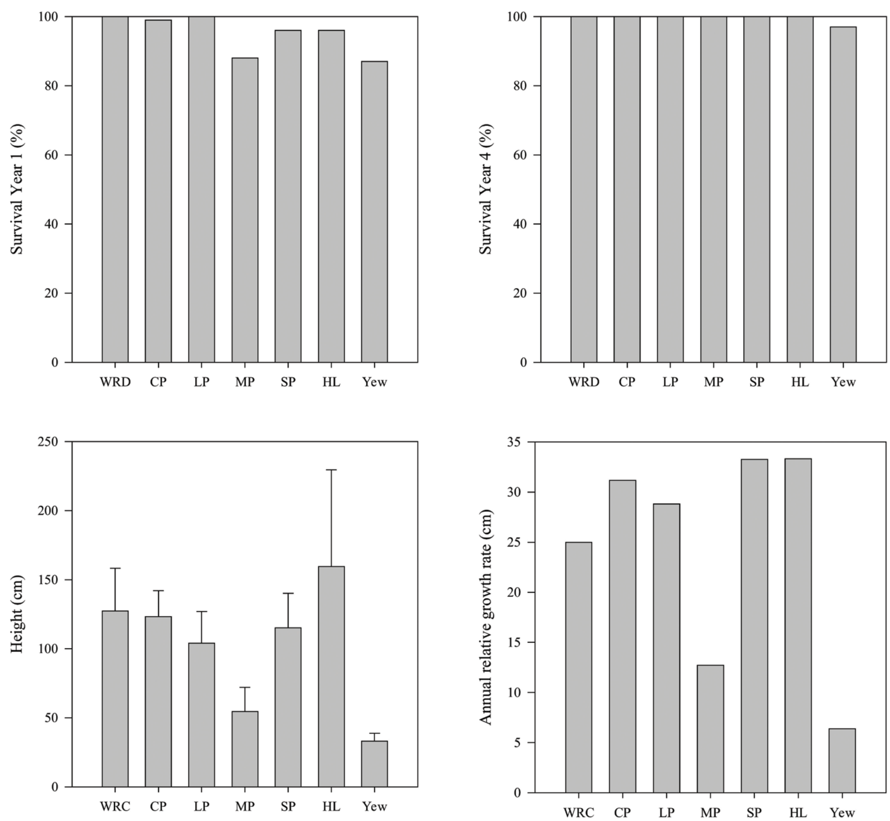

Figure 3: *Survival and height after four growing seasons and annual relative height growth rate of conifers at Blackwater cutaway bog (see Table 2 for species abbreviations).*

<u>Site type 2 (Mount Lucas cutaway bog): woody fen peat, with both deep and shallow areas, good drainage and good aeration</u>

Survival rates of all broadleaved species were good after one year (>90%) but decreased subsequently, especially in beech (Figure 4). Sessile oak, beech and sycamore suffered severely from leader die-back, and although many trees were alive, almost all had lost their leading shoots. Norway maple growth was also mediocre. Poplar and common alder were the tallest broadleaves (Figure 4). Relative to height at planting, common alder had almost double the relative growth rate (RGR) of the Italian alder.

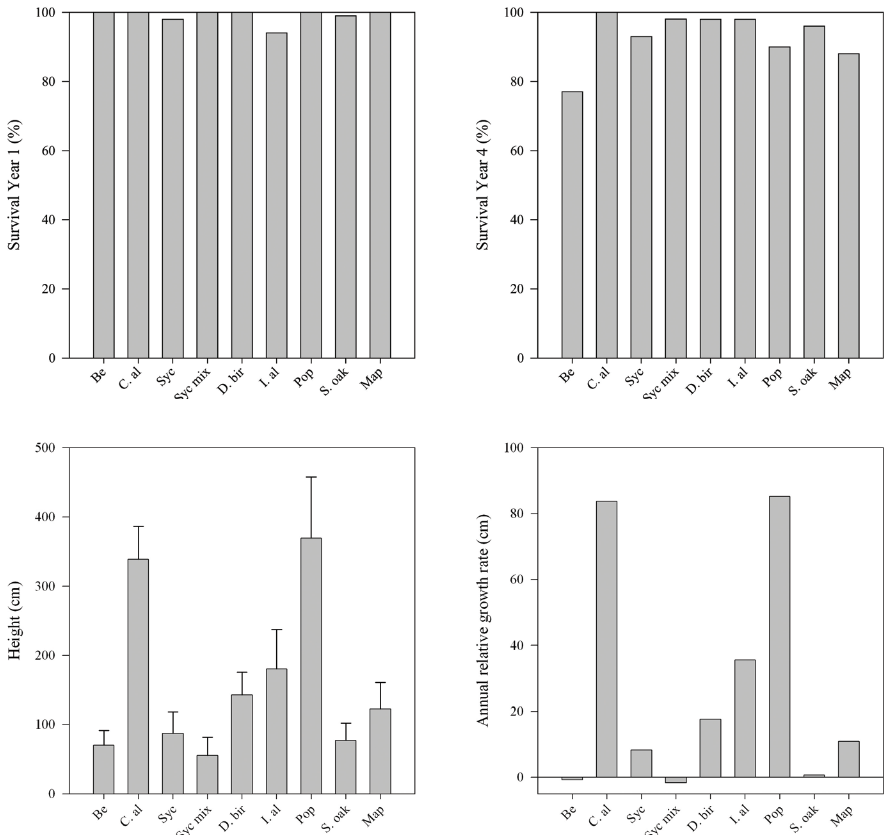

Figure 4: *Survival and height after four growing seasons and annual relative height growth rate of several species of broadleaves in Mount Lucas cutaway bog (see Table 2 for species abbreviations).*

All conifer species survived well at Mount Lucas (>90%), except for hybrid larch which had only 18% survival after one year (Figure 5). Subsequently, one plot was replanted with alder and the second plot filled-in with hybrid larch. The latter had 65% survival after three growing seasons and grew reasonably well. Corsican pine and Scots pine displayed the highest growth rate over the four-year recording period and were very healthy (Figure 5). Western red cedar had also good growth. Yew had good survival but height growth rates were low.

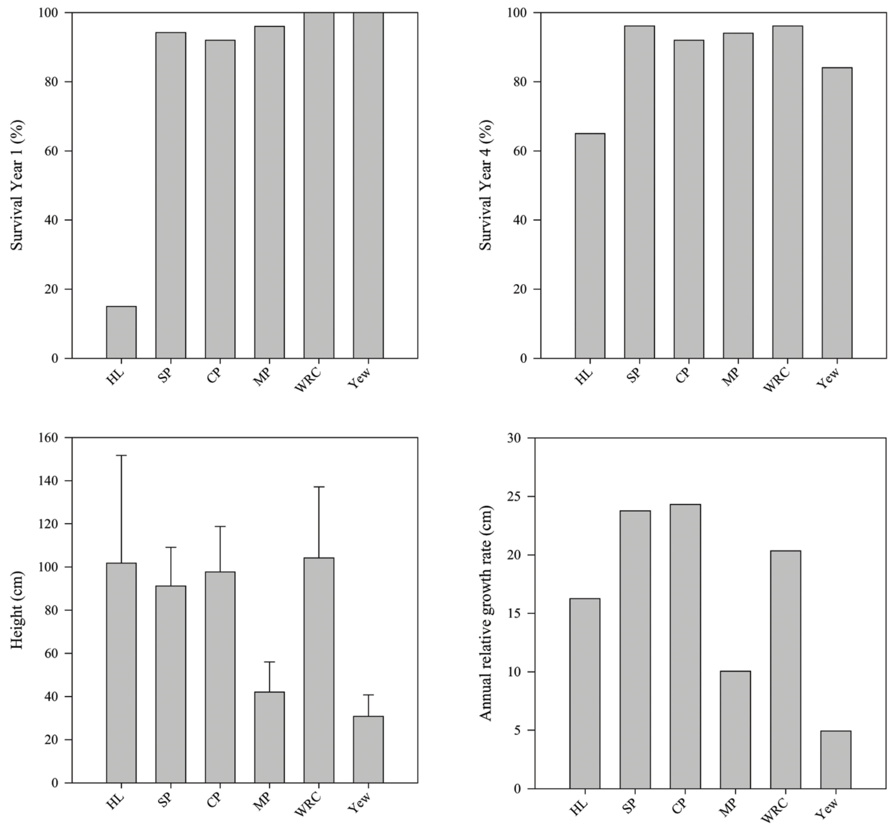

Figure 5: *Survival and height after 4 years and annual relative growth rate of conifers planted at Mount Lucas cutaway bog (see Table 2 for species abbreviations).*

<u>Site type 3 (Tumduff cutaway bog): Sphagnum over Phragmites peat, mostly deep peat, good surface drainage but limited aeration</u>

All species, except Japanese larch, had average survival rates above 75% after year one (Figure 6). Japanese larch performed poorly on this site (less than 20% survival), probably due to wet ground conditions. Sitka spruce height growth was double that of Norway spruce but not as good as most pine species (Figure 6). Corsican pine was the tallest and had the greatest annual RGR. All the four pine species looked healthy after four years growth. Western red cedar was severely damaged by hares as well as being prone to disease. The low height growth is also likely to be the result of winter desiccation damage. Severe leader loss meant that most of these trees were smaller after four growing seasons than after the first year. Many trees, especially the spruce, appeared to be suffering from heather check (Carey 1977).

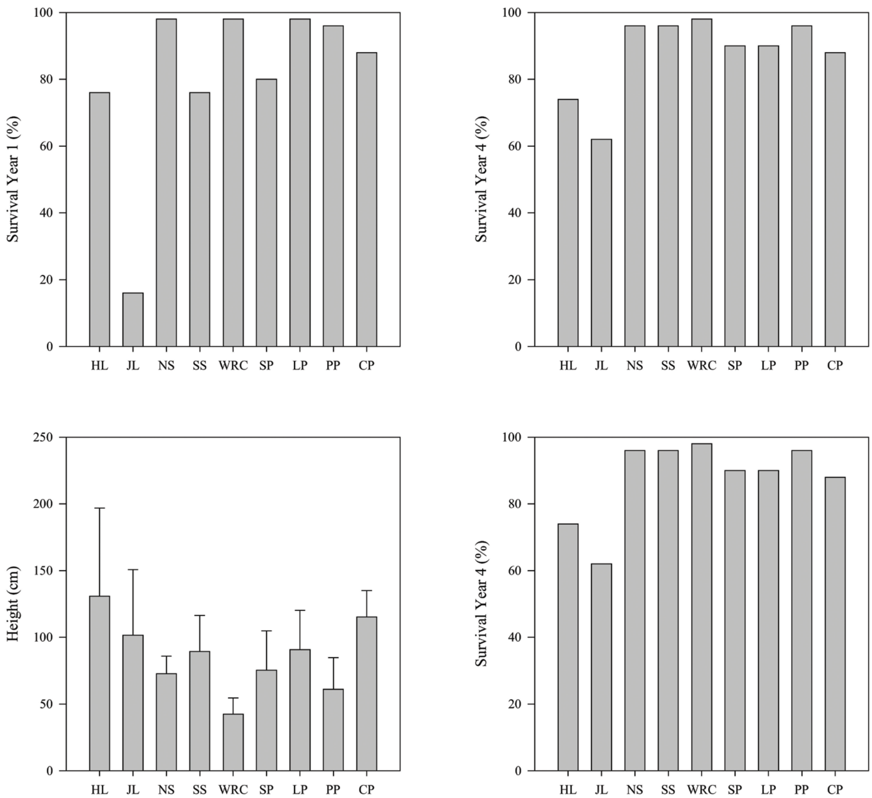

Figure 6: *Survival and height after four growing seasons and annual relative growth rate of several species planted at Tumduff cutaway bog (see Table 2 for species abbreviations).*

Species notes

Norway spruce and Sitka spruce

Data from the BOGFOR field trials suggest that Norway spruce is the species best suited to commercial forest production on the cutaways. The main reason why it should be selected in preference to Sitka spruce is its reduced susceptibility to late spring frost damage. Even within crops of Norway spruce, however, it is very evident that early flushing individuals are more prone to frost damage and are generally not as tall as trees which flush later. Late-flushing provenance material should be used to reduce the risk of frost damage. The best provenances of Norway spruce for use on the midland cutaways are from central Europe – Poland, the Czech Republic and possibly Slovakia which combine late flushing with good growth. Survival rates for Norway spruce were reduced in very exposed sites. Older plots of Norway spruce growing on cutaway peatlands have developed healthy, well-formed canopies and are fairly uniform in size.

In the BOGFOR field trials, the best Sitka spruce growth was recorded under self-sown birch. The key to the success of this system, however, is the timely and effective removal of the 'whipping' birch once its sheltering effect is no longer required. Sitka spruce can thrive on cutaway peatlands, but there is a higher risk of damage from late spring frost than with other species. Therefore, Sitka spruce should not be planted on cutaway peatlands without shelter from a nurse crop. Differences in date of bud flushing among provenances of Sitka spruce are insufficient to provide the potential to reduce damage levels through provenance selection (Thompson et al. 2005).

Pines

In the 1980s and early 1990s, lodgepole pine was the second most commonly planted species on the cutaways. Although considered a low risk choice, because of the low risk of spring frost damage and its low nutrient demand, it rarely produces high-value material. The incidence of pine shoot moth in many Irish midlands sites is an added problem, so the species is now ranked lower on the recommendation list.

Scots pine is a good pioneer species for the cutaway peatlands, especially on the poorest acidic sites. It is very frost-hardy and could be used as a nurse species. Stem form tends to be poor and tree health can deteriorate very quickly on very exposed sites. On suitable sites however, it can produce higher growth rates than spruce and other pine species. The best establishment success is likely to be achieved using small planting stock. Because Scots pine is a strong light-demander, good vegetation control is required to maximise field performance. Scots pine is less susceptible to pine shoot moth than lodgepole pine but will get infested if there are high infestation levels in area. Several older plantations on cutaway peatlands have suffered from unexpected die-off for no obvious reasons, so careful monitoring of established plantations is recommended to confirm the usefulness of this species on cutaways.

As well as having all the advantages of Scots pine, Corsican pine has the added attribute of tolerating exposure quite well. It also tends to produce straighter stems than Scots pine. It is less liable to be attacked by hares and rabbits and also shows resistance to damage from pine shoot moth. In order to ensure satisfactory survival, it is recommended to use containerised stock planted during late spring/early summer. Corsican pine has a role on cutaway peatlands but long-term monitoring is required to verify its performance potential beyond the juvenile phase.

