Forest Research and Development in Ireland 2004 - Underpinning Industry Development

Proceedings of the COFORD conference held on

20 and 21 September 2004, Tullamore, Co Offaly

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Réamhfhocal

Tugann an t-imleabhar seo le chéile tuairiscí ar rogha den taighde a maoiníodh ag COFORD faoi Bheart Foraoiseachta an Chláir Oibriúcháin don Earnáil Thairgiúil, thar an tréimhse 2000-2004 (téann an clár féin ar aghaidh go dtí deireadh 2006). Is spléachadh lárthéarma é ar an obair atá ar lean.

Tugadh na páipéir ag comhdháil dhá lá a bhí ann ag COFORD i dtreo dheireadh 2004. Ba é an cuspóir ná torthaí ár dtaighde a thabhairt chuig pobal níos leithne de dhéantóirí polasaí agus cleachtóirí. Thar an dá lá d'éirigh linn lucht éisteachta suntasach de dhaoine dá leithéid a tharraingt chun na hócáide, agus tháinig cuid mhór ceisteanna agus teagmhálacha breise as. Chomh maith le bheith ag déileáil le clár Taighde agus Forbartha na bhforaoisí náisiúnta, bhí láithreoireachtaí sa chomhdháil ar chlár Chreatlach RTDI an CE, agus ar COST – feithicil le haghaidh cláir thaighde agus fhorbartha náisiúnta a nascadh le gréasáin sa chomhthéacs Eorpach.

Feicfidh léitheoirí ó réimse na dtopaicí a chlúdaítear ann méid na hiarrachta foraoiseachta atá ar bun in Éirinn. Is cinnte go bhfuil an scóip leathan: ó chéim na plandlainne chuig bunú an bharra, go dtí baint an fhómhair agus an próiseáil – slabhra iomlán na foraoiseachta. Chomh maith le fiontar na foraoiseachta tá na tairbhí poiblí a thugann foraoisí don tsochaí, mar spás caithimh aimsire, gabháil carbóin, agus bithéagsúlacht agus soláthar uisce. Earraí a bhfuil a bpróifíl agus a n-éileamh ag méadú i rith an ama, de thoradh idir phróisis idirnáisiúnta agus

Treoraigh CE, agus mhéadú na mbailte agus na gcathracha. Iniúchtar na gnéithe seo sna páipéir, chomh maith le tionchar eacnamaíoch thionscal na foraoiseachta.

Ag teacht amach as an déscaradh idir fhiontar agus leas an phobail, feicimid go bhfuiltear ag dúil le agus ag éileamh rudaí difriúla ón fhoraoiseacht agus go bhfuil ar lucht déanta polasaí agus cleachtóirí déileáil leis seo. Is é atá le tairiscint ag an taighde, maraon leis na réitigh is fearr i ngach gné, ná smaoineachas ceangailte arbh fhéidir leis tosú a fhreastal ar an dá riachtanas. Anseo, is é atá i gceist againn ná cóireáil adhmaid atá oiriúnach don timpeallacht, córais coillshaothraithe de thionchar íseal a úsáid, foraoisí agus a dtionchar ar cháilíocht uisce, gnéithe a ndearnadh cur síos orthu sna láithreoireachtaí. Tugann cuid mhór de na modhanna oibre seo dúshlán na ndóigheanna oibre atá ann faoi láthair, nó an dóigh a gcuirtear seirbhísí ar fáil. Ach tá siad seo ar na cúiseanna a ndéantar infheistíocht sa taighde – le dúshlán an cheartchreidimh thraidisiúnta a thabhairt agus nuálaíocht a spreagadh. Ar ndóigh, ní próiseas furasta é an t-athrú, go háirithe maidir le rudaí mar an fhoraoiseacht agus úsáid an talaimh go ginearálta, a mbíonn traidisiúin fhada ag baint leo go minic. Bíodh sin mar atá, ní mór dúinn muid féin a chló le tosca agus dúshláin úra; gan sin thiocfadh leis an fhoraoiseacht a hábharthacht pholaitiúil agus a cumas iomaíocht a dhéanamh ag leibhéal idirnáisiúnta a chailleadh go gasta.

Mar fhocal scoir, ba mhaith linn buíochas a ghabháil le hIníon Lauren MacLennan ó COFORD as a hobair ag cur na tuairisce seo le chéile agus leis na húdair go léir agus na foirne bainteacha as a gcuid iarrachtaí.

David Nevins, Cathaoirleach

An Dr Eugene Hendrick, Stiúrthóir

Foreword

This volume brings together reports on a selection of the research funded by COFORD under the Forestry Measure of the Operational Programme for the Productive Sector, over the period 2000-2004 (the programme itself runs to the end of 2006). It is a mid-term snapshot of work-in-progress.

The papers were delivered at a two-day conference held by COFORD towards the end of 2004. The objective was to bring the results of our research to a wide audience of policy makers and practitioners. Over the two days we succeeded in attracting a significant audience of such people to the event, and it generated significant follow-up queries and contacts. As well as dealing with the national forest R&D programme, the conference saw presentations on the EC Framework RTDI programme, and on COST – a vehicle for networking national R&D programmes in the European context.

Readers will see from the range of topics covered the extent of the forestry endeavour in Ireland. The scope is indeed wide: from the nursery stage to crop establishment, to harvesting and processing – the full forestry chain. As well as the forestry enterprise there are the public goods that forests deliver to society, from recreation space to carbon sequestration to biodiversity and water provision. Goods that are increasing in profile and demand, as a result of international processes and EC Directives on the one hand, and growing urbanisation on the other. These aspects are dealt with in the papers, as is the economic impact of the forestry enterprise.

Arising from the enterprise/public goods dichotomy, we see that policy makers and practitioners are now faced with differing expectations and demands from forestry. What research can offer, as well as optimal solutions in each domain, is joined-up thinking that can begin to serve both demands. Here we are thinking of areas such as environmentally compatible wood treatment, the use of low impact silvicultural systems, forests and their impact on water quality – areas that are covered in the presentations. Many of these approaches challenge existing ways of working or how services are delivered. But these are among the reasons for investing in research – to challenge orthodoxy and stimulate innovation. Of course change is not an easy process, particularly in areas such as forestry and land use in general, that often have long traditions. However, we must adapt to new circumstances and challenges; otherwise forestry can quickly loose its political relevance and its ability to compete at the international level.

In closing we wish to thank Ms Lauren MacLennan of COFORD for her work in putting together this report and all the authors and the associated teams for their endeavours.

David Nevins, Chairman

Dr Eugene Hendrick, Director

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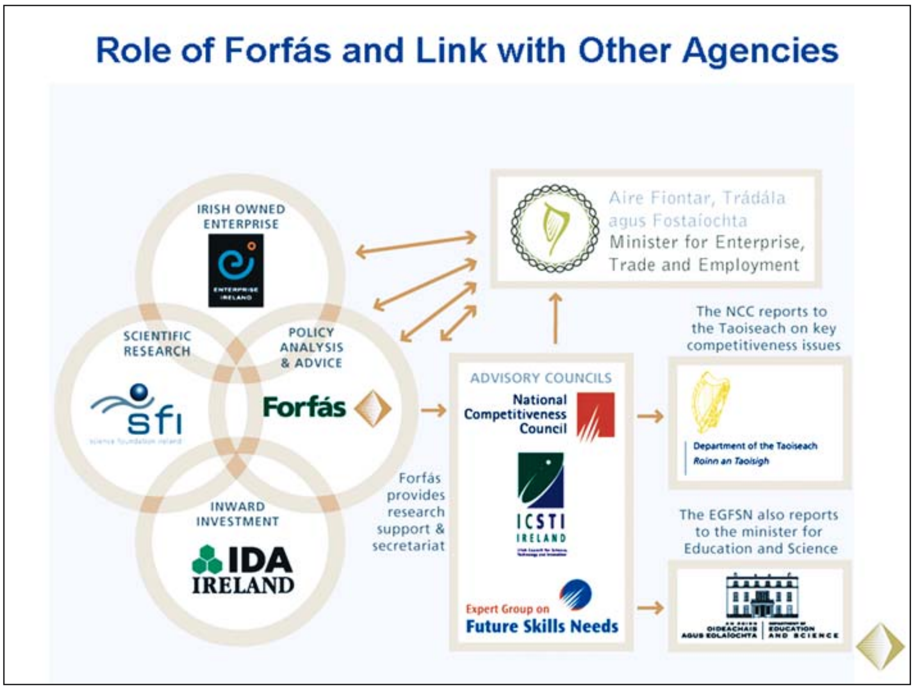
M. Breathnach*



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Background on European Research Area

Perceived weaknesses in European research system

- Level and quality of publicly funded research
- Weak research links between enterprise and academia
- Attractiveness for leading researchers
- Fragmentation in the research system

European Research Area

The European Research Area initiative combines three related and complementary concepts:

- the creation of **an "internal market" in research**, an area of free movement of knowledge, researchers and technology, with the aim of increasing cooperation, stimulating competition and achieving a better allocation of resources;
- a restructuring of the European research fabric, in particular by **improved coordination of national research** activities and policies, which account for most of the research carried out and financed in Europe;
- the development of a **European research policy** which not only addresses the funding of research activities, but also takes account of all relevant aspects of other EU and national policies.