Macedonian pine survived very well on cutaway peatlands but displayed slow growth compared to Scots and Corsican pine. Vegetation control may be required for up to four years after planting. It has two major advantages: firstly it is a good pioneer species with a well-developed deep root system. This means that it can, in effect, improve raw deep peat soils. Secondly, Macedonian pine appears to be attacked by fewer insects than other pines. Growth rate usually increases after 6-10 years, making this species particularly promising for cutaways.

Larch

Both hybrid and Japanese larch displayed the lowest survival rates of all the planted species, but there was much variation among and within sites. As the dwarf-shoot buds flush very early in season, hot-planting (i.e. planting the seedlings immediately after being lifted from the nursery beds) should be completed by early March. However, planting directly in cold wet conditions has resulted in high plant mortality. Larch has also suffered from late spring frost damage. The use of containerised larch offers the opportunity to delay planting until the risk of frost is reduced. Containerised seedlings are likely to grow more quickly, so they may emerge above the frost layer sooner.

On well-drained woody fen peat, both larch species grew very fast but, as expected, hybrid larch was the more productive. This rapid early growth makes it very useful as a nurse species. While its use may be limited, its growth is sufficiently promising to justify further planting on appropriate sites. Generally, waterlogged areas and frost hollows are unsuitable for larch. It should also be avoided on shallow peat soils.

Western red cedar

Great variations in growth were encountered with this species across different sites. Western red cedar seemed to suffer adversely from wind exposure (discolouration and reduced needle size) as well as browsing damage which render it unsuitable for planting on most cutaway peatland sites. On more sheltered sites, best development is probably to be expected on shallower peat sites.

Oak

Of the two native oak species, sessile oak is less suitable for cutaway peatlands. Pedunculate oak has shown potential on some areas, particularly those which are relatively fertile and sheltered from exposure (Renou-Wilson et al. 2008b). Exposure is a big problem on the cutaway peatlands, and when severe, oak can suffer from critical leader die-back. In our field trials, however, oak grew back quite well once other species had established around it. It is thus preferable to grow oak in mixture with a fast-growing species, but considerations should be given to the mixture species and spacing. Oak is not suitable in frost hollows, on poorly drained peat, very infertile peat and very shallow peat where the sub-peat mineral soil is essentially unweathered. In addition to the above factors, a hare-proof fence is essential if the species is to grow well on cutaway peatlands.

Birch

Birch species had high survival rates and established quickly on cutaway peatlands (Renou et al. 2007). Of the two native species B. *pendula* is the superior species, displaying both quick growth and reasonable form. In all cases, browsing and vegetation competition will need to be controlled, especially if small seedlings are planted. Birch is a pioneer, and as such, is a key species in ecosystem development which can broaden options for future uses of the cutaways, such as for biomass production.

Alder

Of all species planted on cutaway peatlands, common alder has been the most productive. Unlike all other species, it also demonstrated a relatively uniform growth over different site types. Alder grew well on acidic peat but also on the more shallow woody fens. It did not suffer from exposure and because of its fast early growth, very little vegetation control was required. As with all broadleaves, it requires adequate protection against hares. Alder is probably the best species with which to quickly establish forest cover or shelter on cutaway peatlands. It has soil-improving attributes due to its vigorous fibrous root system and its capacity to fix atmospheric nitrogen. This makes alder a particularly useful nurse species for growing in mixture with more commercial species such as spruce (Schaible 1992). Because of its coppicing ability, alder can also play a role in biomass production.

<u>Other species tested on cutaways</u>
Aspen and ash showed relatively good (but slow) growth rates and neither can be excluded as potentially suitable for planting on cutaways. Both sycamore and beech are unsuited to cutaway peatlands where they suffered high levels of mortality, apparently due to late spring frosts and exposure damage. In particular, they performed poorly on very acidic *Sphagnum* peat. Beech is also very susceptible to browsing by hares. Although not considered a commercial species, yew survived on all sites but its growth rate was very low. It may, however, have a role to play as part of a native woodland scheme or for biodiversity.

Notes on tree establishment
Early results from field trials showed that direct seeding of birch or alder was not successful; shelter and fertilisation seem to be critical to improve emergence and survival. Planting seedlings from cold storage in April/May is likely to be successful on such sites. Later planting would delay fertilisation which has been found to be environmentally detrimental in terms of nutrient leaching (Renou-Wilson et al. 2008a).

It has been ascertained that the application of phosphatic fertiliser is critical for the survival of new plantations on cutaway peatlands. Research to determine the optimum fertiliser levels for various peatland types have been the subject of a number of studies (Carey et al. 1985, Renou and Farrell 2004, Renou-Wilson and Farrell 2007a, Kaunisto and Aro 1996) but are beyond the scope of this paper. Some other BOGFOR research work carried out on Norway spruce stock on a cutaway site showed that good quality small bare-root or containerised seedlings had greater growth rates than large bare-root stock (Renou-Wilson et al. 2008a).

Protection of broadleaves from hares is critical, so fences must be well maintained throughout the first three years following planting.
Norway spruce, Sitka spruce and oak performed best when planted under nurse crops of birch, alder or hybrid larch but attention must be given to subsequent management (e.g., timely vegetation control and pruning of a whipping nurse crop). Any nurse crop (natural or planted) should reach a sufficient height (5 m tall) and density before underplanting.

Conclusion
The results of the BOGFOR project showed that a wide range of conifer and broadleaved species were suitable for planting on cutaway peatlands. This means that the forester has the opportunity to create a range of forest types, most of which

are likely to be ecologically sustainable and varied landscapes with the potential to provide other options at a later date. The variation in site conditions encountered in any given cutaway peatland means that, not one, but several species might flourish within a given area.

It is important that the monitoring of the BOGFOR trials and demonstration areas should be continued to verify the promising early findings. A phased approach to the afforestation of cutaways peatlands is needed, with due consideration to wider land-use issues.

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Developing a site classification system to assess the impact of climate change on species selection in Ireland

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Abstract

Correct matching of tree species to site is the first and most fundamental step in sustainable forest management. This key art, practised by foresters over centuries, was neglected in Britain and Ireland during a period of rapid forest expansion in the mid to late 20th century. The period of expansion was dominated by intensive site amelioration to plant a small number of chosen species. Forestry has matured to recognise sustainable management as key to the delivery of multiple values to society. Site classification can be used to re-establish the link between site type and species choice, and multifactor classification systems are currently used by forest practitioners in different countries. Since 2001, Ecological Site Classification (ESC) has provided support on ecological suitability analysis and site yield estimation for forest managers in Britain. Recently it has been extended to consider changes in suitability and yield resulting from different climate change scenario projections.

We are now developing a similar system for site/species suitability analysis in Ireland in the CLIMADAPT project, which is part of the CLIM-IT programme funded by COFORD. CLIMADAPT will develop a decision support methodology, similar to ESC, using soil and climatic information for Ireland. The paper discusses the stand-based and spatial analysis modules within CLIMADAPT. Spatial information is useful for strategic decision making, and stand-based analysis is appropriate for operational decisions. CLIMADAPT will be delivered as a web-application, to allow wide access to practitioners in Ireland.

Future climate projections suggest warmer, drier summers in the south and east of Ireland. This may affect growth and yield for drought sensitive species such as spruce, beech and ash. The project is also investigating the degree to which climate variables affect drought sensitive and drought tolerant species along a climatic gradient through Ireland and Britain. Knowledge and information about changes in species suitability, species tolerance and forest management adaptation will be incorporated within the decision support tool.

Keywords

Ecological classification, forest classification, adaptation, climate change, web applications, knowledge-based models, species choice

Background

A key decision in forestry, which has a bearing on subsequent sustainable forest management opportunities, is choosing the right tree species for a site. For example, poor species choice reduces establishment success (Perks et al. 2007), and leads to poor growth (Pyatt et al. 2001), poor form and low timber quality (MacDonald and

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Hubert 2002), and stressed trees frequently suffer from increased incidence of damage from pests and diseases (Evans et al. 2002).

The ability of the forester to recognise site conditions and select well suited tree species is of fundamental importance. Throughout the middle to later part of the 20th century commercial forestry objectives tended to be ranked most highly, prompted by government forest policy that favoured single species, even-aged conifer forest. Forest expansion was, mainly driven by the state sector and focussed largely on fast growing conifer species from the Pacific North West – in particular Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and lodgepole pine (*Pinus contorta* Douglas ex Loudon). The acquisition of land for forestry in Ireland was hampered by a policy which set strict upper limits to the value of land which could qualify (Joyce et al. 1998). The poor quality of land available at such a low price resulted in afforestation being predominantly comprised of coniferous species capable of growing on poor and wet sites. It was necessary to adjust site conditions through ground preparation and fertilization to ensure growth on the marginal land that was less valuable for agriculture (Ray and Broome 2003). The sequence of events paved the way for a generation of forest managers practised in this form of commercial forestry, and the skill of selecting species according to site type declined.

Policy targets for forest cover in Ireland date back to 1948 when a forest cover of 1 million acres, to be achieved by an annual planting programme of 25,000 acres (10,000 ha) was agreed in a bid to start a reforestation policy in Ireland, and reduce the reliance on wood imports (OCarroll 2004).

Since the introduction of the afforestation grants and premium scheme in the mid 1980s, more than 250,000 ha has been established over the period 1990 to 2006 (Black et al. in press). Rapid expansion in the private sector, and changes in the conditions of the forestry grant and the premium schemes have resulted in an increase in broadleaf cover since the 1990s. Recent National Forest Inventory data suggest that 24% of the forest estate is comprised of broadleaves (NFI 2007).

Forests have a role to play in sequestering carbon dioxide from the atmosphere, and so recent incentives have been offered to encourage forest expansion. The Irish Government has committed to expanding 'Kyoto forests' that will contribute towards the emissions reduction targets as outlined in the National Climate Change Strategy (NCCS) 2007-2012. It has also been recognised (Black 2008, Malone 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 attractive. 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). 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 2008b, 2008a, Ray et al. 2008). Forests planted now will grow and mature through a period of unprecedented climate change. Therefore the new challenge of site classification systems is to assist and support robust species choice and silvicultural systems to minimise the negative effects of climate change on forests and forest ecosystems, as well as other goods and services that forests provide to society.

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 (see examples in Ellenberg 1988). However, in Ireland (as in Britain) very little of the natural forest cover remains due to clearance, which started about 5500 BP (Cross 2006), and resulted in a woodland cover of only 1% of the land area at the beginning of the 20th century (Rackham 1986). A recent estimate of native woodland by the Forest Service (Higgins et al. 2004) indicated less than 0.8% of the land area had native woodland cover, and all was highly modified.

In Britain, work on Ecological Site Classification (ESC) began in 1992. The project was conceived following a study tour of British Columbia where the Biogeoclimatic Ecosystem Classification (BEC) system is used to classify natural forests (Krajina 1969, Pojar et al. 1987, Klinka et al. 1989). The ESC method (Pyatt et al. 2001, Ray 2001) was adapted to suit the site classification of species of tree in plantation forests, and to classify the semi-natural woodland types described in the National Vegetation Classification (Rodwell 1991).

The approach in Germany, of adapting forestry to site conditions, was described as Forstgesellschaft (planted forest communities) by Ellenberg (1988). Similar approaches have been suggested for use in Britain (Anderson 1950, Anderson and Fairbairn 1955), and indeed multi-factor site classifications have been developed in Germany (Wagenknecht et al. 1956), Finland (Kuusipalo 1985) and later in France (Rameau et al. 1993), and the US (Barnes et al. 1982, Cleland et al. 1993) which also classifies managed and highly modified forest types.

ESC methodology took shape over four years and the project was expanded in 1996, in order to develop ESC as a computer-based decision support system (DSS) tool. A focus was the developing policy for sustainable forestry following the 1992 Earth Summit (Anon 1992), and the vision was a user-friendly computer DSS system that could deliver the complex methodology of ESC, allowing users to assess the ecological suitability of alternative forest planning options. It was envisaged that the development of ESC-DSS would provide a core planning tool for species choice, and would provide a stimulus for linked modules to help guide forest managers and planners by indicating the likely effects of management on forest ecology. ESC was also deployed on a GIS system (Clare and Ray 2001, Ray and Broome 2003, Ray et al. 2003) and has since been used to assess the impacts of projected climate change scenarios on species suitability (Ray et al. 2002, Broadmeadow and Ray 2005, Broadmeadow et al. 2005, Ray 2008b, 2008a). 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 dynamic coupling between climate and soil factors, to accommodate adjustments in soil moisture and nutrient supply in projected future climates.

This paper describes the spatial and site-based components of the CLIMADAPT decision support tool. The spatial system uses digital soil data and is useful for strategic planning, whereas the stand-based system can be used to help select species for a site, based on information surveyed at that site. Both are based on the ESC methodology, and provide an assessment of species choice in the projected changing climate of Ireland.

Methods

CLIMADAPT concept

Plans for a computer-based site classification system for Ireland were included in a research programme to investigate and develop climate change mitigation and adaptation options. It is important to consider the interaction between the impacts of climate change, adaptation for sustainable forestry and mitigation options. Future climate change policies and actions should consider all of these factors.

Multi-factor forest site classification systems, by definition, separate the effects of climatic and edaphic factors on tree species, woodland community, or forest type suitability. However, most site classification systems do not differentiate the effect of the climatic variables. For example, Flore Forestièr Française (FFF) (Rameau et al. 1993) defines major climatic zones in France to differentiate climatic effects on species suitability; the Ecosite classification system of Alberta (Beckingham and Archibald 1996) defines typical seasonal and annual climate variables for natural sub-regions. The ESC development had followed a different approach, in which the variability of climate was defined in four climatic factors: warmth (accumulated temperature - AT), droughtiness (moisture deficit - MD), wind exposure (DAMS), and continentality (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) following a similar method to those described for BEC (Pojar et al. 1987), Ecosites (Beckingham and Archibald 1996) and FFF (Rameau et al. 1993).

It is the differentiation of climatic variables that has allowed future climate projections from the scenarios described by the Intergovernmental Panel on Climate Change (IPCC) to be included in ESC. The mean monthly temperature, total rainfall and evapotranspiration projections from the Hadley Centre Regional Climate Model, published by the United Kingdom Climate Impacts Programme (UKCIP) (Hulme et al. 2002) were used to estimate future values of AT and MD, and the effect on SMR and SNR through dynamically coupled models. A similar approach was used to develop the six classification factors for CLIMADAPT based on Regional Climate Model simulations for Ireland.

The CLIMADAPT site classification system (Figure 1) offers both spatial (national and regional) assessments of species suitability based on low resolution digital data and site-based assessments of tree species suitability. Site analyses also use digital climatic data for baseline and future climate projections, supplemented by more precise site quality assessment gathered by the user, based on soil and vegetation surveys of the site type. The complete system is developed as a web-application, offering wide accessibility.