EU Activities to promote the European Research Area

Europe's 3% Target

Ireland supported launch of *European Research Area* strategy at Lisbon European Council (*March 2000*) -

"…to become the most competitive and dynamic knowledge based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion by 2010."

Ireland agreed target to increase EU research to 3% of EU GDP by 2010 at Barcelona European Council, 2002 (*September 2002*)

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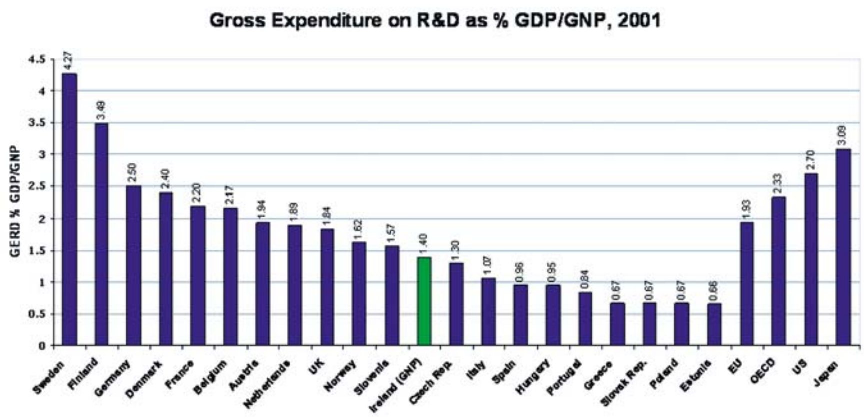

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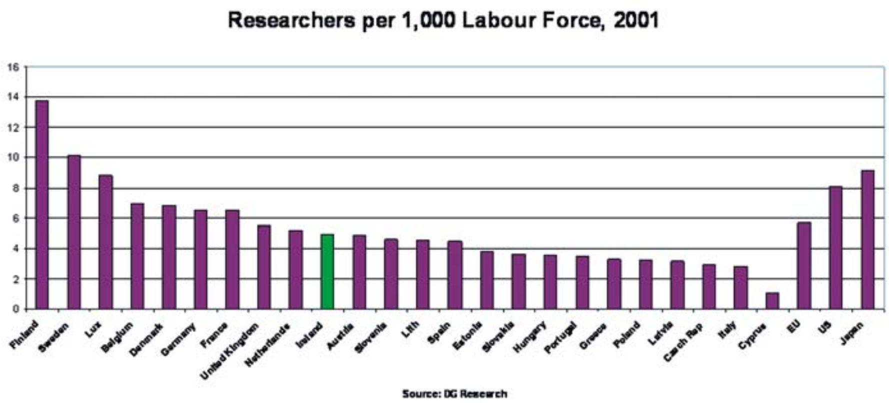

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Ireland's Contribution to 3% Target for Europe

Targets to 2010

- Gross expenditure on R&D to increase from 1.4% to 2.5% of GNP
- Business investment in R&D should increase from 0.9% GNP in 2001 to 1.7% GNP in 2010.
- Triple the number of enterprises performing significant R&D (>€2m) to 250 by 2010.
- R&D performance in the higher education and public sectors should increase from 0.4% GNP in 2002 to 0.8% GNP in 2010 .
- The number of researchers to increase from 5 per 1,000 of total employment in 2001 to 9.5 per 1,000 in 2010.

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Vision for Research Performance in Ireland to 2010

"Ireland by 2010 will be internationally renowned for the excellence of its research, be at the forefront in generating and using new knowledge for economic and social progress, creating well paid jobs and improved standards of living and catalysed by a national pro-innovation culture ".

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Perspectives on Future EU Research Funding

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Framework Programme is a key aspect of the European Research Area…

Role of EU Framework Programmes (FPs)

Ireland has benefited greatly from successive FPs

Links developed through consortia have been key benefit

Issues with the current FP:

- Industry and SME participation in FP6 is disappointing
- Objectives of new instruments barrier to industry participation
- Bureaucracy remains a barrier to participation

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Planning for next FP has already commenced at EU level…

- Financial Perspectives 2007–2013 (Feb 2004) - proposed doubling of EU research budget
- Commission's Communication on Guidelines for Future EU Policy to Support Research (June 2004) to launch political debate ahead of proposals for FP7 (Early 2005)
- Communication identifies six major objectives for EU action corresponding to areas of structural weakness

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Six Pillars of a Future EU Framework Programme

Pillar	Objective (as per Commission document)	Correspondence with FP6
Collaborative Actions	Creating European centres of excellence through collaborative actions between laboratories	Yes – Thematic Actions
Technology Platforms	Launching European technological initiatives	**New**
Competition in Basic Research	Stimulating the creativity of basic research through competition between teams at European level	**New**
Human Resources	Making Europe more attractive to the best researchers	Yes – Marie Curie etc.
Research Infrastructures	Developing research infrastructures of European interest	**New** (in terms of construction of facilities)
Coordination of national programmes	Improving the coordination of national research programmes	Yes – Coordination of ERA

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ICSTI Consultation Process

Initial Consultation by Forfás based on Indications from Commission **June – July 2004**
More Detailed Consultation and Development of Ireland's Position on Broad Parameters of FP7 **Sept – Nov 2004**
Specific Proposals from Commission for Design of FP7 and Budgetary Parameters **April – May 2005**
Reaction from Member States and Continuous Refinement of FP7 Design **Mid – Late 2005**
Council and Parliament Approval of FP7 Design **2006**

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ICSTI Consultation Process - Overview

- ICSTI to issue a consultation paper based in part on the initial consultation exercise organised by Forfás
- Paper to be written in the style of ICSTI's advice to Government
- People will be asked to agree or disagree with specific recommendations made
- ICSTI will consider feedback and adapt position accordingly
- Advice to be presented to Government in time for November Competitiveness Council

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1. Collaborative Actions

- Creating European centres of excellence through collaboration between laboratories:
  - Collaborative research – has always been at the heart of EU research policy
  - One of the main issues will be choice of thematic areas – continue as per FP6 or adapt?
  - The use of “new instruments” (Integrated Projects; Networks of Excellence) vs “old instruments”
- ICSTI position paper likely to argue strongly in favour of this pillar – retain at least 66% of budget for collaborative research
- ICSTI paper to support idea of rebalancing in favour of “old instruments” (STREPs etc.)

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2. Technology Platforms

- Large-scale European Technological Initiatives to make major advances in specific fields:
  - Technology Platforms to define common research agenda
  - Implementation through *Integrated Projects* or through *joint technology initiatives* for a limited number of key technologies
  - Funding mechanisms to be thought through
  - Looking at a loan guarantee fund to help leverage finance for these projects
- ICSTI consultation paper will suggest need for caution – Technology Platforms may tend to favour big rather than small; closed networks rather than open...

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3. Competition in Basic Research

- Stimulating creativity of basic research through competition between individual teams at European level:
  - Dublin Symposium achieved consensus on need for EU level support
  - Excellence as exclusive selection criterion for funding, to be identified by ‘peer review’
  - No obligation of transnational cooperation
- Still a need for greater clarity here – blue skies research or more oriented?
- Still question marks about the precise institutional arrangements for funding

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4. Human Resources and Mobility

- Making Europe attractive to be best researchers
  - Sufficient quantity of high-quality researchers an essential condition for attracting research investment
  - Promote mobility of researchers and improve attractiveness of research careers in Europe
  - Build on success of *Marie Curie* fellowships
- ICSTI starting point likely to be strongly in favour of continuation "as is" – Marie Curie Fellowships etc. considered very important from Irish perspective

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5. Research Infrastructures

- Developing research infrastructure of European interest
  - Building on first steps towards European infrastructure policy (European Strategy Forum on Research Infrastructures)
  - EU financial support for the construction and operation of new infrastructure of European interest
- ICSTI paper likely to express need for caution – concerns about Framework funding being used for construction costs
- Concerns also about infrastructure selection process – based on roadmaps – some issues about validation of roadmaps

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6. Coordination of National Programmes

- Improving the coordination of national research programmes:
  - Key to overcoming fragmentation of national efforts
  - Reinforce existing mechanisms for networking and exchange / create new opportunities for the integration of national programmes (ERA-NET, Art. 169)
- ICSTI paper likely to express support for coordination initiatives

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Some Horizontal Issues

- Instruments for delivering FP initiatives – "new instruments" are perceived as being more about bigger projects over longer time periods.
- Administrative Simplification/Management of Projects
- Mechanisms for SME involvement – special calls for SMEs or greater integration with mainstream thematic areas?