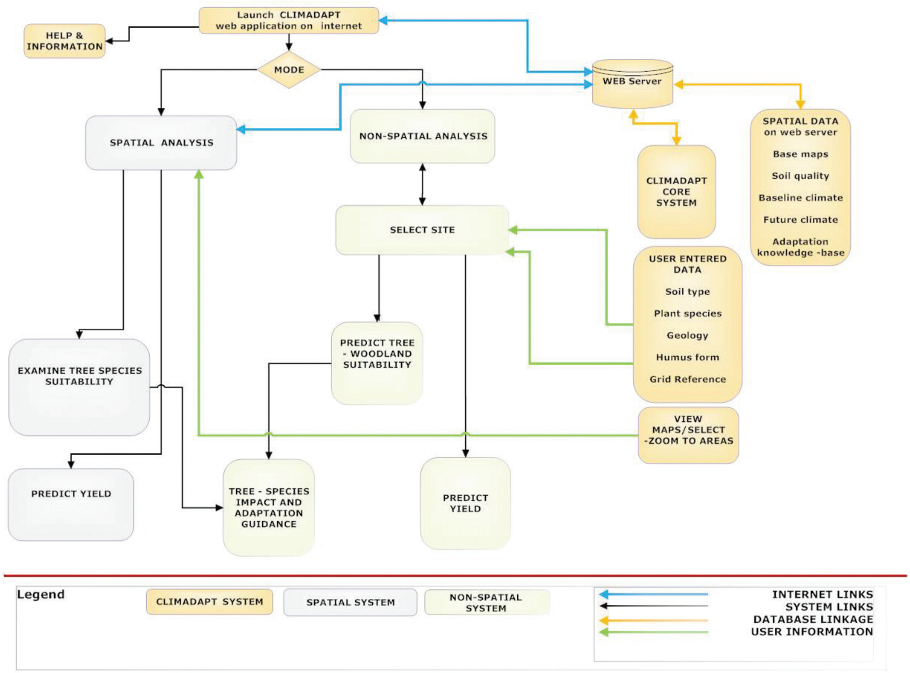


Figure 1: *Schematic overview of the CLIMADAPT site classification system showing site-based, spatial, and web-service components.*

Results

30-year period mean climate data

The CLIMADAPT baseline and future climate data for Ireland have been calculated from simulations of future climate scenarios (IPCC - A2 and B1 scenarios). The simulations are from a regional climate model (RCM) developed by the Rossby Centre in Sweden (McGrath et al. 2005). The data 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). The simulated daily mean temperatures, daily total rainfall, and daily total evaporation were 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). A relationship (Ray et al. 2002) was used to estimate actual evapotranspiration (AET) from potential evapotranspiration (PET), from which the maximum seasonal moisture deficit was calculated from mean AET and rainfall. Example spatial data representations of moisture deficit (Figure 2a-

c) show the changes associated with drier and warmer summers in the south and east of Ireland for climate simulations associated with the B1 and A2 emissions scenarios.

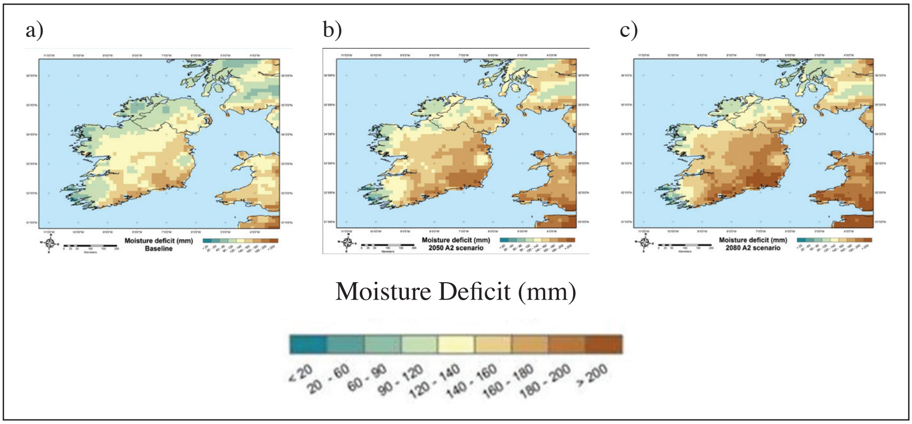


Figure 2: *Average moisture deficit (mm) for a) the Baseline Period 1961-1990, and from simulations for the 30-year climate period 2020-2050 for b) the B1 Medium-Low emissions scenario and c) the A2 Medium-High emissions scenario.*

The wind climate of Ireland was modelled using the DAMS approach (Quine and White 1993). This used a method proposed by Quine (2000) who correlated windiness scores and mean windspeed with the probability of extreme wind events and the parameters of the Weibull distribution. In developing the method for Ireland, the assumption was that the relationship between mean wind speed and the c parameter of the Weibull distribution was the same in Ireland and Britain.

Extreme climate data

The representation of climate data in all site classification systems has focussed on 'typical' or on 'average' climatic conditions, and this includes the climate data used in ESC. However, changes in climate over the last 40 years in Britain (Barnett et al. 2006, Jenkins et al. 2007) and over the last century in Ireland (McElwain and Sweeney 2003), and projections of future climate change (FAR 2007), indicate that the seasonal distribution of rainfall has changed, and is likely to continue to change, to slightly drier summers and wetter winters. 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, intense rainfall events, leading to flooding events in summer and winter. Although the CLIMADAPT site classification is based on average climate data over a 30-year period, it will include information on the projected likelihood of extreme events on tree species. This will be in the form of a database that links extreme events with sensitive species on particular site types. One example links the projected frequency of dry summers to areas of Ireland (Figure 3), thereby providing a mechanism to assess the risk of drought damage to sensitive species caused by frequent dry summers.

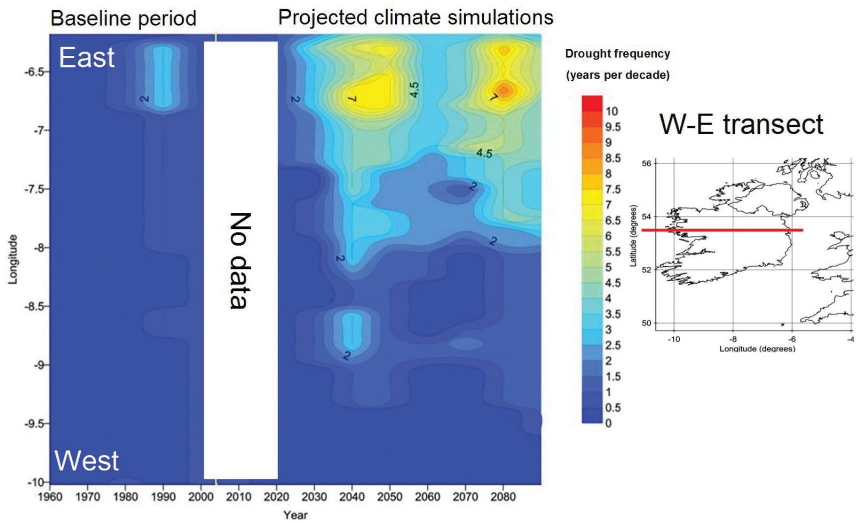


Figure 3: *The frequency of dry or droughty summers along a transect through the centre of Ireland, defined as the number of years per decade the moisture deficit is projected to equal or exceed 180 mm.*

Frost sensitivity

Many species, including Sitka spruce, are sensitive to frost. Damage can occur during the period of flushing, when young tender shoots can be damaged, but more critically in the autumn, prior to hardening following warm weather. Central Ireland is particularly prone to late spring frosts (Renou-Wilson et al. 2008), and Sitka spruce is not recommended on frost sensitive sites (Renou and Farrell 2005). Given the predominance of a mild oceanic climate over much of Ireland, the risk of frost is low for many site types, but is particularly severe on flat land in the Midlands central areas. A site classification should therefore assess the risk of frost to sensitive species, particularly since a predicted change to a warmer climate might tempt foresters to plant less hardy species.

For CLIMADAPT a method has been developed based on five topographic variables including elevation, slope, aspect, slope plan and profile curvature, as well as distance from the sea. Each variable was classified in three risk categories; low, medium and high, based on expert knowledge and literature. Slope exposure was set to high risk for East and South-East slopes, medium for North-East and South and low for North, South-West and North-West facing slopes (Day and Peace 1949). Concave and flat areas were set to high frost risk whereas convex areas were set to low risk. Also inland regions of Ireland were set to high risk with the risk decreasing when getting closer to the sea. All variables were combined to produce a tentative frost risk map (Figure 4) that compares well with the published map (Keane and Sheridan 2004) of the date of the last spring air frost, with a 2-year return period. Frost risk is not included as a constraint within CLIMADAPT, but the frost risk score for a site will be held in the database and provided to the user for information and assessment.

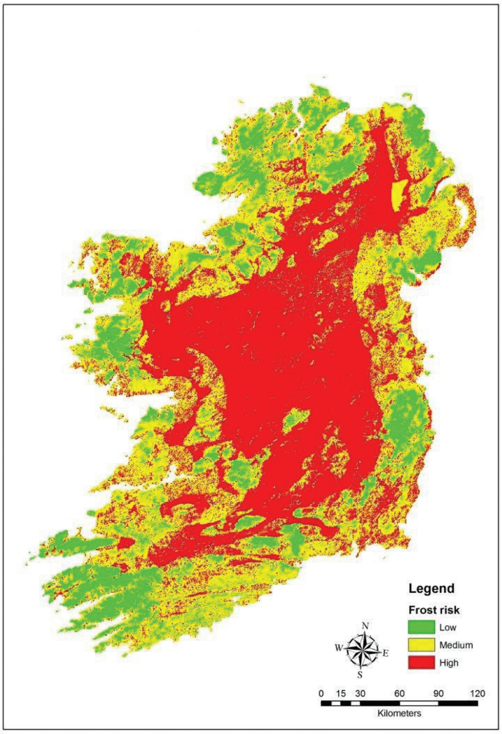
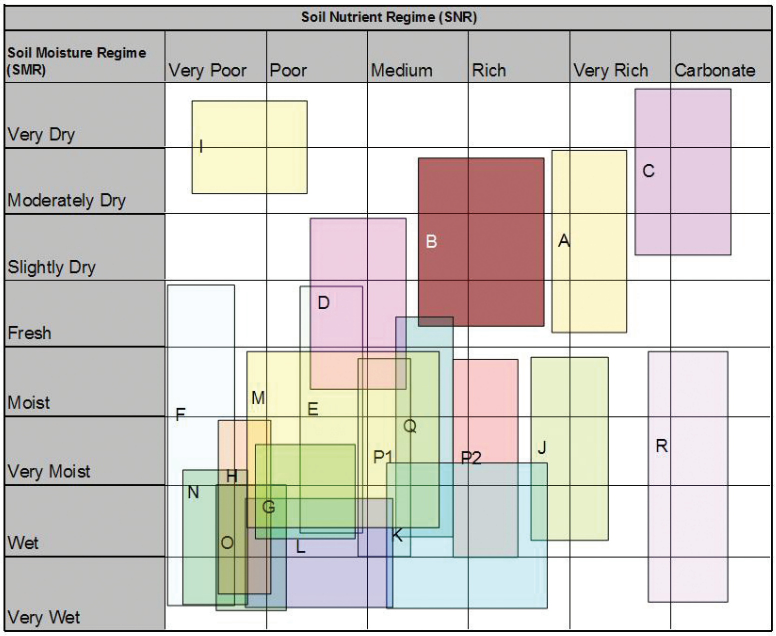


Figure 4: *Tentative map showing the distribution of damaging frosts in Ireland calculated from topographic variables.*

Soil quality

Soil fertility and water availability axes are used in CLIMADAPT to describe soil quality, in a similar way to BEC and ESC, in which axes define classes in an edatopic grid. For CLIMADAPT the soil classification follows the Irish Forest Soil Classification description in Horgan et al. (2004). This is a modified version of the site classification used by the Forestry Commission (GB) as described in ESC (Pyatt et al. 2001). At a Delphi meeting of forest soil experts in Ireland the soil types were arranged within an edatopic grid (Figure 5). The position on Soil Moisture Regime (SMR) axis of the grid follows the method described by Pyatt et al. (2001) in Tables 3 and 4. Soil Nutrient Regime (SNR) was estimated by the expert group, since the main method of positioning fertility in CLIMADAPT is through vascular indicator plants using the modified (Hill et al. 1999) R and N values originally described by Ellenberg (1988). Observations have shown that soil type assessments alone can give unreliable estimates of soil quality and that a survey of vascular plants that occur in a stand (or adjacent – in dense stands of conifers) will provide a more precise estimate.



Soil Type Description - For full descriptions see Horgan *et al.* (2004)			
A Alkaline brown earths/ grey brown podzolics	F Indurated iron-pan podzols (scrawed with heather)	K Gleys/ peaty gleys (blue grey profile fertility class B)	P1 Cutaway raised bogs (milled peat post 1980)
B Acid brown earths & brown podzolics	G Peaty podzolised gleys (organic layer present)	L Gleys - peaty gleys (fertility class C)	P2 Fen peat
C Rendzina/shallow brown earths/ shallow grey-brown podzolics	H Peaty podzolised gleys (scrawed)	M Flushed blanket peat	Q Cutaway raised bogs (hand-machine sod pre-1980)
D Podzols/peaty podzols and weak iron pans	I Lithosols	N Unflushed blanket peat and intact raised bog	R Marl
E Indurated iron-pan podzols (with furze)	J Gleys and peaty gleys (mottled) fertility class A or B	O Cutaway blanket bogs (millet peat)	

Figure 5: *The proposed edatopic grid of CLIMADAPT based on axes of soil moisture regime (SMR) and soil nutrient regime (SNR). Soil quality default values are defined by the central position of the soil type on the edatopic grid. Descriptions of each soil type are shown (Horgan et al. 2004).*

CLIMADAPT modules

The CLIMADAPT decision support tool provides two methods of access. The first is a spatial module which uses coarse resolution soil data to show the regional spatial distribution of suitable tree species, and how suitability and yield may change with climate change. The second mode of access is through a stand based module in which the user inputs information from soil and plant survey to specify more accurately site conditions. CLIMADAPT uses the survey information to show tree species suitability and yield. Here we discuss results from the development of each module.

I Spatial Module

This is accessible through a web browser and uses Google™ Map backdrops to locate points or areas of interest. The interface provides access to all of the spatial datasets used in CLIMADAPT. Spatial analyses will be useful for assessing the changes in suitability or yield of species, and in future climates, across the country or at a regional level.