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Consultation Strands

Strand 1	Strand 2	Strand 3	Strand 4
Consultation by Task Force with key public **funders** of research	Consultation by Task Force with key **industry and sectoral representative** bodies, in particular for SMEs	Consultations to be organised by **National Delegates** in thematic areas with their respective constituencies	Consultation document to be made available on ICSTI **website**

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ICSTI Consultation Process
Full detail to appear in national press before end of September
Detail will also appear on ICSTI website (www.forfas.ie/icsti)
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COST Domain on Forests and Forestry Products – Opportunities for European Networking

Y. Birot*

The inventory of research capacities in Europe carried out by the COST domain in the field of forestry (Bystriakova and Schuck 1999) has shown that there is a substantial human research resource in the forestry area. In addition to major institutions, however, there are also numerous small organisations and forestry faculties, leading to a general pattern of fragmentation and dispersion. Therefore, there is a large space for synergy and networking through international processes. Among the various instruments, COST is certainly one which contributes to making the European Research Area (ERA) a reality.

The paper aims to answer the questions:

- What is COST?
- What are its activities and achievements in the field of forests and forestry products?
- What are the prospects for COST in relation to ERA and FP7;
- What are the technical and scientific challenges in the forestry cluster and how COST can contribute to meet them?

WHAT IS COST?

COST stands for European Co-operation in the field of Scientific and Technical Research. It was created in 1971 through an intergovernmental agreement, independently of the framework of the European Community. Although COST is not a body with a legal personality, it was, when it was set up, the only vehicle for formal co-operation in science and technology in Europe, apart from the Joint Research Centre set up by the EC, and some major common research facilities on nuclear physics, astronomy and molecular biology resulting from multilateral agreements. This initiative was later on followed up by the launching of new instruments such as the European Science Foundation (ESF) in 1974, the first European Framework Programme for RTDI in 1983 and the EUREKA programme in 1985. Notwithstanding the establishment of these additional instruments, the interest of the scientific community in COST has constantly increased. From 1971 until the present, COST membership has grown from 19 member countries to 35 (Figure 1) and the number of COST Domains (=Research Areas) from 7

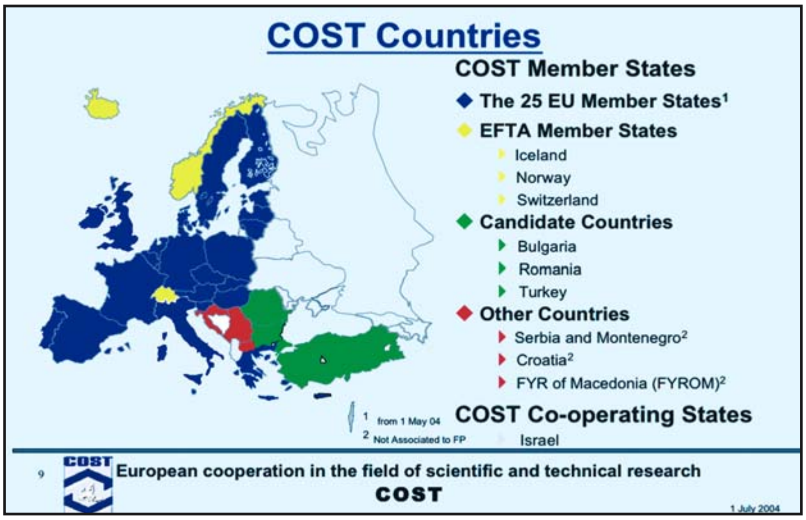

Figure 1: COST membership.

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to 14, while the number of ongoing Actions (=projects) has increased from 7 to almost 200.

The main objectives of COST are to:

1. ensure a strong position of Europe in research and technology,
2. co-ordinate nationally funded research through concerted projects called COST Actions (= network of co-ordinated research projects),
3. to deal with non-competitive research and pre-normative co-operation, environmental and cross-border problems, problems of public utility, sustainable development, etc.,
4. maximise European synergy and add value in research co-operation and
5. integrate Eastern Central European countries and non-COST member countries.

COST activities are based on very simple principles. The basic idea is to encourage bottom up, à la carte, flexible Actions through a loose organisation. That means that any researcher in any COST country can propose an Action, and any COST country can also initiate an Action. The participation is open to and voluntary for COST member states. No domain is prohibited and there is no priority within domains. COST is quality driven, through evaluation processes of Actions at different stages; ex ante, mid-term and final. COST does not fund research but organises research co-operation on the basis of Actions and pays for co-operation costs of European participants in areas such as: science management meetings, scientific workshops and seminars, Short Term Scientific Missions (STSMs), training Schools and research conferences, evaluations and studies and dissemination. To sum up: research is home-funded while co-ordination is shared.

COST has become the most important platform for scientific co-operation in Europe covering almost every field of research. The relative weight (in terms of number of Actions) of COST domains is given in Figure 2 based on 2003 data, but the most recent information shows that Forestry will become number 1 at the beginning of 2005. It is estimated that about 40,000 researches partake annually in COST Actions, while the mean number of participating countries is about 16. The annual budget of COST is only €14 million, to be compared to the total cost of the ongoing research programme in COST countries in the corresponding areas, estimated to be as high as €2 billion.

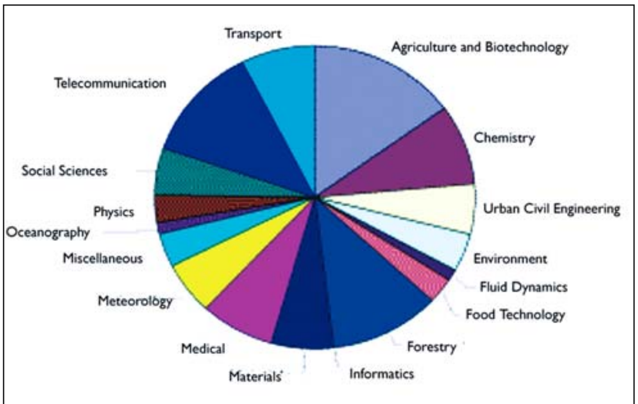

Figure 2: Relative size (in terms of numbers of Actions) of COST domains.

The governance of COST is based on different bodies. The highest is the Conference of COST Ministers, while the operational decision making element is the Committee of Senior Officials. The latter is composed of up to two delegates per country, one of them being the COST National Co-ordinator. The CSO is responsible for the overall strategy of COST and supervises the Technical Committees (TCs). The TCs, composed of representatives from member countries (in general up to two); are in turn responsible for the quality control of Actions, from the selection process to the final evaluation, and any aspects related to the implementation of Actions. Each individual Action is managed by a Management Committee (up to two delegates per signatory country).

The Council of EU provides secretariat assistance to the CSO through financial contribution from the member states to a COST General Secretariat, while the COST Office provides the secretariat facilities to the Technical Committees and the Management committees of individual Actions (Figure 3). In 2003, the COST Office was transferred to the European Science Foundation (ESF) through a contract between the EC and ESF, having the form of a ‘specific support action’ granted through FP6.

The main strengths of the COST system are linked to its capacity of:

1. building upon the commitment of countries through the signature of a memorandum of understanding for every new Action,
2. being led by science and giving scientific exposure,
3. providing opportunity for networking with international colleagues.

It is also a platform for further development and co-operation. Last but not least, it offers very good value for money. The European scientific community sees large advantages in COST as it is the only

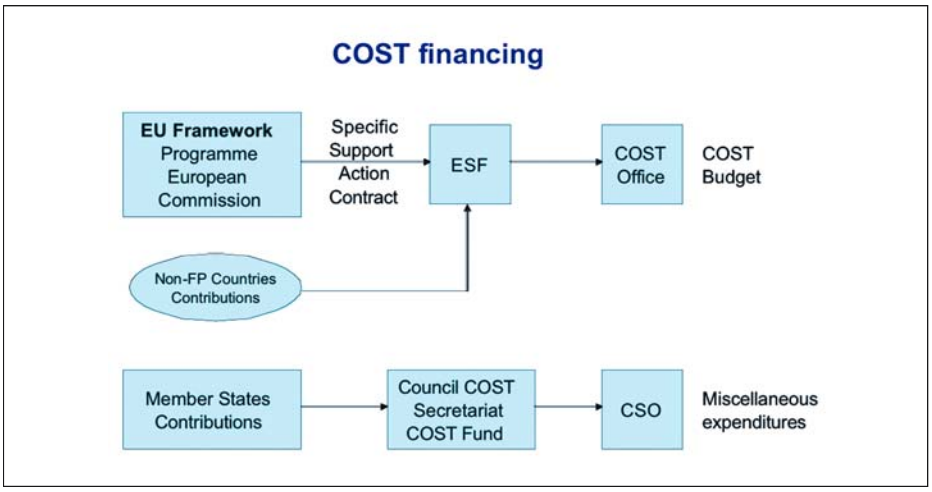

Figure 3: Funding of COST.

mechanism in Europe that in less than two years can start a very large completely new research co-operation project in any field. COST also gives researchers a bottom-up way to influence research direction on the macro-level. The system is also good for activating non EU-member participation.