Spatial soil data

The spatial component of CLIMADAPT uses digital soils and sub-soils (lithology) data generated by Teagasc with co-operation of the Forest Service, Environmental Protection Agency, and Geological Survey Ireland, from a project completed in May 2006 (see Fealy et al. 2006 and Black et al. in press). Although the spatial data has low resolution (captured from imagery at a spatial scale of 1:40,000) it does provide a useful method of assessing national and regional trends and priorities for adaptation.

Spatial suitability analysis

The suitability of different species of tree to site types was explored and developed by five experts using a modified Delphi approach (MacMillan and Marshall 2005) in Dublin during the summer of 2007. The meeting sought agreement on the threshold values of tree species suitability on each of the four climatic variables used in CLIMADAPT. Using the results of the Dublin Delphi meeting, continuous functions were developed to describe a suitability response against each climatic variable. This information was compared with existing response curves used in ESC for Britain. The correspondence between the two methods was good for most species, but poor for some. Overall suitability of a species for a site is determined by the most limiting factor; two or more favourable factors cannot compensate for one which is unfavourable.

A comparison of the ESC model output and the model developed from the Dublin Delphi process is shown for Sitka spruce in Figure 6. The AT models (Figure 6a) are very similar at the AT suitability threshold 0.5 but diverge at the Suitable/Very Suitable threshold. As a result the Dublin model sets a lower climatic warmth threshold (1050 day.degrees above 5°C) for Very Suitable compared with ESC (1250 day.degrees above 5°C). The models for moisture deficit (Figure 6b) are quite different, ESC shows a higher moisture deficit threshold between U-S and S-VS compared with the Dublin model, and this causes areas with a MD above 130 mm to be shown as unsuitable in Ireland. This difference is the main cause of the inconsistency between the models shown in Figure 7, in which large areas of eastern, central, and southern Ireland are described as either Unsuitable or Suitable compared to an ESC classification of Very Suitable or Suitable (green areas).

In view of the discrepancy between the Dublin Delphi process and the results of the Delphi experts in Britain, CLIMADAPT will incorporate the latter models as these have been tried and tested for a longer period in Britain. For Sitka spruce and lodgepole pine this is likely to be a temporary measure, as a suitability and yield validation project using point samples from the National Forest Inventory will produce empirically derived models in the near future.

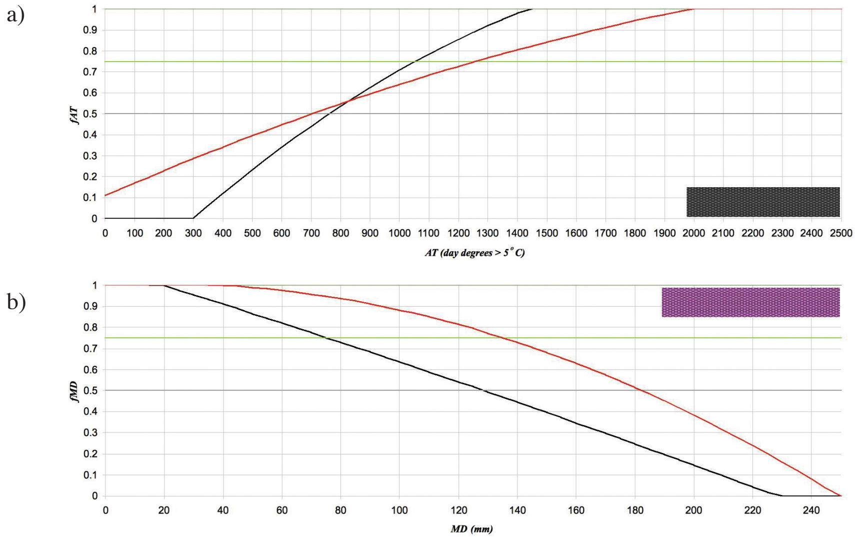


Figure 6: *A comparison of the Delphi group work in Dublin (2007) and the Ecological Site Classification expert group work in Edinburgh, Scotland (2000) to develop response curves showing the suitability of Sitka spruce according to a) Accumulated Temperature (AT - day. degrees above 5°C) and b) Moisture Deficit (MD - mm). Suitability is classified on a scale from 0 to 1, where values >= 0.75 are Very Suitable, >= 0.5 are Suitable and <0.5 are Unsuitable.*

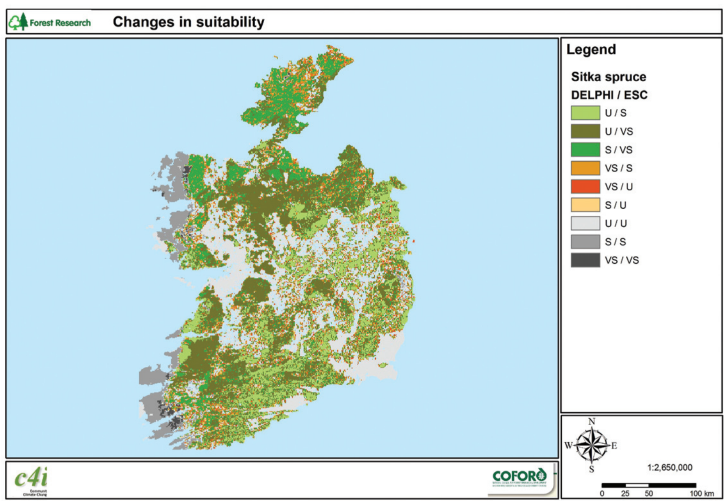


Figure 7: *A spatial comparison of the results from using different suitability models described by the Dublin Delphi group (2007) and the Edinburgh expert group for ESC (2000). The groups specified the range of AT and MD for assessing the suitability of Sitka spruce in Ireland. The map classifies areas in colour where the models show a different suitability defined by the map legend: U - Unsuitable, S - Suitable, VS - Very Suitable. Areas in which the models show the same suitability result are shown by a grey-scale.*

II Site-based module

To demonstrate the site-based version of CLIMADAPT, the suitability of Sitka spruce was assessed for the permanent sample plot at Avoca Forest, Ballinvalley, Co Wicklow. In Table 1, following a method described by Pyatt et al. (2001), data from a vascular plant survey were used to calculate the cover weighted mean Ellenberg R + N values (Hill et al. 1999), based on British conditions from associations described by Ellenberg (1988). This provides a mechanism to adjust the default SNR for a site, in which observed plant species provide information of the soil fertility (Wilson et al. 2001 and 2005). The SMR at Avoca was estimated from soil texture, rooting depth, and stoniness from soil pit observations. The method of calculating SMR in CLIMADAPT, for dry soils and wet soils, is the same as described by Pyatt et al. (2001). Table 2 includes the estimates of SMR and SNR from default digital data (as used in the spatial analysis) and from site survey. It shows how the accuracy of the CLIMADAPT site classification is improved by site investigation.

For all soil types it is important to assess rooting depth. For wet soils the anaerobic conditions of winter waterlogging may restrict rooting depth causing problems of droughtiness in the summer in soils where the water table fluctuates seasonally. For this reason, in CLIMADAPT the summer and winter seasonal SMR is calculated and used for separate suitability analyses for future climate change projections (Table 2). This is an important feature that can assess the degree to which projected changes in seasonal rainfall might affect rooting depth with consequences on summer droughtiness.

At Avoca the SMR was classed as fresh/slightly dry, from combining MD (128 mm) and available water capacity (AWC = 154 mm.m-1), using the method suggested by Pyatt et al. (2001). Slight signs of gleying resulting in orange mottles at a depth of 0.75 m also suggest a SMR class of Fresh (Pyatt et al. 2001).

Table 2 also provides a summary of climatic information for the baseline period and for the 2050 A2 emissions scenario. The Avoca site is favourably warm (AT = 1865 day. degrees >5°C) for tree growth and has a moderate mean summer moisture deficit (MD = 128mm). Wind exposure, measured by DAMS (see Quine and White 1994) and continentality measured by a modified Conrad Index (Conrad 1946) are also shown.

The projected climate change in 2050 using the A2 emissions scenario suggests the default SMR values at Avoca will become half a class drier in the summer, whereas JFK is likely to become moderately dry during summer conditions. The change will occur as a result of a seasonal shift in the rainfall distribution coupled with warmer summers. Default winter SMR has been adjusted in CLIMADAPT from slightly dry to fresh/moist suggesting the wetter winter conditions.

Site-based suitability analysis

Table 3 shows the general yield class estimated from top height measurements at different ages using relationships published by Edwards and Christie (1974), and the site index predicted from the dynamic growth model GROWFOR (Broad and Lynch 2006). Table 4 compares predicted suitability and yield estimates using CLIMADAPT.

Table 1: *Vascular plant indicator species of the woodland floor at the Sitka spruce permanent sample plot at Avoca, Co Wicklow.*

Plant species	*Cover proportion %*	*Ellenberg - R+N value*	*SNR class*
Broad buckler-fern	2	9	*Medium*
Foxglove	2	9	*Medium*
Bracken	5	6	*Poor*
Bramble	20	12	*Very Rich*
Holly	2	10	*Rich*
Creeping soft-grass	60	6	*Poor*
Common bent	40	8	*Medium*
Chickweed	2	13	*Very Rich*
Wood sorrel	5	8	*Medium*
Hard fern	1	6	*Poor*
Cover weighted mean		7.8	*Medium*

Table 2: *Sitka spruce plot at Avoca, Co Wicklow, showing baseline climate, projected future climatic variables, and estimates of soil quality.*

Site attribute	*Avoca*
Species	Sitka spruce P.1943
Location	Avoca PSP, Wicklow
Latitude (deg. N)	52.864803o
Longitude (deg. W)	6.170690o
Elevation (m)	167
Slope (deg.)	9.9
Aspect (deg.)	242
Topography	Water shedding site
Soil quality	
Soil type	Brown earth
Soil texture	Silt-clay Loam
AWC constant (mm.m-1)	180
Rooting depth - RD (m)	0.75
Effective RD = RD + capillary zone (capillary zone = 0.15 m)	0.90
Stoniness (%)	5
AWC (mm.m-1)	(180 x 0.90) x 0.95 = 154
Mean winter waterlogging (m)	Below 0.80

Site attribute	*Avoca*
SMR (default)	Slightly dry
SNR (default)	Medium - rich
SMR (measured)	Fresh/slightly dry
SNR (measured from Table 1 for Avoca)	Medium
Baseline climate	
Accumulated Temperature (day. degrees>5oC)	1865
Moisture Deficit (mm)	128
Wind Exposure (DAMS)	16
Continentality (Conrad)	5
Projected climate 2050 A2 scenario and soil quality adjustment	
Accumulated temperature (day.degrees>5)	1880
Moisture deficit (mm)	153
Wind exposure (DAMS)	16
Continentality (Conrad)	5
SMR (default summer)	Slightly dry
SMR (default winter)	Fresh/moist
SNR (default)	Medium

Table 3: *Comparison of measured top height and general yield class and site index estimates of Sitka spruce in 2 permanent sample plots at Avoca.*

Factors	Mean of plots 1 and 6
Year measured	1971
Age (yr)	28
Mean top height (m)	17.1
Site Index (GROWFOR)[1]	18.5
Yield -GYC (m3ha-1yr-1)[2]	20
CLIMADAPT yield estimate 1961-2000 ($m^3ha^{-1}yr^{-1}$)	23
CLIMADAPT suitability score3 and constraint factor 1961-2000 baseline	0.72 – marginal/very Suitable
CLIMADAPT yield estimate 2050 A2 scenario (m^3ha-$^1yr^{-1}$)	18
CLIMADAPT suitability score3 and constraint factor 2050 A2 scenario	0.55 – marginal/suitable

[1] GROWFOR - Broad and Lynch (2006)
[2] General yield class - Edwards and Christie (1974)
[3] Suitability scores: 0-0.5 = Unsuitable; 0.5-0.75 = Suitable; 0.75-1 = Very Suitable

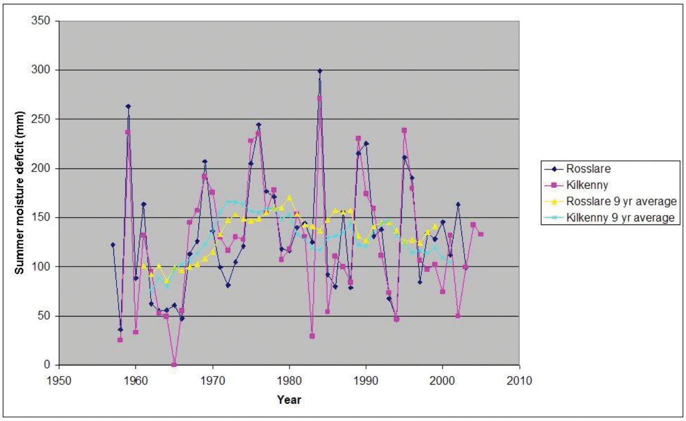


Figure 8: *Comparison of summer moisture deficit from rainfall and evaporation recorded at Rosslare and Kilkenny meteorological stations close to the Avoca permanent sample plot.*

Moisture deficits calculated from meteorological stations in the region of Avoca (at Kilkenny and Rosslare) show reasonably good agreement and consistency between records (Figures 8 and 9). Assuming rainfall is similar between the forest site and the meteorological stations, it shows that Avoca experienced 6 years with high moisture deficit over the last 35 years, and although the 9-year running average declined during the 1960s, it increased in the 1970s, and has since declined slowly. Climate change projections suggest the frequency of high summer moisture deficits will increase. Sitka spruce is considered suitable in climates where the mean moisture deficit is below 200 mm (Pyatt et al. 2001). More frequent exceedance of this threshold is likely to cause drought stress to trees leading to cracking, stem shake, and biotic impacts (Green and Ray 2009).

Over the same period, the warmth index, accumulated temperature (AT - day degrees above 5^{o}C), has increased substantially since the mid 1960s. Figure 9 shows more than a 10% increase in the 9-year running mean between 1960-2000, as a result of warmer and longer growing seasons, from recent decadal changes in warmth. Climate change projections for the A2 emission scenario suggest AT will increase from 1865 to 1880 day degrees above 5^{o}C by 2050 compared with the baseline climate period. Warmer growing seasons will stimulate increased growth, assuming moisture and nutrients remain in sufficient supply.