COST also shows some weaknesses. It is a fact that, until recently, its role has been largely underestimated by the EC. Within the member countries, the political support given to COST is not always at the level that it should be. The COST system is also suffering from a insufficient publicity and dissemination; this is largely due to the fact that COST activities are based on the good will of people acting on a voluntary basis. The average budget allocated to each Action is too limited and does not allow sufficient flexibility. There are also not proper mechanisms for continuing successful networks, even through the maintenance of a simple website.

There are nevertheless good reasons for joining a COST Action. There is no better way to get the state of the art input from the scientific world to one's project. COST also brings added value to national science and technology programmes.

COST ACTIVITIES IN THE FIELD OF FORESTS AND FORESTRY PRODUCTS

In Europe, the COST Forests and Forestry Products (FFP) domain is unique in the sense that it is the only research platform that encompasses the whole Forestry-Wood-Chain (Birot *et al.* 2004). The TC FFP, created in 1994, covers the fields of forests, wood technology and pulp and paper and comprises three sector groups that deal with these areas. Since its establishment the number of ongoing Actions has increased from 3 to 25, while 21 have been successfully completed. On average, the number of participating countries is rather high; for some specific Actions, it may even be larger than the 25 members, as non COST countries are allowed, under certain rules, to join Actions. It is estimated that about 1,400 researchers partake annually in COST FFP Actions. The annual budget for a COST Action is about €70,000, while the corresponding total research investment in the member countries are on an average of €3.7 million.

The fact that FFP has become the most important domain within the COST system, as mentioned before, demonstrates the relevance of a common research platform for the forest sector. Moreover, the organisational structure of the TC FFP in three sector groups, allows addressing sectoral as well as cross-sectoral issues. The success of COST FFP also reflects the fact that, apart from the pulp and paper research sector where there are major research institutions, research forces in the field of forests, and especially wood, are rather dispersed and fragmented; this situation can be compensated to a certain extent by the networking offered by COST.

The five thematic areas covered by the domain FFP are listed below: the full list of individual Actions (on-going and completed) is given in Annex 1:

- Biophysical basis of sustainable forest management
- Forest policies for people
- Forest products and the environment
- Forest products: properties and performances
- Process engineering in wood based industries

At the beginning of its life, the TC FFP set up a flexible process aimed at identifying priority co-ordination areas. Later on, the door was opened to a more bottom-up approach. Within the domain FFP, the nature of Actions is very diverse. The spectrum ranges from basic science to very applied aspects, from policy to technology and engineering. For example, Actions on: 'forest tree genomics', 'wood fibres wall structure' or 'fracture mechanics' are very much science orientated. Other actions deal with social and policy sciences, while in the field of wood and pulp and paper, many are related to properties (characterisation methods for fibres, reliability analysis of timber structures) and processes (drying of wood, de-inking recycled papers).

The domain FFP has been efficient in creating synergies and adding value to nationally funded research, by producing syntheses and state of the art publications, and sometimes, good support to policy making processes and to industrial needs. In former Framework Programmes (prior to FP6), COST Actions in the FFP domain have very often resulted in successful 'shared cost projects' or 'concerted actions': very significant by-products of the COST process.

As examples, some success stories in the domain FFP are highlighted below. The first example is the Action on 'the contribution of forests and forestry for the mitigation of greenhouse effects'. This Action addressed the issue of carbon exchange between forest and the atmosphere. In ecosystem functioning processes, carbon is absorbed in trees and plants trough photosynthesis, stored in soils (organic matter), and emitted (respiration, mineralisation of organic matter); C is also stored into wood based products. The idea was to develop a commonly agreed carbon accounting strategy in Europe within the framework of the Kyoto Protocol, through the harmonization of methods of C pools and flux assessment. This Action, ranging from science to policy, was quite successful and provided a significant technical support to the political process, including the sixth and subsequent Conference of the Parties to the UNFCCC in The Hague.

A second success story is related to the Action 'wood adhesion and glued product'. There is clear trend for the development of engineered wood products and structures, which require improved gluing in terms of: performance, competitiveness and environmental properties of processes and products. A forum between engineers and scientists from 15 countries defined the state of the art and established basic knowledge for industrial development. A framework for structuring knowledge and methods was established. A book and CD on the state of the art have been a basis for academic instruction and common production procedures in industry.

The third example is the Action on 'paper recyclability'. This Action has addressed a very timely subject. The enhancement of recycling fibres and waste paper processing has become a key issue for the paper industry. This requires improved knowledge on fibres and processes. The Action has tackled the problem from several angles: fibre properties, fundamentals of de-inking, stock preparation chemistry, new technologies, life cycle analysis. The main outcomes were new knowledge on the influence of repeated recycling on fibres, and new analytical methods for solving process related problems and the identification of the reason of their occurrence. The Action has also resulted in the publication of a handbook on recycling.

THE FUTURE ROLE OF COST IN RELATION TO ERA AND FP7

New challenges in the Forest and Forest Industry Cluster require increased co-ordination and co-operation in research and technology.

A first issue is the future positioning of COST within the ERA and in the next EU Framework Programme (FP) for RTDI. It would be wise not to kill COST by too high an expectation, but rather to keep it on its basic role, which is to get good scientists together under a light strategic guidance, and let them work out their ideas. It is also recommended to preserve COST's comparative advantages: small size, efficiency, fastness, effectiveness and flexibility. The possibility of acting outside the strict confines of the FPs, is part of COST's value, and this should be maintained. But COST is financed through FPs; therefore it should find its place there.

From an EU perspective relevant objectives for COST should be the continuation of the co-ordination of research funded by sources in the Member States. COST has obviously anticipated the ERA-net structure under the current FP, but there are major differences between both systems in terms of size and involvement of the industrial sector. Therefore, COST should aim at complementing future ERA-Nets. COST also should anticipate and complement the activities of the FP, both for 'networks of excellence 'and 'integrated projects'. An increased coherence and synergy between COST (bottom-up driven) and FP (priorities driven) is absolutely necessary; as recongised recently by the EC. Furthermore, COST should provide inputs regarding Community thematic research and on horizontal European research policy issues.

The sustainable management and use of forest resources and products, as pillars of a bio-based economy, are certainly a key component of a sustainable European society. However, they are becoming more complex due to major changes already going on in our world. Concerns are growing regarding the possible impact on forest ecosystems of global climate change. Urbanized people see forests as the last reservoir of 'naturalness'. Multiple environmental, social and economic functions in the same areas, adjacent areas or distant ones are assigned to the forests by more and more diverse stakeholders, calling also for diversified management strategies and scenarios; moreover, forests have to be seen in the broader context of landscape and land-use. This is turn requires more diversified and increased research efforts. At the same time, the economic indicators are predicting a slightly increasing consumption of wood based products, while wood based energy is emerging as a potential area. Forest industries are also fragile in the global context: strong restructuring is taking place in the pulp and paper industry, paper and engineered wood products are exposed to the competition of other materials. In Europe, it appears that a closer coupling between forest producers and forest industries is one condition of the viability of both sides, as the competitiveness of the whole forestry-wood chain is at stake.

Addressing these issues is of major importance for Europe's countries, their citizens, and the forest and forest industry cluster. Research and technology activities on forest and forest based products will undoubtedly contribute to solving many problems by acquiring the knowledge and creating the tools which will allow the sector to respond to increased expectations and the needs of professionals, policy-makers and society as a whole. It is expected that COST TC FFP will continue to be a unique instrument for enhancing co-operation and co-ordination of scientific research and technological development related to forests and forest products. New opportunities also exist for developing synergies within the COST systems, between TC FFP and other TCs (Environment, Agriculture, Meteorology, Materials, etc.), and also with the European Science Foundation (ESF), particularly in the field of biophysical sciences. The involvement of other disciplines through partnership, such as: population biology, integrative biology, genomics, nano-sciences, biotechnology, surface chemistry, modelling, landscape science, environment economics, human behavioural science, policy and decision science, also appears highly desirable.

The size of the COST network on forests and forestry products makes it a key player in the European Research Area (ERA). In addition to its own activities, the TC FFP can contribute, in its field of competence, to the development of new initiatives aimed at creating new instruments of co-operation such as: ERA-Net, Technology Platform, Networks of Excellence, Integrated Projects and others (Birot *et al*. 2004).

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ANNEX 1

List of completed and ongoing Actions in the COST domain FFP

Biophysical basis of sustainable forest management

- Forest tree physiology research EUROSILVA (E6)
- European Forest genomics network GENOSILVA (E28)
- Woody root processes (E38)
- Bark and wood boring insects in living trees (E16)
- Long term forest ecosystem and landscape research (E25)
- Contribution of forests and forestry to the mitigation of greenhouse effect (E21)
- Chestnut multidisciplinary research (G4)
- Growing valuable broadleaved tree species (E42)
- Harmonisation of national inventories in Europe (E43)

Forest policies and people

- Forestry in the context of rural development (E3)
- Forest reserves research network (E4)
- Urban forests and trees (E12)
- National forest programmes (E19)
- Protected forest areas in Europe (E27)
- Economic integration of urban consumer's demand and rural forestry production (E30)
- Forest for recreation and nature tourism (E33)
- Forests, trees and human health and well-being (E39)
- European Forest externalities (E45)

Forest Products and the Environment

- Wood durability: mechanisms and improvement with environment friendly methods (E2)
- High performance in wood coating (E18)
- Environmental optimisation of wood protection (E22)
- Towards zero liquid effluent in paper making (E14)
- Effective solutions to reduce the impact of waste arising from the papermaking process (E26)
- Life cycle analysis: from forest to end of life (E9)
- Recovery wood management (E31)
- Sustainability through new technologies for enhanced wood durability (E37)
- Innovative utilisation and products of large dimensioned timber including the whole forest wood-chain (E40)

Forest products: properties and performances

- Timber-frame building systems (E5)
- Mechanical performances of wood and wood products (E8)
- Wood properties for industrial use (E10)
- Characterization methods for fibres and papers (E11)
- Wood fibres wall structure (E20)
- Reliability analysis of timber structures (E24)
- Innovative timber and composite elements/components for buildings (E29)
- Characterization of paper surfaces for improved printing paper grades (E32)
- Fracture mechanics and micro-mechanics of wood and wood composites with regard to wood machining (E35)
- Analytical tools with applications for wood and pulping chemistry (E41)

Process engineering in wood based industries

- Multi-phase flows in paper-making (E7)
- Advances in the drying of wood (E15)
- Paper recyclability (E1)
- Wood adhesion and glued products (E13)
- Microbiology in paper making (E17)
- Biotechnology in the pulp and paper industry (E23)
- Bonding of timber (E34)
- Modelling and simulation in papermaking industries (E36)
- Wood processing strategy (E44)
- Improvements in the understanding and use of de-inking technology (E46)

The Importance of Knowledge Transfer in the Forestry Sector in Ireland

L. MacLennan*

INTRODUCTION

COFORD was established in 1993 to co-ordinate and fund appropriate and cost-effective research to secure long-term industrial viability and optimise social, environmental and economic developments associated with forestry and the wood products sectors. One of our key functions is to transfer the knowledge into practice, as can be seen from our mission statement, which is to:

- establish and strengthen links between research and industry;
- determine forest research and development needs to maintain international competitiveness, provide sustainable employment, encourage innovation and enhance environmental harmony;
- evaluate research and development progress and transfer technology to ensure maximum benefit.

Essentially, COFORD may be seen as a channel between research and application – this is an important and essential role. Members of the Council and the Executive are all involved directly in forestry and related areas and industries, and we have a wealth of in-house expertise, so are well positioned to fulfil this function.

The knowledge transfer process should be planned into any research project as the potential and value of research can only be realised if the findings are taken to and used in the appropriate application areas. In this presentation COFORD's knowledge transfer programme will be discussed, with an invitation to researchers to participate in it, so as to facilitate the delivery and uptake of their findings into relevant areas for application.

KNOWLEDGE TRANSFER MECHANISMS

COFORD's co-ordination function makes it a central hub in the flow of forest-related information in Ireland. One of the key functions of COFORD is to transfer technology and knowledge from research to industry and the wider forestry sector. The audience, or end-users, are the stakeholders in Irish forestry: professional foresters, private growers, nurserymen, sawmillers, contactors and users of wood products, government agencies and departments, as well as those involved in research and development.

We fund a wide range of projects, and results and recommendations arising from the research are imparted to these users. COFORD develops projects and initiatives to address the programme objectives through applied and strategic R&D programmes, and desk studies. Our current projects are being showcased at this conference.

Our short-term research mission programme has been reviewed and as a result has been revised and expand. It is now known as the networking and knowledge transfer supporting initiative. Applications are invited from eligible organisations, companies, institutions or individuals for support for workshop/seminar grants, travel/mobility grants and working visit grants (both inward and outward working visits) in the priority areas: the wood energy supply chain; forest economics; land-use policy; wood products; harvesting technology; non-wood forest products; integrated pest management; and grower co-operatives. We have just awarded two working visit grants in the past week, resulting from the most recent call. Pieter Kofman from Denmark will be hosted by Waterford Institute of Technology for a 6-week period to guide the sector on wood

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biomass supply chain development. This will include organising a whole tree chipping demonstration. In addition he will meet with key players in the renewable energy sector to advise them on developing long-term supply contracts for wood biomass. Also, Martine Blaix and Dr Paddy Walsh from GMIT will travel to CSIRO's European Laboratory in France to study techniques for parasitoids in biological control programmes and to establish collaboration for the Forest Biosecurity Network that will be launched at GMIT in 2005. We hope to have another call for working visit grants early in 2005 – watch the website www.coford.ie and the press for details.

Our continuous development programme demands that the cost-effectiveness and value-for-money of all activities is constantly reviewed. We operate on a tight budget, and so we are constantly seeking more cost-effective ways of accessing and transferring information, for packaging, filtering and translating research results for a wider audience. We attempt to utilise the latest technology to improve the effectiveness of our information dissemination activities. Over the past years this has led to the adoption of new methods of communication including a monthly email newsletter and mobile phone text alerts. These are very effective in terms of cost and impact.

The COFORD newsletter *Forestry and Wood Update* was started in April 2001. It is distributed once a month, free-of-charge, via email to subscribers. The contents include the latest news and events from COFORD, as well as articles on groups with whom the COFORD executive is involved. We also feature information about events of interest taking place throughout the world. There are over 2,000 subscribers at present, from all over the world, with new members being added each week. We invite members of the forest industry to submit relevant information for inclusion in the newsletter, and thereby to access this large audience. Current and previous issues can also be downloaded from the COFORD website, either as MS Word documents or in html format.

WEBSITE

The COFORD website is a key component of the technology transfer arsenal. We try to keep it as up-to-date as possible with the latest reports, publications and information about events and activities. The on-line ordering of publications, as well as signing up for the newsletter is well utilised and makes the administration of these functions more streamlined and organised. The website also attracts many queries from people around the world. In the near future, we hope to add functionality to the website, by developing active server pages (ASP), to make the site more dynamic and interactive, such as allowing on-line booking for seminars. Our front page is regularly updated and always lists new developments and forthcoming events.

COFORD also hosts the Woodspec site - www.coford.ie/woodspec – the guide to designing, detailing and specifying timber in Ireland. The Woodspec team recently conducted a series of regional workshops to promote and explain the guide in greater detail to target audiences. COFORD has set up a free technical advisory service for anyone seeking further assistance with detailing, specifying or designing with timber. To avail of this service, users simply fill out the form on the Woodspec website and email it to woodspec@coford.ie

More recent additions to our web fleet are the Wood Energy site – www.woodenergy.ie - which we will be launching at the Wood Energy conference in October, and the link to the Home-Grown Hardwoods Supply and Procurement Portal.

SEMINARS

Conferences, seminars and workshops are excellent ways of transferring information – not only through the formal presentations but also because they provide important opportunities for personal interaction and networking. As such they form the backbone of COFORD's technology transfer programme. They are an effective means of addressing or responding to current issues. When appropriate topics are identified, a group of experts in the field are invited to address delegates about current knowledge from various perspectives. We have a wide network of contacts in various fields and disciplines and, after consultation, a relevant programme of presentations is compiled, offering a range of approaches and opinions. Wherever possible, an outdoor or practical element is included as part of the event, to supplement the more formal presentations. Brochures are sent out to selected addresses on the database, and information is made available on the COFORD website and emailed to potentially interested people.