Climate change adaptation

The CLIMADAPT suitability and yield model shows that Sitka spruce at Avoca (Table 4) is Suitable, indeed borderline Very Suitable. By 2050, for the Medium-a High emissions scenario, the suitability score declines to borderline Suitable, and the CLIMADAPT yield model suggests that productivity will decline at Avoca to YC 18 (m^3 ha^{-1} yr^{-1}) as a result of an increased moisture deficit caused by drier and warmer summers. The average climatic factors in CLIMADAPT are not able to reflect variability or extreme events, and so climatic suitability is assessed for the 30-year

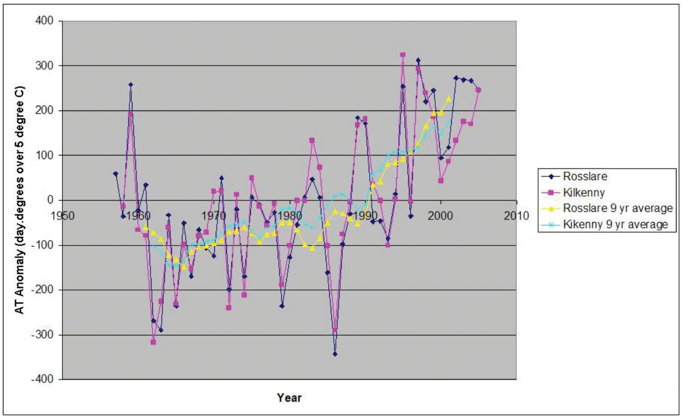


Figure 9: *Comparison of the warmth index (accumulated temperature) throughout the April to September growing season from records from Rosslare and Kilkenny meteorlogical stations, close to the Avoca permanent sample plot.*

period (1961-1990) as a whole. The site is fertile and warm, and so a change to a more drought tolerant species, such as Douglas fir (*Pseudotsuga menziesii* (Mirabel) Franco), Corsican pine (*Pinus nigra* Arnold ssp. Laricio Maire), or sweet chestnut (*Castanea sativa* Mill.), or a mixture of several species, would form the basis of a robust adaptation strategy. On less fertile mineral soils, species such as Scots pine (*Pinus sylvestris* L.), European larch (*Larix decidua* Miller), and in addition sessile oak (*Quercus petraea*) could be considered on sites further west.

Severe summer moisture stress in Sitka spruce can damage the stem causing longitudinal lesions and cracks to develop (Green and Ray 2009). Following stress conditions spruce is susceptible to biotic impacts (Csoka 1997, Broadmeadow et al. 2005, Rouault et al. 2006) and in particular aphid attack (Day et al. 1998, Evans et al. 2002).

Soils affected by fluctuating water tables are particularly sensitive to climate change due to the likelihood of even wetter winters and drier summers. Such changes will have an increasing impact on decisions as to how and when forest operations may be carried out. Wetter winter conditions will certainly affect operations that could damage soil, cause rutting and cause soil to erode and enter watercourses.

Many tree species are also sensitive to fluctuating water tables. For many species, wetter winters will increase anaerobic soil environments, thereby restricting the depth of rooting further. Consequently, drier summer conditions may have a more serious impact on trees that have restricted rooting depths. On these sites the range of suitable species is limited. It has been reported that lodgepole pine is able to tolerate seasonally fluctuating water tables on nutritionally poor soils (Coutts and Philipson 1978). Other species such as downy birch (Betula pubescens Ehrh.), Norway spruce (*Picea abies* (L.) Karsten), sycamore (*Acer pseudoplatanus* L.), pedunculate oak (*Quercus robur* L.), and common alder (*Alnus glutinosa* (L). Gaertner) may also be suitable on seasonally waterlogged soils.

The link between climatic factors projected under different climate change emissions scenarios, site fertility and the seasonal change in SMR need to be considered in choosing species suited to future climate conditions at a particular site. A database within CLIMADAPT will provide this context sensitive information in relation to a suitability analysis of conditions at the site.

For foresters, climate change adaptation is about adjusting silvicultural systems in response to actual or potential climatic threats and opportunities. Seeking to benefit from improvements in climate as well as being aware of, and minimising, the impacts of negative climatic change. General recommendations have been made on changes to silvicultural systems in Britain (Broadmeadow and Ray 2005, Ray 2008b, 2008a) which favour mixed species woodlands for a 'no-regrets' management policy. However, there may also be a case for adaptation to take advantage of warmer sites, and faster growth on sites with adequate water supply. On such sites the selection of material of superior provenance would provide wood for fuel, or other products, to offset the emissions of carbon from fossil fuel use (Broadmeadow and Matthews 2003).

It is clear that climate modellers are uncertain about the rate and the degree to which the climate will change in the future, and it is inevitable that there will never be certainty in this regard. However, this is no excuse for inaction, as evidence shows that the climate has changed in recent decades and that it is very likely to continue to change as a result of recent increases in the emissions of greenhouse gases into the atmosphere. There appears to be a great risk in not adapting tree species and forest management systems for resilient woodlands in the future.

Conclusions and recommendations

Modern computer-based spatial and operational site classification systems provide an efficient mechanism for strategic scenario planning, targeting incentives, and providing key decision support on tree species choice at an operational level. Site classification systems are fundamental decision support tools for forest managers, and are central to the concept of initiating sustainable forest management.

Multi-factoral site classification systems can be particularly useful at separating the component effects of site, and therefore have an important role to play in assessing changes in site conditions likely as a result of climate change. These tools must be developed to help foresters judge how, when, and where to adapt to the impacts of climate change.

Forest expansion is now recognised as an integral concept for countries striving to meet greenhouse gas emissions reduction targets under the Kyoto Protocol. Indeed industrialised countries are keen to identify where and how forests might be expanded as part of an integrated land-use policy initiative. In Ireland, as in many other European countries, incentives will almost certainly be required to encourage woodland expansion.

Climate change adaptation requires incentives to help woodland owners and manages reduce and spread the risk of uncertain future impacts on forests. Management must move away from always accepting single species - same age plantations, to more mixed species - mixed age forests. However, there is likely to be a continued role for fast grown single species stands of improved or specific trait selected material for climate change mitigation. Spatially explicit site classification systems have an important strategic role in helping forest policy teams assess expansion opportunities, and they provide a high level overview of regional priorities for species selection and suitable management systems.

Site classification systems must be developed using methods to allow information and new data to be easily incorporated. This requires a framework approach to design, and a modular schema to the data and information systems used. Climate change modellers will continue to update us with their most recent findings. This will require the development of new functionality in site classification systems, such as probabilistic forecasting, as well as risk classification and analysis.

The Delphi approach is a powerful mechanism for gleaning information from both experience- and evidence-based knowledge. The approach is best performed by domain experts familiar with the issues of the problem to be evaluated.

At the Dublin Delphi group meeting, the group of forest scientists were the best domain experts available for the task. However, the Delphi process failed to reach a robust agreement on species suitability thresholds for moisture deficit for several species. Furthermore, the compromise threshold values obtained were not consistent with the Delphi procedure performed for ESC in 2000. The problem was almost certainly an artefact of the Delphi process in Dublin. The expert group may have misidentified or confounded the effects of climatic moisture deficit and soil moisture regime. In retrospect, although the Delphi experts had information to support the analysis, more time should have been allocated to ensuring that experts were comfortable with the climatic factors, their individual effects, and the nature of their interdependence.

Delphi derived models for CLIMADAPT were developed from both the Dublin meeting and from the ESC Delphi meeting performed for Britain in 2000. The models are intended only to show initial relationships and responses and will be replaced by process-based model components in due course.

The key requirement of decision support tools includes a mechanism to organise and process information in a transparent, repeatable, and systematic way. Site classification systems must be able to provide this function to allow the forestry authority to audit the rationale and science that underpins key decisions on species choice in forests.

Finally, the development of CLIMADAPT will help add to the site classification work already achieved (Horgan et al. 2004) by providing the framework for climate change impacts to be assessed, and by extending the accessibility of a forest site classification system on the internet. It is hoped that this information provision will play a part in disseminating the impacts of climate change on forests and forestry in Ireland, help forest policy makers assess the opportunities of forest expansion in mitigating climate change in Ireland, and help forest managers and owners make informed decisions based on the current thinking of climate impacts and forest adaptation.

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Forest Perspectives

A Supplement to *Forestry in Ireland, a Concise History*

Niall OCarroll

My book, *Forestry in Ireland - A Concise History* (hereinafter referred to as "the main work") was published by COFORD (The National Council for Forest Research and Development) in 2004. My interest in the subject has continued, and I have therefore noted any relevant items which have since come to my attention. I now offer these as a supplement to the main work. They are arranged in the same order as the sections in that book.

Times Past

Giraldus

Giraldus de Barri, called Cambrensis (of Wales) (1146-1223), came to Ireland with Prince John (Monarch 1199-1216) in 1185. His *Topography of Ireland* was published in 1188.

Giraldus is briefly quoted at second-hand in the main work in connection with the woodland cover of Ireland towards the end of the twelfth century AD.

The *Topography of Ireland* was written, or perhaps one might say "composed", by Giraldus after his visit. It has been published in several translations. That by John O'Meara (1951) is claimed to be from the earliest manuscript, dating from the twelfth century. In a section on agriculture it is reported that Ireland "has bees that produce honey but the swarms would be much more plentiful if they were not frightened off by the yew-trees that are poisonous and bitter, and with which the island woods are flourishing". It is not clear whether the term "island" here refers to the island of Ireland or the lake islands. O'Meara's version of the statement quoted by Joyce (1903) that "the open plains are of limited extent compared with the woods" and repeated in the main work, is that "…there are, here and there, some fine plains, but in comparison with the woods they are indeed small". (It is pointed out in the main work that Fergus Kelly takes a different view.) That statement is also found in another translation, that of Forester and Wright (1887), from an unspecified source. That version talks of the "yews with which the woods of the island abound", which seems to suggest that the statement applies to the whole island. In describing the "barbarous" nature of the people, Giraldus, in O'Meara's translation, says the cultivator "is too lazy to plant the foreign types of trees that would grow very well here". Forester and Wright's translation, states that "the lazy husbandman does not take the trouble to grow the foreign sorts [of trees] which would grow very well here". And adds "There are four kinds of trees indigenous in Britain which are wanting here. Two of them are fruit-bearing trees, the chesnut and the beech; the other two, the arulus and the box [a footnote states that other manuscripts have 'alarus' and that it is uncertain what tree is alluded to], though they bear no fruit, are serviceable for making cups and handles… The forests of Ireland also abound with fir-trees producing frankincense and incense". [A note here states 'Giraldus means no doubt the *pinus sylvestris*, which is also indigenous in Scotland'.] Elsewhere in this version "the soil of Ireland" is described as "friable and moist, well-wooded, and marshy".

Giraldus is quoted here because it would not be reasonable to ignore his existence. However, many of the phenomena and occurrences he describes are so outrageously incredible that it is impossible to take seriously the work as a whole, even where it is seen now to be true, as in his account of the Irish climate and on the excellence of Irish musicality[1]. It might be pointed out that according to O'Meara's (1951) Foreword, Giraldus produced at least four later revisions adding further material until his final version was almost twice as long as that used by O'Meara[2].

Deforestation

One possible effect caused by the decline of woodlands in Ireland is suggested in Bielenberg (2003, p 20). There Colin Rynne writes "Until quite recently the cluster of early medieval [c 500-1100 AD] dates for Irish horizontal-wheeled sites [a primitive form of water-mill], and the apparent absence of high medieval [c 1100-1400 AD] sites from archaeological record, led to the suggestion that a shortage of timber for building purposes seriously curtailed mill-building activity". Rynne does not provide source references for this speculation.

The diarist, John Evelyn (1620-1706), author of Sylva: *A Discourse of Forest Trees and the Propagation of Timber in His Majesties Dominions* (1664), one of the first books in the English language dealing with forestry, worried about the depletion of English timber reserves through the "increase of devouring Iron-mills" and suggested that Ireland would be a better location for that industry (Campbell-Culver 2006).

In 1973 Eileen McCracken, author of the well-known 1971 volume *The Irish Woods Since Tudor Times*, later contributed an article on The Woodlands of the Central Shannon Basin to the *Journal of the Old Athlone Society* (McCracken 1973). Her account is based largely on the Civil Survey of 1654-6, intended as a preliminary to the Cromwellian confiscation, and The Books of Survey and Distribution, summarizing the Cromwellian Settlement and its modification at the Restoration (O'Connell 1998). McCracken lists woodland areas by townland in Counties Clare, Galway, Roscommon, Leitrim, Longford, Westmeath and Offaly, but specific forests are

1 Both versions include a rather fanciful account of the generation of a species of wild goose. In Forester and Wright this is in a chapter *On barnacles, which grow from fir timber, and their nature*. It begins 'There are here likewise many birds called barnacles, which nature produces in a wonderful manner, out of her ordinary course. They resemble the marsh-geese, but are smaller. Being at first gummy excrescences from pine-beams floating on the waters, and then enclosed in shells to secure their free growth, they hang by their beaks, like seaweeds attached to the timber. Being in process of time well covered with feathers, they either fall into the water or take their flight in the free air, their nourishment and growth being supplied, while they are bred in this very unaccountable and curious manner from the juices of the wood in the sea-water'.

2 John J. O'Meara (1915-2003), a former Jesuit novice in the Gandon-designed Emo Court, Co Laois, Professor of Latin in University College Dublin (1948-84). In his Foreword to the translation he admits to having toned down some of the expressions connected with bestiality.

generally not identified. She points out that "the presence of ironworks is an indication of nearby woods for the works were fuelled by charcoal and it was uneconomic to transport wood over a distance of twenty miles". She mentions 560 acres of wood in the Coologory townland in the parish of Aughrim[3]. In Roscommon "it is abundantly clear that the most densely wooded area lay in the extreme north of the county, in the parishes of Ardcarne, Boyle and Kilbryan". "Thick tall woods" were found in the townlands Aghrafinigan, Drumcormick, Kilfaughna, Derreendonagh and around Lough Skean. In Boyle parish lay the "thick tall woods of Aghacarra" and in Kilbryan parish there were "tall timber woods".

There are many similar examples listed but the conclusion appears to be that in the seventeenth and eighteenth centuries the counties bordering the river Shannon were well furnished with discrete areas of woodland but apparently there were no extensive areas of forest cover.

Positive Moves

Afforestation by Planters

And few in the candlelight
Thought her too proud,
For the house of the planter
Is known by the trees

(From *The Planter's Daughter* by Austin Clarke)

It is to be presumed that the term "planter" here refers to a participant in one of the strategic political human "plantations" of the 17th century, rather than the literal meaning of a planter of trees. The implication is that only the "planters" were disposed to plant trees.