Seminars and workshops that we have planned to the end of this year are:

- The Wood Energy 2004 conference which we host in collaboration with Sustainable Energy Ireland Renewable Energy Information Office (SEI REIO), to be held on 6, 7, and 8 October at the Rochestown Park Hotel, Cork.
- Forest mammals conference – back at this hotel on 26 November.

Members of the COFORD executive are frequently invited to participate in working groups, meetings and seminars hosted by other organisations, and contribute to publications produced by other groups. The executive are active members of national bodies including the Forestry Climate Change Team, the Irish Forest Industry Chain, the Timber Standards Consultative Committee of NSAI, the Wood Technology Centre at the University of Limerick, and the Wood for Energy Strategy Group.

They are also involved in international groups such as the European Tropical Forest Research Network, IUFRO, The European Forest Institute, European Forest Genetic Resources programme (EUFORGEN), British and Irish Hardwoods Improvement Programme (BIHIP), COST and the EC Framework RTDI Programme.

By participating in these groups we have access to a wide range of issues and expertise and can bring this back to contribute to the Irish forestry sector and feed the latest findings into policy formulation forums.

PUBLICATIONS

High quality publications have been produced by COFORD since its inception. Reports are widely circulated in the sector and are sent to abstracting organisations like CABI, as well as to legal deposit and other libraries, and to a number of other organisations. Most can be downloaded from the COFORD website or hard copies can be ordered for a small fee from the COFORD office. We receive orders for our publications from all over the world, showing that we are not catering only for the local audience, and that our research has relevance beyond Ireland.

The COFORD annual report reflects the current status of the projects funded by COFORD. All project leaders and teams contribute information about the status and achievements of their projects so it is an important 'snap-shot' in time of the research funded by COFORD. Flagship publications include *Growing Broadleaves*, *Sitka Spruce in Ireland* and *A Guide to Tree Species Selection and Silviculture in Ireland*, which is being reprinted. Later this year we will be launching two new books: *Trees, Forests and the Law in Ireland*, by Damian McHugh and Gerhardt Gallagher, and *Forestry in Ireland – A Concise History*, by Niall OCarroll. We also have a new report available on *Markets for Non-wood Forest Products* and have a number of other publications in preparation. We will be producing the proceedings of this conference.

COFORD is selective and cost-conscious about what it publishes in hard copy. As an alternative, electronic publishing is a very convenient and cost-effective option. COFORD has published conference proceedings electronically as well as CDs of unedited presentations made at the various seminars and workshops.

COFORD Connects is a series of practical information notes, launched in March 2001, which review various aspects of forestry. The notes are produced on an ongoing basis and presented in a purpose-made folder. Emphasis is on practical recommendations to facilitate the implementation of research findings. The notes are aimed at all sectors of the forest industry, and cover six primary areas:

- Reproductive Material and Nursery Management
- Silviculture and Forest Management
- Harvesting, Transport and Forest Machinery
- Wood Processing and Product Development
- Socio-Economic Aspects of Forestry
- Forestry and the Environment.

The series also draws on work outside the scope of COFORD-funded research, to inform practitioners of new and relevant developments beyond current best practice. The latest set of notes includes:

- Common alder (*Alnus glutinosa*) as a forest tree in Ireland
- Realising the potential of private plantations
- Thinning to improve stand quality
- Pruning adds value to plantations
- Considerable savings possible by planning harvesting systems
- Uses of home-grown Irish timber
- Improving the stability of structural timber
- Liming options in afforested catchments in Ireland
- Global forest certification - 2004 update

OTHER PROMOTIONAL MECHANISMS

COFORD is active in the promotion of wood products through its involvement in the *Irish Joinery Awards*, where it sponsors the prize for *Innovative Use of Irish Wood*. It also sponsored the *About the House* television series which features the innovative use of wood products in construction and refurbishment. Last year we sponsored an award at the *ESAT Young Scientist Exhibition* and we gave a prize for the project that best depicts the positive role of trees and forests in the landscape/environment. At the *Environmental Researchers Colloquium* we give a prize for the best presentation on a forestry-related theme.

CASE STUDIES

A few examples of successful knowledge transfer are given below to show how these research projects have influenced policy and practice in the Irish forest industries. You will be hearing more detail about these projects during the course of the next two days but I want to touch on the importance of transferring the knowledge generated through these projects and their impact on the forest industry.

- ***CarbiFor – Carbon sequestration in Irish forest ecosystems*** – is a particularly good example of how the knowledge transfer mechanism has taken the research findings and filtered them into national policy. The research findings from this project cluster provide data to determine carbon stocks and sequestration rates spanning the entire lifecycle of the major forest type in Ireland, Sitka spruce. The Forest Service, EPA and the Department of the Environment, Heritage and Local Government use these findings in the development of national policy and in reporting to the UN Framework Convention on Climate Change. The development of Biomass Expansion Factors (BEF) has been of considerable importance.
- ***WoodEnergy*** is another excellent example of research being taken to a practical application, with important ramifications for the economy and environment. The project's full title is Maximising the potential of wood for energy generation in Ireland. The concept of generating energy from wood biomass is taking off in this country, and COFORD has teamed up with the SEI REIO for the past three years to host an annual conference on the topic. This year the conference will be held from 6 to 8 October at the Rochestown Park Hotel in Cork. The COFORD project was the spark that lit the now widespread interest in this form of renewable energy. It identified the potential of wood energy to contribute to Ireland's renewable energy and carbon emission reductions target. It also identified the regulatory, institutional and policy barriers to the greater realisations of this potential. Joe O'Carroll (Operations Manager, COFORD) was selected to sit on the interdepartmental Bioenergy Strategy Group which is charged with making recommendations to overcome these barriers, and make wood energy a reality in this country.
- The ***RoadMan*** project was completed last year, and a key output from this research was the *Forest Road Manual – Guidelines for the design, construction and management of forest roads*. This document is available from COFORD – and can be downloaded from our website – and promises to have a very positive influence on best practice. This guide will become the standard work for the design, construction and maintenance of forest roads. Proper, fit-for-purpose roads are essential harvesting and haulage infrastructure to realise the potential roundwood production from Irish forests.

These examples show that the potential value of research can only be realised if the information is taken to an arena, in an appropriate form, where it can be applied.

CONCLUSIONS

One of our key functions is the dissemination of research findings to the forestry community. We rely on a range of forums and media to accomplish this, and are constantly striving to improve the effectiveness of this programme by incorporating new technology where relevant and implementing cost-effective and innovative ways of responding to current issues. One of the problems of knowledge transfer is assessing how effective efforts have been. The only real way to estimate this is to see how recommendations are being practised and how the industry is developing as a consequence of research findings being adopted and applied.

We constantly strive to be aware of the requirements of the end users in terms of information needed, current and potential issues to be addressed and the most appropriate forum for transferring the knowledge. We rely on feedback and input from the people who use the information.

Meetings such as this are very important opportunities for sharing of information, and discussing approaches. I would like to close by inviting you to participate pro-actively in the COFORD technology and knowledge transfer programme, and hope that you make full use of the opportunity to network, share ideas and interact at this conference.

Improving the Quality of Broadleaf Planting Stock in the Nursery

C. O'Reilly*, N. De Atrip, C. Doody, P. Doody, D. O'Leary, N. Morrissey and B. Thompson

INTRODUCTION

The production of high quality seedlings in the shortest period of time at the lowest price possible is essential in maintaining the commercial viability of bare-root nurseries. Until recently, the majority of broadleaf planting stock was imported into Ireland: about seven million (69%) broadleaves were produced in the country in 1999/2000 while the remainder was imported.

The current government target is for broadleaves to account for 30% of afforestation planting. However, Irish nurseries have had relatively little experience in the growing of broadleaves. It takes about two years to produce most broadleaf planting stock here, whereas continental European counterparts can produce equivalent sized stock within one year. The warmer growing season than in Ireland may be the main reason for this. Also, the seed treatment and cultural practices used in Irish nurseries may weigh against the production of low priced, high quality stock.

While all phases of the production cycle in the nursery are important, research effort may yield best results if first focussed on improving germination and early seedling growth. Poor and uneven germination and slow initial growth are likely to lead to the production of a crop that is uneven in size. Treatments used later in the growing cycle to improve growth and uniformity may not be required if problems are corrected during the early part of the cycle. Improvements in the seed pre-treatment protocols (including invigoration treatments) might lead to and an increase in percentage germination and in the speed and uniformity of germination. For example, the date of seedbed germination of oak acorns can vary as much as three months in Irish bare-root nurseries. Temperature has a large impact on the germination response, so selecting the optimum sowing date may lead to additional improvements in growth and yield. This information is of practical significance in a nursery-sowing programme. Species that require low temperatures might be sown earliest, while those requiring higher temperatures might be sown latest. For example, results from recent research carried out in Ireland showed that noble fir should be sown early and Douglas fir late in the sowing programme (Doody and O'Reilly 2005).