However, according to Connolly (1998) "Early planters exploited the local forests…"

Introduction of beech
Forbes (1933) refers to an appendix to Boate's *Ireland's Natural History*, being a letter from Dr Molyneux FRS to the Bishop of Clogher describing "swarms of Cockchafers…which at Eyre Court [Co Galway]…stripped groves of beech in 1697". Boate's volume was published in 1652, so the report clearly was not carried in the original edition. Forbes does not specify the edition he consulted. In Boylan's (1998) *Dictionary of Irish Biography* William Molyneux (1656-1698) is described as a student of philosophy, optics, and astronomy, and a specialist in optics. Forbes appears to throw doubt on the likelihood that "one of the commonest trees in England

3 Only one townland of this name is listed in the *Townland Index* (H.M.S.O. 1861), comprising 895 acres (362 ha), located in the parish of Tomgraney near the town of Scarriff.

should not have found its way here before the Robinia from N. America, or the stone pine [*P. pinea*], evergreen oak [*Quercus ilex*], or walnut [*Juglans regia*] from the Mediterranean region".

According to Nelson and Walsh (1993) "The date of introduction of beech to Ireland is not known" although they speculate that it may have come "with the Normans to whom this was a familiar tree". No supporting reference is provided. Hayes (1794) already cited in the main work, suggests Shelton Abbey, Co Wicklow, as the location of its first introduction.

We may conclude that we do not know when beech was introduced into Ireland.

Nimmo's contribution

Alexander Nimmo (1783-1832), a Scottish engineer, came to Ireland in 1811 and was employed by the government to carry out surveys and supervise engineering works such as road and pier construction in the west of Ireland. He soon became a visitor and guest at the homes of Connemara landowners where "he offered advice and made recommendations on engineering matters, on agriculture and on forestry, and these were frequently acted upon" (Villiers-Tuthill 2006).

He believed that "The region [Connemara] also possessed many advantages for the raising of timber. And although Connemara was 'destitute of wood', in some sheltered spots oak, beech and hazel appeared in abundance and with a little care could be cultivated more widely. Most of the old timber had been consumed by several ironworks established a century before, and he was surprised that no attempt had been made to replace them. For Nimmo, planting was the obvious solution for the 'extensive moors, which [were] so far from manure or limestone', and the advantage of 'sheltered vales, navigations and abundant water-power', all pointed towards the possibility of developing a timber industry in the future.

"Between Galway and Oughterard several of the proprietors had planted trees, principally for ornamentation, and they seemed unaware of their potential commercial value. In contrast, nurseries and copses already thrived along the coast: 'Mr John Darcy (sic)[4] of Killolla (sic)[5], has succeeded well in raising most kinds of timber at Clifton (sic) [presumably Clifden] and Ardbear Bay, though immediately exposed to the Atlantic. His nursery there is in good order, and he is extending his plantations. The copses at Ballinaboy, Munga [near Clifden] &c. are also very near the ocean and the wood of Cloonill (sic) [Cloonisle, near Clifden], and Birterbuy (sic) [Bertraboy] Bay, grows down to the water edge.

'Mr Martin had planted extensively at Ballinahinch, but for want of enclosures, much of it has been ruined. Mr Thomas Martin, his son, has formed an extensive nursery, and begun to plant upon a very great scale; there could not be a finer field than what his demesnes afford. He is also rapidly fencing in his numerous copses.

'[William] Bald [Scottish Surveyor, (1789-1857), conducted the Trigonometrical Survey of Mayo] held the opinion that the bog could be easily reclaimed and

4 John D'Arcy (1785-1839), of Kiltullagh, Co. Galway, founded the town of Clifden in 1812.

5 *The Townland Index*, 1861, records a townland "Killola" near the town of Oughterard, Co Galway.

cultivated…' He compared the bogs to new colonies: 'The reclaimed bogs in Ireland would have all the advantages of new colonies, both as to room and food in abundance, and none of their difficulties in distance and transport'. And in areas where the bog was on high ground, too high for the cultivation of grain, he suggested that it be fenced off and planted with trees.

'McLaughlin [owner of a fish-curing house in Galway] was employing a number of coopers to contain the fish and this had increased the demand for local timber and sally rods. Prior to this the sally had been imported from England and Scotland, but was now being raised on marshy waste-ground locally'" (Villiers-Tuthill 2006, with quotations from Nimmo).

Villiers-Tuthill quotes further from Nimmo/Bald 'Connamara is very destitute of wood, a few scrubby patches only being scattered thinly through it.

"The country, however, possesses an extensive stool of timber, for in almost every dry knole [knoll] or cliff the oak beech and hazel appear shooting in abundance, and require only a little care to rise into valuable forests; several bloomeries[6], which were erected about a century ago, consumed much of the timber, and copsing was afterwards neglected. The sheltered vales, navigations and abundant water-power, would form great advantages in the cultivation of timber."

Commercial Estate Forestry

George Moore, who was extensively quoted in the main work on the subject of rural poverty and the related land hunger, also became aware of the commercial value of sustainable exploitation of woodland. In 1880 he wished to continue his writing career, not yet financially successful. He returned to Mayo and appointed a neighbour, Tom Ruttledge, as his agent. This move was questioned by his widowed mother, who enquired "But is Tom going to advance money, and where is the money to come from?" "Tom tells me that the woods have not been thinned round Moore Hall for the last thirty years. He has had them examined by a timber merchant, who will pay four hundred pounds for the surplus trees. The woods will not be spoiled but benefited." "And you will live, George, in London for two years on four hundred pounds?" "I hope to do so[7]. The trees of Moore Hall shall not be wasted, that I promise you, Mother, and you can live at Moore Hall as long as it pleases you and invite your friends to keep you company." (Moore 1933). Hone (1939) also records that "soon after" 1851 George Henry Moore, the novelist's father, supervised the construction of an oak-panelled dining-room using oak cut in the demesne woods.

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British attitude

Lord Lovat, first Chairman of the Forestry Commission of the then United Kingdom of Great Britain and Ireland, in his opening address to the first British Empire Forestry Conference, held in London, July, 1920, said "If we take the case of our blood relation, the United States of America, we find an almost exact replica of our own policy of

6 'From the earliest times up until the late sixteenth century, wrought iron in Ireland was produced in one step in a *bloomery* by smelting the iron directly from its ores…in primitive furnaces where temperatures reached about 800º C. (Colin Rynne. 2006. *Industrial Ireland 1750-1930, An Archaeology*. Collins Press, Cork.

7 Moore eventually became quite wealthy through his publications.

inaction. As early as 1799, possibly under French influence, the first forest legislation was attempted." […] "If we glance for a moment at the forest history of Europe, we are struck by the fact that in the Middle Ages, whilst forestry laws on the Continent were being built up on national and constructive lines, our forest laws were based on injustice, cruelty and repression." […] "It is a significant fact, whether arising from British dislike of forests or lack of appreciation of the possibilities of communal forest enterprise that the area occupied by the British during the French Wars of the Middle Ages is the only area in France where no communal forest exists, and this in a country where five million acres of communal forest are to be found in the departments untouched by British rule!" […] "We are at heart not forest preservers as they are in Switzerland, France, Germany and Belgium, but at heart forest vandals who look on all forests as their prey." (Richard 2003).

An estate owner's involvement

Sir Shane Leslie (1885-1971), a hereditary Baronet born at Glaslough estate, Co Monaghan, was, according to his biographer Otto Rauchbauer (2009), "… probably the most notable amateur forester in Ireland at that time (after c.1919).[8] The issue was strongly politicised and delicate, particularly as far as Irish farmers were concerned, who were reluctant to invest in schemes that promised no short-term profits". After the war of 1939-45 "Leslie became involved in organising a congress of the international society known as Men of the Trees which took place in July 1948 in Dublin".

Men of the Trees is an organisation founded in 1924 by the Englishman, Richard St. Barbe Baker (1881-1982). Its purpose is "to use every possible means of moulding world opinion so that people everywhere will cooperate with their governments in passing wise and beneficent laws for the protection and preservation of their forests, which are so vitally important to the health, wealth and well-being of every country."

Sir Shane addressed the Annual General Meeting of the Society of Irish Foresters in January 1945 reading a paper entitled *National Parks in State Forests*. In it he said that "since the year 1903 I have had an intense, overwhelming interest in trees". (1903 was the year of the great storm when "a [60 and 70 years old] famous wood" on his grandfather's place was blown down.) "I knew the great Theodore Roosevelt [US President, 1901-1909] and his great lieutenant, Gifford Pinchot [1865-1946, First Head of the US Forest Service]. I have followed as well as I could the developments in England and Scotland and tried to reproduce them, if I could at all…I have known two public men in this country, each of whom, I think, was a milestone; each of whom, if he did not actually reverse a side of our life, certainly altered it for all time. One was George Wyndham, whom I knew when he was passing the Land Act[9] which, I think, changed this country as far as he could, and the other was Horace Plunkett[10],

8 In a letter to his gamekeeper in 1909 Leslie wrote "…I am afraid I should never come and live [at Glaslough] like in the old days. The world is worse than I ever thought and I have got to help put it right." (Rauchbauer 2009)

9 George Wyndham was chief secretary for Ireland (1900-5). His Land Act, 1903, gave landlords who sold their whole estate to the Land Commission a bonus of 12 percent over the agreed valuation. (O'Shiel and O'Brien 1954)

10 Sir Horace Plunkett (1854-1932) first president of the Irish Agricultural Organisation Society, largely responsible for the establishment of the Department of Agriculture and Technical Instruction for Ireland in 1899 (Boylan 1998).

who changed farming. The great disaster is that neither of them was interested enough to change forestry … but perhaps the man who will make Irish forestry a reality, a monument to himself and a delight to posterity, is not yet on the horizon." (Leslie 1946). Sir Shane clearly did not then foresee the advent of Seán MacBride and his 25,000 acre (10,000 hectare) annual planting target.

Learning

University Education
William Delany, President of University College, Dublin, in a letter to the Chairman of Dublin County Council in 1910 advocated that scholarships supported by County Councils should be devoted to "… an education dealing with agriculture, industries, and commerce". Expanding on that he envisaged that "Travelling scholarships would be made available in this whole area [of agriculture], and scholarships would also be available to the University of Nancy [France] for the study of forestry "with the view of utilizing our waste lands". By means of such a programme and such scholarships he believed that professorships, fellowships and scholarships in Agriculture would become as highly regarded as in Medicine, Arts and other academic subjects in the university." (Morrissey 1983).

Both Augustine Henry (1857-1930) first Professor of Forestry at the Royal College of Science, Ireland, incorporated into University College Dublin in 1926, and Gifford Pinchot, studied at the forestry school at Nancy.

Forest Research in Wicklow, ca 1830
Possibly the earliest record of forest research in Ireland is that published in 1878. "At the sixth meeting of the British Association for the Advancement of Science (1836), a paper from John Nuttall, of Tittour[11], county of Wicklow, was read on this subject [Management of the Pine Tribe]. Having noticed that almost all the plants of *Pinus sylvestris* and other species, when planted in a light clay-slate soil on exposed situations, grew too rapidly, or out of proportion to their rootings, and thereby become *wind-waved*, and that those which, by accident, had lost their leaders took a strong hold on the ground, he commenced a series of experiments, as follows: In the spring, when the buds were fully developed, he went over those that were suffering from the foregoing causes, and broke off all the buds except those on short branches. By this process their upward growth is checked for a year, the trunk increases in bulk, and the plant roots much more freely than if the shoots had been allowed to grow. New buds are formed during the summer, and in the following spring these plants present the most vigorous aspect.

"The larch he cuts down to a strong lateral branch, on the windward side, when possible. These soon begin to spread their roots, increase in size similarly, and ultimately become choice trees. In some instances he had cut them down a second

11 This townland is listed in the Townland Index (H.M.S.O., Dublin 1861), as Tithewer, in the parish of Calary near the town of Rathdrum. P.W. Joyce, in his Irish Names of Places (Dublin, 1869) interprets this as Tigh-tuair, the house of the bleach-green.

time, when he found it necessary, and with equally good effect." (Hough 1878).

Conclusion

I have chosen not to extend this account beyond the period covered in the main work, therefore it does not deal with the increasing emphasis on broadleaf planting or on the virtual cessation of state afforestation. Much extra information on trees and forestry in Co Wicklow, including the plantations at Tittour (Tithewer) referred to above, and, generally, about earlier centuries, is to be found in Carey (2009).

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Trees, Woods and Literature – 33

A kilometre or two farther on, at the crossroads which goes to Chillarón del Rey, the traveller unfolds his blanket and lies down to sleep at the edge of the highway, under a hawthorn bush. The night is calm and starry. An owl is hooting from an olive tree and a cricket sings among the thistles. The traveller, who is tired, is soon sleeping quietly, deeply, refreshingly …

It is still dark when wakes up; he takes a swallow of wine, eats two oranges and a hunk of bread, and starts walking more vigorously than ever, never felling the pack or his legs on the road.

The first faint light of dawn finds him already in site of Pareja, in a region of rich, well-cultivated fields of reddish clay, full of small plots among which he can see an occasional brickyard with the people already hard at work.

Pareja is a big busy town, with new houses beside others in ruins and an inn on the town plaza. The plaza is square and roomy; in the center is a fountain with a number of spouts and a basin all around, and an ancient, heavy-branched patriarchal elm tree, an elm as old perhaps as the oldest building in the town. Standing around the fountain, the women are waiting to fill their pitchers and jars. The women carry their pitchers on their hips and have a hollow reed over their shoulders; they use the reed to guide the water as it falls from the fountain, a couple of yards above the rim of the basin. The women of Pareja show rare skill in hunting down–or rather, in fishing for–the water without spilling a drop.

The traveller enters the inn; he wants to have a hot breakfast, wash up, and then sit down for a little rest. The inn has some tempting rocking chairs and there are two rosy, plump, friendly girls who giggle as the bustle from one place to another carrying crockery, emptying a chamber pot, dusting the furniture, making a bed, scrubbing the floor; all at once, all in glorious confusion, all as merrily as can be. One of the girls is named Elena and the other María. As the traveller watches Elena and María working, he observes that he is being invaded by a lazy, cheerful feeling. The breakfast is really very good. The sparrows are chattering in the old elm on the plaza, opposite the open balcony full of geraniums in pots, and a yellow canary sings in his cage, ruffling his neck feathers. Inside, a cat is sleeping in the sun on the corner on the esparto-grass mat, and a little boy is pissing gloriously, challengingly, off the balcony.

Extract from ***Journey to the Alcarria* (Viaje a la Alcarria)** by Camilo José Cela, first published in 1948, and in translation by Frances M. López-Morrillas, Granta Books, London. Reproduced here by kind permission of Granta Books.

The reference to a "heavy-branched patriarchal elm tree" seems to be a mistranslation. A colleague, Jesús GarcíaLatorre writes: "The original has: *Olma le llaman porque es redondo, copudo, matriarcal, un olmo tan viejo…* – which translates as: They call it lady elm because it is rounded, full-bodied, matriarchal, a very old elm. The name of the elm tree in Spanish is *olmo* (masculine). *Olma* is a very specific name, only used to refer to veteran trees. The definition of *olma* in the dictionary of the Royal Academy of the Spanish Language reads: *Olmo muy corpulento y frondoso*–a very great (*corpulento*: large, great body, from *cuerpo*, body) and densely foliated elm tree. In the Spanish version, Camilo José Cela makes use of both terms. He says that there is an elm tree (*olmo*) and emphasizes that the people in the village refer to it as *olma*, because it has a big crown and is ancient; the *Olma de Pareja* is matriarchal.

"In former times on almost every village plaza there were several ancient elms. It was so also in my own mountain village. But, unfortunately, they have disappeared in the course of time. Furthermore, apart of their presence on plazas I have found coppiced and shredded elms (*Ulmus minor*) in semiarid areas in south-eastern Spain (but with accessible ground water), which is indicative of old management practices."

Camilo José Cela was born in 1916, in a small village–Iria-Flavia–in Galicia. He fought against the Republican government but later published an anti-fascist magazine, which became a forum for opposition to the Franco dictatorship.

His first, and most famous, novel was *The Family of Pascual Duarte*, probably the most widely-read work of fiction in Spanish since *Don Quixote* (published in the early 1600s). The book marked a departure in theme and style from previous Spanish writing. Cela's style, which came to be called *tremendismo*, was simple and straightforward, unlike the romantic writing which prevailed prior to his achieving prominence. His originality, and the breadth and quality of his output, were marked by the award of the Nobel Prize in Literature in 1989. After an eventful and colourful life, he died in Madrid in 2002.

Cela's venerable Lady Elm Tree of Pareja (*La Olma de Pareja*) came under threat from Dutch elm disease in the 1980s, at a time when over 90% of the species had been wiped out in Spain. The inhabitants of the village rose to the challenge however, and after treatment with fungicide the tree was saved. These efforts were rewarded in 2008, when Pareja won a €3,000 prize in a competition organised by a non profit group Forests Without Borders. The contest is designed to raise environmental awareness in Spain, and to protect emblematic trees and forests from developments such as golf courses and flats.

Lia Coille

Designing Sustainable Forest Landscapes

Simon Bell and Dean Apostol. Taylor & Francis, 2008.
356 p. ISBN 10 0 419 25680 (£47.50)

In Europe the outlines of landscape ecology began to develop at least 60 years ago. However, until the late 1980s, foresters and most ecologists in North America focused on plant communities (or stands) and circumscribed habitats as discreet entities with more or less clear boundaries.

In this book we garner the knowledge of two Continents. Dr Simon Bell is Senior Research fellow at Edinburgh College of Art. He is a forester and landscape architect with special interest in public access to the outdoors, forests and remoter landscapes. He has been involved in recreation design projects in the UK, Canada, Ireland, Latvia and Russia. Dr Bell is also Associate Professor at the Department of Landscape Architecture, Estonian University of Life Sciences, at Tartu, Estonia. Dean Apostol is a landscape architect and ecological restorationist with 30 years of experience. He is a Professor of Landscape Architecture at the University of Oregon, and is currently active in the design of a new city (Damascus, Oregon). He was chief landscape architect for Mount Hood National Forest in Oregon and has been active in the Society for Ecological Restoration International.

The book is neatly divided into three sections; section one deals with the key concepts for forest design. Section two deals with the process, techniques and implementation of forest design. Finally, section three deals with forest design application. This section which considers the design of plantation forest is most relevant to Irish conditions.

This book is a definitive guide to the planning, design and management of forest landscapes; it reviews the theory and principles of forest design as well as providing practical guidance on methods and tools. It focuses on ecosystem regeneration, the landscape planning of natural forests and the design of plantation forests. The reader is presented with a variety of international case-studies. The authors use visualisation techniques, design process and evaluation techniques to promote landscapes that are designed to optimise the balance between human intervention and natural evolution. Overall, it is a comprehensive, practical and accessible book essential reading for all those working in forestry, natural resources and the landscape.

Foresters who ignore this new thinking do so at their peril. There are many other professions with an interest in the countryside and they will not allow foresters to develop new areas of woodland which ignore the wider ecological and landscape consequences. Failure to consider the wider landscape inevitability leads to time consuming and expensive conflict.

John Mc Loughlin

(John Mc Loughlin is the Executive Director of the Tree Council of Ireland and the current Vice-President of the Society of Irish Foresters.)

If trees could talk. Wicklow's trees and woodlands over four centuries

Michael Carey. COFORD, Dublin. 290 p. ISBN 1 902696 64 6 (€25.00)

Travelling through Wicklow today, it is clear that there are two types of woodland, the old broadleaved woodland and the new coniferous plantations. The casual observer might be forgiven for thinking that the old oak woodland has always been there, that it was, in a sense, natural. It is, today, a place of great beauty and tranquillity. By contrast, the coniferous plantations are dynamic; many of them planted when some among us were students, have now been clearfelled and replanted. They are intensively managed and clearly, a valuable economic resource. They are what makes Wicklow the foremost county in Irish forestry today.

Dr Michael Carey's book makes it clear that this haven of tranquillity, the old "unchanging" broadleaved woodland, was itself a valuable economic resource and the focus of intensive management for many centuries. It is quite clear from this excellent book on the history of forestry in Wicklow, that before ever the sustained yield principle was formalised, in the early nineteenth century, the woodlands of the county were managed on a sustainable basis not only for timber production, but to supply a range of forest products from bark to coppice material for charcoal production. That this woodland industry was viable is evidenced by the fact that it endured for several centuries.

There wasn't a great deal of woodland in Wicklow for at least a few hundred years prior to the massive expansion in coniferous afforestation in the twentieth century. Michael takes us, in a highly readable fashion, through a maze of surveys, ancient documents, paintings and old photographs. The picture we get is of a landscape largely devoid of trees. In 1791, only 1.6% of the county was wooded. By 1904, this had increased to 3.4%. These woodlands were all privately owned, most of them on the lands of large private estates.

It is clear from the increase in woodland cover over this period of a little more than one hundred years that the process of reforestation had already begun, long before the State programme of the twentieth century. Indeed, Michael quotes from a document written in 1652 in which Sir William Petty, who served Oliver Cromwell in Ireland, set a target to plant "5 million fruit trees…. and 3 million timber trees…. in order to create employment and wealth". In the second half of the eighteenth century, the Dublin Society (now the RDS), offered incentives to encourage tree planting. In the relative stability of the late-eighteenth and early-nineteenth centuries, tree planting on private estates became fashionable, a symbol of their maturity and their stability.

For foresters, familiar with the many introduced coniferous species in Ireland, the section on the plant hunters will be particularly interesting. Most of us who have made our careers in forestry owe them and the landlords, who enthusiastically planted these new species on their estates, a debt of gratitude.

The book is divided into three main sections, "The Woodland Resource", "Tree Planting over the Centuries" and "Woodland Industries". The activities of the major estates in planting, silvicultural work and marketing are detailed. The uses of wood for ship building, house building and firewood, pipe and barrel staves, bark for tanning and charcoal for iron smelting are each described in detail. Bark was very profitable between the seventeenth and nineteenth centuries. The need to control debarking in order to protect the tree was recognised as early as the seventeenth century. The author describes the process of harvesting the bark, quoting from a variety of sources.

The meticulous attention to historical detail is one of the great strengths of this book. For natives of Wicklow or those intimately familiar with the county, it is an essential read, but its appeal is far wider than that. This is history at the level of the townland, recounting the presence of forest since time immemorial in certain places and the silvicultural treatment of others, supported by copious quotations from contemporary sources and beautiful reproductions of ancient maps.

A substantial part of the book is devoted to woodland industries, again in fascinating detail. We all know of the market for oak for ship building and house construction, but how many were aware that spools for thread were once made in Kilpedder, or that wood was used for glassmaking in Arklow in the seventeenth century?

The woodland business of the large estates was documented, by their owners, in considerable detail. The description of this is fascinating, particularly that of the largest forest owner, the Watson-Wentworth-Fitzwilliam estate, based at Coolattin, in south Wicklow. The forest operations carried out on the estate are described, including detail on outgoings and income.

This is a truly excellent book, which I strongly recommend not only to foresters and to natives of Wicklow, but to all who have an interest in how life was lived in past centuries. It is beautifully produced with many excellent illustrations, photographs (the great majority the work of the author), maps, line drawings and paintings.

Ted Farrell

(Professor Ted Farrell is recently retired from University College Dublin where he lectured in forest soils and ran research programmes in forest soils and ecology.)

Letter to the Editor

Badge – a rare Forestry term

Sir

I was a student of forestry in the early 1950s. As part of my practical year I was employed in 1953 as a forest worker in Ballygar State Forest. Ballygar Forest at that time was centered mainly in east Co. Galway but also stretched into Co Roscommon.

During my time there the operation generally known as 'grass cleaning' was referred to by the forest workers as 'badging', as in the exchange 'Were you at the planting of this compartment?' 'No, but I was at the badging of it.'

Since that time I have not heard or read of this usage either among professional foresters or in dictionaries or published Forestry Terminologies.

In the Sixth (2007) edition of the *Shorter Oxford English Dictionary*, '**Badge** *verb*^{3}' refers the reader to '**BAG** *verb*^{2}'. There we find '**bag**/bag/verb^2 trans… Also **badge** [origin unknown]: Cut (wheat etc.) with a reaping hook' I believe there can be little doubt that this is the same sense of the word that was in use in Ballygar Forest, where the implement used was a grass hook.

The date range of the first recorded use of this sense is given by the Dictionary as 1670-1699. It is not clear how an English word from the seventeenth century came to be in common use in Co Galway in the 1950s. It may be relevant that, according to an NUI Galway internet site the Kelly family had settled in Aghrane, the principal property of Ballygar Forest, also known as Castlekelly, in the late seventeenth century, and the estate continued to exist until 1910 when it was bought by the Department of Agriculture for forestry. Here we might note P.W. Joyce's statement in his *English as we Speak it in Ireland* (1910 and reprinted) that 'our people are very conservative in retaining old customs and forms of speech. Many words accordingly that are discarded as old-fashioned – or dead and gone – in England, are still flourishing – alive and well – in Ireland.'

I sent a note about this to *The Oxford English Dictionary*. They have informed me that the most recent example of this use of the word *badge* in their records is from a poem published in 1877 and that they would be interested in any further examples. I will be happy to send them any such examples which readers can send me, either through the medium of *Irish Forestry*, or directly to this address.

Yours sincerely

Niall OCarroll
Ballynakillew
Ballinrobe
Co. Mayo

Society of Irish Foresters
Study Tour to California 8–16 September 2008

On Monday, 8 September, forty four members of the Society of Irish Foresters departed for Los Angeles, California to begin the 65th Annual Study Tour. The group was welcomed at the airport by the tour guide and travelled to the Radisson Westside Hotel in Culver City, south of Los Angeles.

A large and hugely diverse state with a population of 38.6 million, California stretches 1,400 km from the Mexican border to its northern border with Oregon. It is 300 km wide – from the Pacific Ocean to the eastern deserts which adjoin Nevada and Arizona. Its largest city is the megalopolis of Los Angeles, which is home to six million inhabitants and the Hollywood movie industry.

The tour began in the San Bernardino National Forest, south of Los Angeles, then headed north and inland to the Sierra Nevada Mountains, Sequoia National Park and Yosemite National Park and ended in the coastal forests of the San Francisco Bay area, 670 km north of Los Angeles. The group returned to Dublin from San Francisco International Airport on Tuesday, 16 September.

Tuesday - 9 September

The first day began with a visit to the headquarters of the Pacific Southwest Forest and Range Experiment Station (PSFRES) in Berkley. The station is part of the research and development branch of the US Forest Service, and deals with California, Hawaii and the US affiliated Pacific Islands.

Staff at the station undertake research in natural resource management, conservation, and environmental protection. The emphasis is on fire – its prevention, management and control, which is understandable in a State where up to 40,000 ha can be damaged by fire in a single year. This is more than the total area of fire damage in Ireland since the State became involved in forestry in 1904.

Our guide for the day, Tim Paysen, Assistant Director of the Forest Fire Laboratory, pointed out that 2008 was likely to be an extremely bad year for fire damage. He introduced us to some of the staff at the station and explained the range of projects being undertaken by the PSFRES. For example, research meteorologists develop and refine weather models to optimise forecasts for fire management decisions; soil scientists develop technologies to monitor major wildfires and their impact on the environment; plant ecologists assess the impact of fire suppression and selective logging, in addition to testing the effectiveness of emergency post-fire rehabilitation treatments such as grass seeding, aerially applied mulches and erosion barriers on hill slopes.

The group discussed the major issues of concern to foresters and researchers in the region before heading into San Bernardino National Forest. Fire, water quality, insect, pest and disease damage, conservation and recreation are major issues, while timber production is of minor consequence. Some timber is harvested, usually as a salvage operation following fire damage. Dead and dying trees are removed because they exacerbate the fire risk as they become dry tinder for wind-whipped fires.

Presidents left and right - Pat Farrington (2009-2011) and Kevin Hutchinson (2007-2009), with Technical Director Pat O'Sullivan (second from right) beside Tim Paysen (Research Forester) outside the HQ of PSFRES.

(All photos: C. and K. Hutchinson)

Fire has always been an issue here, but more recently global warming and population increase are putting additional pressure on many forests in California. This is especially true in San Bernardino, which was established as a National Forest in 1907. It covers an area of 270,000 ha but more than half is chaparral (shrubland) which is hugely susceptible to wildfire during long periods of drought.

While the dry climate and vegetation type contribute to fire, an increasing number of fires are caused by human activity. This is a particular concern because California has a population of more than 38 million (California Population Bureau Census 2008) and is the most populous state in the US. Its population has increased by almost ten million in the past 20 years alone. Forest fire records since the 1880s show a pronounced increase in fires from east to west which mirrors the westward migration of settlers, their activities and industries. San Bernardino National Forest is very heavily used for recreation, as it is within easy reach of Los Angeles County which has a population in excess of ten million. Since 1980, 12 of America's 15 most destructive wildfires have occurred in California, mostly in chaparral areas.

As we headed higher and deeper into the San Bernardino Mountains, the group made a number of stops, beginning at a stand of Jeffrey pine (*Pinus jeffreyi*), a species that grows well on the driest of sites and at elevations up to 2,800 m. A close relative – but distinct species – Ponderosa pine (*P. ponderosa*) also grows in San Bernardino but does not reach the high elevations attained by Jeffrey pine. Ponderosa pine has a wide geographic range and Society tour veterans will remember it from their visit to Sisters in southern Oregon in 1992. Sugar pine (*P. lambertiana*) and Coulter pine (*P. coulteri*) were also present, as was Douglas fir (not Pseudotsuga menziesii, the species familiar to Irish foresters, but *Pseudotsuga macrocarpa* or bigcone Douglas fir). The main deciduous species was California black oak (*Quercus kelloggii*).