The aim of on-going research work at UCD and Coillte's Ballintemple nursery is to improve seed germination and plant growth in common alder (*Alnus glutinosa* Gaertn.), birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.), ash (*Fraxinus excelsior* L.), and pedunculate oak (*Quercus robur* L.) in the nursery (QualiBroad project funded by COFORD and Coillte). These native species were chosen because they are difficult to grow successfully in the nursery.

The project involves laboratory and field experiments. Seed pre-treatments, seed storage practices and seed covers are being examined in the laboratory phase of the project. Treatments that deliver improvements compared with the standard method in the laboratory experiments are being evaluated in the nursery, but few data are yet available because most of these experiments are scheduled for the latter part of the project period. In the nursery experiments, the effects of sowing date, mulches, cloches (polythene or other fabric materials raised over the nursery bed), nitrogen fertiliser and biostimulants on plant growth and seedling size uniformity are being investigated.

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1 *The term seed is used in the broadest sense since some of the fruit (e.g. pericarp) is frequently dispersed as part of the 'seed unit'.*

MATERIALS AND METHODS

Pre-treatment and storage of seeds

The effect of seed moisture content (MC) during pre-chilling treatment to break dormancy or during storage on the germination performance of alder, birch, ash and oak seeds was investigated. Seeds of each species were adjusted to different MC levels and then chilled at 4°C for various periods. The results of experiments showed that the optimum or target MC (TMC) during pre-chilling was about 30% in alder and 35% in birch (DeAtrip and O'Reilly 2005).

Unlike the other species, oak acorns have recalcitrant characteristics, which means that their MC must be relatively high otherwise they will deteriorate during storage. However, acorns stored at very high MC levels will respire heavily and are more likely to succumb to fungal diseases. Acorns were adjusted to various MC levels in this study and then stored at 4, 1 and -3°C. The highest acorn MC treatment was evaluated in a nursery trial in 2004. Ash seeds require very long pre-treatments (both a warm and a cold phase) to release dormancy. Information on the effect of seed MC levels on dormancy release in ash is not yet available.

Sow date, mulches, cloches, N fertiliser levels and biostimulants in the nursery

The effect of sowing date, mulches and cloches (perforated and non-perforated polythene materials, fleece, and turkey manure) on seedling emergence and growth were evaluated for each species in a series of experiments in 2002. The effect of fertiliser rates and type (slow release and 'exponential' method) and a biostimulant ('Lysaplant') were also evaluated, mostly in combination with cloches. The treatments, which appeared to deliver the most practical benefit in the 2002 experiments were evaluated further in 2003 and 2004, but were modified on the basis of the 2002 results. In particular, the effects of cloche removal date, higher levels of N fertiliser than had been used in 2002, and fertiliser application method were examined in 2003 and 2004. Data for all the 2003 and 2004 experiments have not been analysed. The effect of treatments on the seedling emergence and growth was monitored during the growing season. Seedlings were lifted and dispatched to UCD to evaluate height, diameter, shoot and root dry weights. Furthermore, root growth potential of seedlings was assessed after growing seedlings in a heated greenhouse for several weeks.

RESULTS AND DISCUSSION

Pre-treatment and storage of seeds

The TMC method does not appear to increase total germination in alder or birch, but it allows the seeds to be pre-chilled for a longer period without the risk of premature germination or deterioration. The effect of pre-chilling on the germination response of alder is shown in Figure 1. Dormancy is expressed at low germination temperatures in these species, as shown for alder (Figure 1). Furthermore, TMC seeds could also be stored at -3°C for up to 24 weeks following pre-chilling without adversely affecting germination potential, whereas the fully imbibed (standard method) seeds deteriorated. Therefore, the TMC method provides flexibility in nursery sowing operations, especially since adverse weather conditions and other factors frequently delay sowing.

Acorns deteriorated during storage at 4 or 1°C, regardless of acorn MC level. Acorns that had been adjusted to the highest MC level (46%) and stored for 4-6 months at -3°C had excellent germination in the laboratory tests, while the non-soaked controls had poor germination (Özbingöl and O'Reilly 2005). The laboratory germination of acorns in response to MC content following storage at -3°C for 4 months (until March) is shown in Figure 2.

The effect of high acorn MC during storage at -3°C on seedling emergence in the nursery was evaluated in 2004. Acorns that were soaked prior to storage germinated better and faster in the nursery than acorns that were stored in the standard way. The effects of seed pre-chilling and storage treatments on seedling emergence in the nursery for species other than oak have not been fully evaluated.

Sow date, mulches, cloches, N fertiliser levels and biostimulants in the nursery

The results showed that perforated cloches improve the growth of all species, while the effect of biostimulants and mulches were small and not entirely consistent. The effect of date of sowing and cloche type on the proportion of birch seedlings that reached target dimension (>40 cm tall and 4 mm root collar diameter) in 2002 is shown in Figure 3. More than 50% of the seedlings reached target size when grown under perforated cloches after sowing in March (Figure 3). A negligible number of plants reached target dimensions when grown without a cloche. In general, seedlings derived from seeds sown

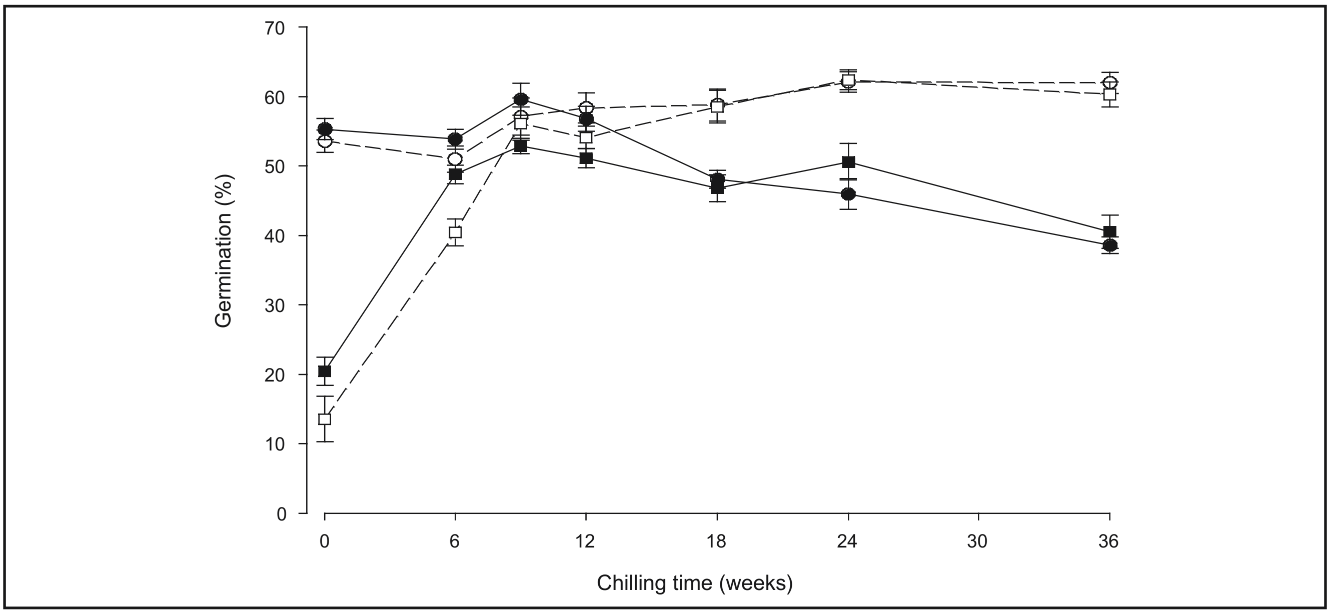

Figure 1: Effect of pre-chilling duration on percentage germination of alder seeds at 15°C (squares) or 20/30°C (circles). Seed treatments: target moisture content (discontinuous lines, empty symbols) and fully imbibed (continuous lines, full symbols). The vertical lines are standard errors (some smaller than symbols).