At the higher altitudes many species appeared under stress, including pines and bigcone Douglas fir, whose snags (standing dead and dying trees) were a reminder of the threats, not just from fire but also from drought and insect damage in San Bernardino.

Ponderosa pine suffers severe damage from western pine beetle (*Dendroctonus brevicomis*). This beetle, whose increase has been linked with global warming, thrives in drought conditions, when the trees are under stress. The beetle can reproduce several times in a year, is extremely aggressive and is capable of not only destroying stressed trees but can also attack neighbouring healthy trees.

The Jeffrey pine beetle (*Dendroctonus jeffreyi*) attacks Jeffrey pine in San Bernardino and other areas but is not as prolific as the western pine beetle. Other insects that cause damage include Ips and the fir engraver (*Scolytus ventralis*).

Broadcast forest spraying using insecticides is not a control option although individual high value trees in some leisure areas are sprayed.

After exploring the San Bernardino forest, the tour headed for Big Bear Lake a popular tourist resort which offers camping, skiing, and fishing (mainly for brown trout). Even here, global warming is an issue as lake water levels have dropped considerably in recent years.

The group then began the 170 km journey back to Los Angeles, taking in a visit to the luxury liner, the Queen Mary in Long Beach, before dining at Bubba Gump, a themed restaurant strictly for aficionados of the Oscar-winning film *Forrest Gump*.

Wednesday - 10 September

On Wednesday the group visited the Huntington Arboretum and Museum, a research and educational institution established in 1919 by Henry Huntington, a businessman who built a financial empire based on railroad companies and property holdings in southern California.

Huntington was a man of vision with a special interest in books, art and gardens. During his lifetime he built up a valuable research library and created botanical gardens with plants from around the globe. A striking feature of the plants section is the Desert Garden which contains more than 5,000 different plants from dry regions, mostly cacti and succulents.

Another attraction of the Huntington is its library, which specialises in the study of Anglo American civilisation and its place in the more diverse world of early twenty first Century America. Rare manuscripts, books, prints, drawings and photographs from the library's collections portray some of the ways in which scholars have interpreted the past and envisioned the future. There are informative displays on medieval Europe and the social history of the United States of America over the last two centuries.

The Desert Garden at the Huntington Arboretum and Museum

The world famous Huntington Art Gallery presents high-quality exhibitions of the institute's valuable European art collection which focuses on works from the fifteenth to the early twentieth century. Almost 1,200 objects are on view at any given time.

This ended an unusual day, spent among unfamiliar plants and surroundings.

Thursday - 11 September

The group made a long bus journey from Los Angeles to Fresno via Sequoia National Park and a spectacular and interesting visit to Sequoia Canyon. Here the group was enthralled by the massive trees including the *General Sherman* and the *General Grant*.

The 2,300-year-old *General Sherman* is 84 m in height and has a volume of approximately 1,487 m^3. Its circumference at ground level is an amazing 31.3 m and even at a height of 18.3 m it still carries a diameter of 5.3 m. The largest branch on the tree is an incredible 2.1 m in diameter. It is estimated to weigh 1,256 t.

Sequoia National Park has a rich diversity of species including sugar pine, incense cedar (*Calocedrus decurrens*), white fir (*Abies concolor*), black oak, mountain dogwood (*Cornus nuttallii*) and California hazel (*Corylus cornuta var. californica*). On the moister sites azaleas (*Rhododendron* spp) are found, while on drier sites ceanothus (Ceanothus spp) and manzanita (Spanish apple - *Arctostaphylos* spp) grow abundantly.

Sequoia depends on periodic fires caused by lightning strikes to produce the open forest structure which is essential for its establishment. These fires eliminate stretches of pine, fir, cedar and other species but do not destroy the entire forest. Thanks to

The 2,000-year old General Grant at Sequoia National Park

its thick bark, sequoia is well adapted to survive fires and this gives it a significant advantage in colonising newly created open spaces.

After a fascinating day in Sequoia National Park, the group began the long bus journey north to the town of Fresno in central California.

Friday - 12 September

We headed north from Fresno to Yosemite National Park. Our destination was the Mariposa Grove of Giant Sequoias (*Sequoiadendron giganteum*) on the southern edge of the Park. The Mariposa Grove is one of 75 isolated groves of sequoias on the western slopes of the Sierra Nevada Mountains. They represent just 4% of the original area before logging began in the 1850s. Although the sequoias are not the oldest living trees (this honour goes to the bristlecone pine (*Pinus aristata*) which can be more than 4,600 years old), the oldest giant sequoias are more than 3,000 years old. Neither is the giant sequoia the tallest living tree, that honour goes to the coast redwood (*Sequoia sempervirens*) which can reach 112 m. (We saw these massive trees later in the tour at Muir Woods on the coast near San Francisco.)

However, in the presence of these giants, it is impossible not to be impressed by their enormous size. Much has been written of their impact. In *Travels with Charley*, the American writer John Steinbeck wrote: “The vainest, most slap-happy and irreverent of men, in the presence of redwoods, goes under a spell of wonder and respect." Americans are prone to describing things as awesome but, in this case, it is a word which aptly describes these trees.

The Mariposa Grove holds many historic trees and much has been written about them since they were first seen by Europeans in early 1850s. In 1857, Galen Clarke brought attention to the trees by establishing a stagecoach station at Wawona. He became so enamoured of these huge trees that when he was diagnosed with tuberculosis he came to the mountains to spend his last days in their presence. In 1864 Abraham Lincoln took time out from the Civil War to declare the Mariposa Grove and Yosemite Valley protected state reserves. Together with John Muir, a Scotsman, he championed the saving of the sequoias from the axe and was responsible for the establishment of National Parks in the US.

The first tree on our route was the *Fallen Monarch*. It provides a good example of the rooting structure of sequoia. Given its great size and wind firmness, one would expect it to have a deep tap root whereas, in fact, it has only surface roots which are adapted to garner water. The roots are usually no more than two metres deep but they extend outward for 45 m, thus providing a stable base for the tree. Forest biologists believe the **Fallen Monarch** has lain on the ground for several hundred years. Tannic acids in the wood initially suppressed the growth of fungi and bacteria, thus arresting decay and it was only when rain and melting snow had leached the tannins from the wood that decay could begin.

Again we learned about the importance of fire for the survival of the species. Sequoia seeds need direct sunlight, adequate moisture and bare mineral soil to germinate and take root. Ironically, road construction creates the ideal seedbed by opening up the forest floor to sunlight, increasing moisture and providing bare mineral soil. In the early days, naturally occurring fires were suppressed in Mariposa in order to protect the sequoias. However, the more shade tolerant trees such as incense cedar, white fir and sugar pine quickly colonised the forest floor, reducing light, competing for moisture and blanketing the mineral soil with their needles and debris. As a result, it became very difficult for the sequoia to get established.

In nature, lightning causes fires, usually in late summer. The fires reduce competition from other trees and burn away the leaf litter to leave a thin layer of rich ash on top of mineral soil. A second advantage of fire is that the heat dries some of the ever-present green cones high up in the mature trees, causing a shower of fresh seeds to fall on to a perfectly prepared seedbed. This dependence of the sequoia on fire was not fully understood until the 1960s, but by then a century of debris had accumulated, making the grove susceptible to severe crown fires and possibly killing some of the large trees. The Parks Service began a series of prescribed burns which will continue until the grove returns to a more natural state and the lightning generated ground fires on a seven to 20 year cycle will resume.

Next was the *Grizzly Giant*, one of the largest trees in the grove, it is estimated to be at least 2,700 years old. One of its branches is two metres in diameter - which is greater than the trunk diameter of any of the non sequoias in the grove.

Some 50 m from the *Grizzly Giant* is one of the most frequently photographed trees on earth - the *Californian Tunnel Tree*. It was bored through in 1895 to provide a passage for stagecoaches. In fact, two trees in the Mariposa Grove were tunnelled. One of these is still standing and everyone in the group was eager for a photograph. The original tree was tunnelled in 1881 but it collapsed in 1969 under a record snowpack. Our forest guide believed the popularity of this tree may have helped save the remainder of the grove from logging.

The Californian Tunnel Tree in the Mariposa Grove of Giant Sequoias on the southern edge of Yosemite National Park (left to right: John McLoughlin, Pat O'Brien, George Hipwell, Mick O'Brien, Kevin Hutchinson and Christy Hanley)

Nearby is the *Faithful Couple*, two trees fused together at their base but clearly separate above. On the opposite side of the road are two similar but smaller trees which may become the next *Faithful Couple* … in about 500 years time! Next was the *Clothespin Tree*. As a result of several natural fires a tunnel, wide enough to accommodate a car, was burnt through its trunk. Further on, we meet the *Telescope Tree,* once again natural fire burned out the core of the tree with the result that you can now look up inside the tree and see the sky. Although it is now a hollow cylinder, it is still alive and producing viable seed.

Saturday - 13 September

We headed north to the centre of Yosemite National Park, to an area known as The Valley. One could not fail to be impressed by the awesome scale of the park with its sheer granite cliffs rising almost 1,000 m from the valley floor. John Muir said of Yosemite "No temple made with hands can compare with Yosemite, every rock in its walls gleams with life". The cliffs are the tallest in the US and fifth tallest in the world.

The Merced River, with El Capitan at left in background – Yosemite National Park

El Capitan (the Chief) is the centre-piece of the valley and is the tallest unbroken cliff in the world. We saw several rock climbers scaling the cliffs. These are elite climbers, who take three to five days to climb the cliff, sleeping in hammocks suspended several hundred metres above the valley floor.

Yosemite National Park was established in 1890 and is now more than 300,000 ha in extent. Although Yellowstone National Park preceded it by eight years, it was in Yosemite that the idea of protection was first mooted. The Valley itself is 11 km long and 2 km wide. The principal rock found in Yosemite is extremely hard granite, which is more than 100 million years old. While glaciers gouged out and enlarged the canyon of the Merced River, the ice scraped away the softer portions of the granite but only scarred the harder portions which now form the cliffs. As the glaciers melted a lake formed in the valley. It eventually silted up and created the present valley floor.

Sequoia is not naturally present in the valley. Live oak (*Quercus chrysolepis*), Douglas fir (*Pseudotsuga menziesii*), ponderosa pine and big leaf maple (*Acer macrophyllum*) are the main species. Fire is used on a controlled basis by the Parks Service to keep the meadows free of scrub and trees.

Native American Indians lived peacefully in the valley for 4,000 years until the mid-nineteenth century when the Californian gold-rush brought a huge influx of miners and settlers. Today, the park receives over four million visitors annually, 70% of whom visit during the summer. Visitors are transported within the park on a bus and tram shuttle system.

Black bears are plentiful in Yosemite and often cross swords with visitors. This sometimes results in damage to property and occasional injuries. Visitor education

Tour Group in the 'Valley' area of Yosemite National Park

and bear management efforts have reduced the number of bear/human incidents and property damage by 84% in the past six years.

The management of bears in close proximity to visitors is a major issue for the Parks Service. Normally the bears' diet comprises 85% plants and 15% grubs and insects. However, they are poor hunters and given a chance they will scavenge from humans. Visitors are under strict instructions not to feed bears under any circumstances. Special bear-proof food boxes and litter bins have been installed at campsites. Black bear is now the predominant species, the grizzly bear having disappeared in the 1960s.

Sunday - 14 September

We departed Yosemite for the 340 km journey north to San Francisco, where the group visited well known sights such as the Golden Gate Bridge, San Francisco Bay and Alcatraz Prison.

Monday - 15 September

We headed north over the Golden Gate Bridge for 20 km to Muir Woods, home to the coast redwood *Sequoia sempervirens*. In 1905, a local businessman bought Muir Woods and, to ensure permanent protection, donated it to the federal government. In 1908 President Theodore Roosevelt proclaimed the area a National Monument. It was named after the conservationist, John Muir. Unlike the giant sequoia we saw earlier in the tour, the coast redwood grows along a discontinuous 850 km strip along the Pacific coast. The trees at Muir Woods are a remnant of what once covered much of the Northern Hemisphere approximately 150 million years ago. The trees at Muir Woods were never logged. They are of mixed age; the dead trees supporting a biologically rich community of plants and animals.

Coast redwood (*Sequoia sempervirens*) and giant sequoia (*Sequoiadendron giganteum*) are closely related species. Giant sequoia grows larger in bulk than the coast species, up to 1500 t, but not as tall. The coast species grows best in moderate temperatures, protected from the wind and salt spray. Both redwoods need substantial rainfall and summer fog and grow tallest in the flood plains of rivers. The world's tallest living tree is a coast redwood in Redwood National Park, which has a height of 112 m – almost as high as the Spire in O'Connell St. in Dublin (120 m).

We returned to San Francisco for lunch and took a last look at the city and the Bay area.

Tuesday 16 September

We departed our hotel and headed south to San Francisco International Airport and home.

Recorders and accommodation

Date	***Recorder***	***Accommodation***
8 September	Tour begins, travel to California	
9 September	Donal Magner	Radisson Westside Hotel, Culver City
10 September	Frank Nugent	Radisson Westside Hotel, Culver City
11 September	Paddy O'Kelly	The Marriott Courtyard, Fresno
12 September	John McLoughlin	America Best Value Inn, Oakhurst
13 September	John McLoughlin	Yosemite View Lodge
14 September	John McLoughlin	Whitcomb Hotel, San Francisco
15 September	John McLoughlin	Whitcomb Hotel, San Francisco
16 September	Tour ends, return to Dublin	

Participants

PJ Bruton, Frances Burke, Richard Clear, Leo Collins, Tony Collins, Jim Crowley, Bob Dagg, Andy Duffy, Ken Ellis, Pat Farrington (Convenor), Jerry Fleming, Matt Fogarty, Brigid Flynn, Denis Gallagher, Seán Galvin, Eugene Griffin, Christy Hanley, George Hipwell, Kevin Hutchinson (President) Catherine Hutchinson, Kevin Kenny, Richard Lowe, Michael Lynn, Donal Magner, Tony Mannion, Brian Monaghan, Liam Murphy, Kevin Mc Donald, Tom Mc Donald, PJ McElroy, Willie McKenna, John McLoughlin, Jim Neilan, Frank Nugent, Benny O'Brien, Dermot O'Brien, Michael O'Brien, Pat O'Brien, Pat O'Callaghan, Liam O'Flanagan, Paddy O'Kelly, Pat O'Sullivan (Technical Director), Tim O'Regan, Trevor Wilson.