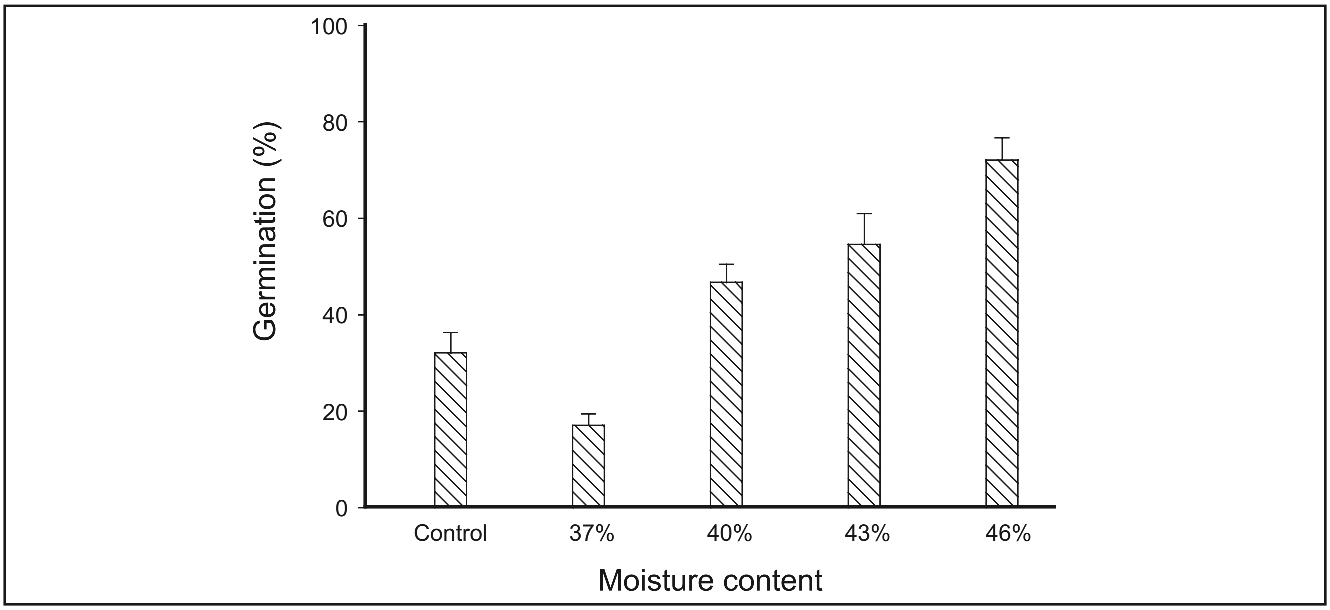

Figure 2: Effect acorn moisture content (MC) levels during storage at –3 °C until March on the germination of oak acorns at 15°C. Acorns were soaked to 46% and then dried back to the different MC levels, except for the controls which were not soaked (40-42% MC at time of storage). The vertical lines are standard errors.

in March and April grew well (exact response varied with species), but sowing later in the season than this was less successful.

All species responded well to higher rates of N fertilisation than are normally used in operational practice, but the exact response varied with species and year of plant growth. It is expected that the trials conducted in 2004 will deliver better information on seedling responses to N fertiliser. It may be possible to grow seedlings of these species to target size in one growing season using high N rates, particularly if used in conjunction with other treatments. A combination of better seed storage/pre-treatments, cloches and higher N application rates might provide the solution to this problem for some species. The total amount of N applied over a one-year growing cycle might be lower than the amount needed to grow seedlings over the standard two-year regime currently used in operational practice.

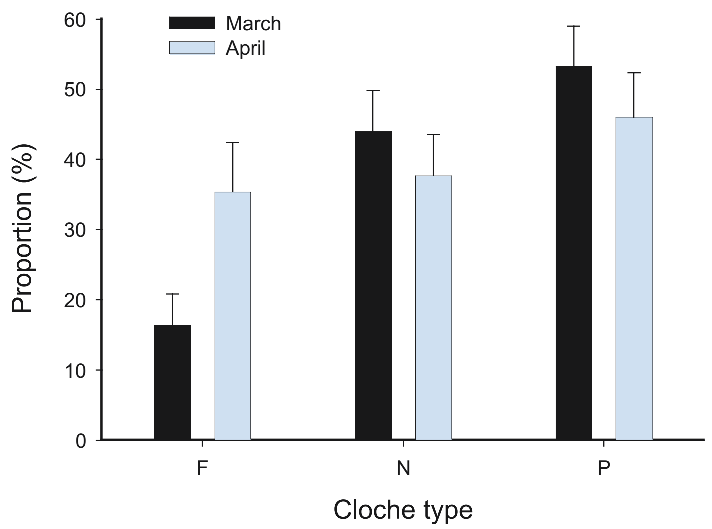

Figure 3: The effect of cloche type and sow date on proportion of birch seedlings reaching target size dimensions (>40 cm tall and 4 mm diameter) in a single growing season in the nursery in 2002. Cloche types: F, fleece; N, non-perforated polythene; and P, perforated polythene.

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Continuous Cover Forestry in Ireland

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BACKGROUND

A continuous forest is one in which the canopy cover is maintained continuously and the soil never exposed (Troup 1927, cited in Yorke 1998). Continuous cover forestry (CCF) is defined as the use of silvicultural systems whereby the forest canopy is maintained at one or more levels without clearfelling (Forestry Commission 1998). It embraces a number of silvicultural systems that do not involve clearfelling, including group felling; shelterwood systems (i.e. uniform, group and strip/group); and group/single tree selection systems. CCF is considered synonymous with alternatives to clearfelling and the term low impact silvicultural system (LISS) (Ní Dhubháin 2003). A LISS is one that has little negative effect on either the forest crop or its general environment.

In some parts of Europe continuous cover forestry has been used for centuries. In Ireland and Britain the clearcutting silvicultural system has been used almost exclusively. It involves clearfelling all the stand and reforestation. However, the use of clearcutting has increasingly been criticised. The sudden change that this practice brings about in the landscape has been one of the primary reasons (Hart 1995).

As a result of concerns about clearfelling and about approaches to forest management, there is a move in countries where clearcutting predominates, to use systems based on natural forest succession or 'near to nature forestry'. For example in Britain, the UK Forestry Standard which sets out the criteria and standards for the sustainable management of all forests and woodlands in the UK requires forest managers to identify areas which are, or will be, managed under a continuous cover forestry system and to build them into forest design (Forestry Commission 1998). Similarly, the UK Woodland Assurance Scheme Certification Standard which sets out the requirements which woodland owners and managers, and forest certification bodies, can use to certify woodland and forest management states (UKWAS 2000; p. 17): 'in windfirm conifer plantations, lower impact silvicultural systems are increasingly favoured, where they are suited to the site and species present'. This increased emphasis on CCF in the UK culminated in the Welsh forestry strategy Woodlands for Wales (Woodlands for Wales 2001; p.25). It states: '[the aim is] to convert at least half of the National Assembly woodlands to continuous cover over the next 20 years'. In Ireland, continuous cover forestry is referred to in the Irish National Forest Standard (Forest Service 2000). One of the measures (4.4.2) of the indicator 'Forest Management' is the area of forest managed for continuous cover. Continuous cover forestry is also referred to in the Forest Management Standards for the Republic of Ireland (FSC) (Mannion 1999). The standard also suggests that low impact silvicultural systems be considered in windfirm conifer plantations where they are suited to the site and species present (Criterion 6.E.3).

Coillte has a policy of sustainable forest management that complies with the Forest Stewardship Council principles. The policy included the commitment to consider continuous cover systems where appropriate. As a result Coillte has begun to install CCF demonstration areas in approximately 1,000 ha of windfirm conifer plantations.

It is known that changing from clearcutting to continuous cover forestry will have implications for a wide range of issues including tree growth, harvesting, economics, amenity, landscape, and recreation. The growth of tree species managed under CCF is poorly documented. Retaining canopy cover

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will have implications for light transmission, temperature, relative humidity, water relations and heat fluxes. In addition, canopy development, growth rate, structure and density all have an effect on throughfall volume and its chemical composition (Nordén 1991, Bouten *et al*. 1992, Ineson *et al.* 1994).

In Ireland, research into alternative silvicultural systems has been limited. Although some work on alternatives to clearfelling began in Coillte in the mid 1990s, most of the current work on conifers commenced in 1998 when COFORD funded a project on this topic (Ní Dhubháin *et al*. 2001) The research project, CONTINUCOVER (An evaluation of continuous cover forestry in Ireland) described in this paper builds on this earlier research work.

METHODOLOGY

The main objectives of the CONTINUCOVER project are to assess the survival and growth of a number of tree species grown under various levels of canopy cover and to monitor throughfall, temperature, relative humidity, light transmission and rates of nutrient turnover (C and N) under these canopies. In addition, demonstration areas were to be established demonstrating the implementation of alternative silvicultural systems to clearcutting. The sites where this research work was undertaken and the methods used are described below.

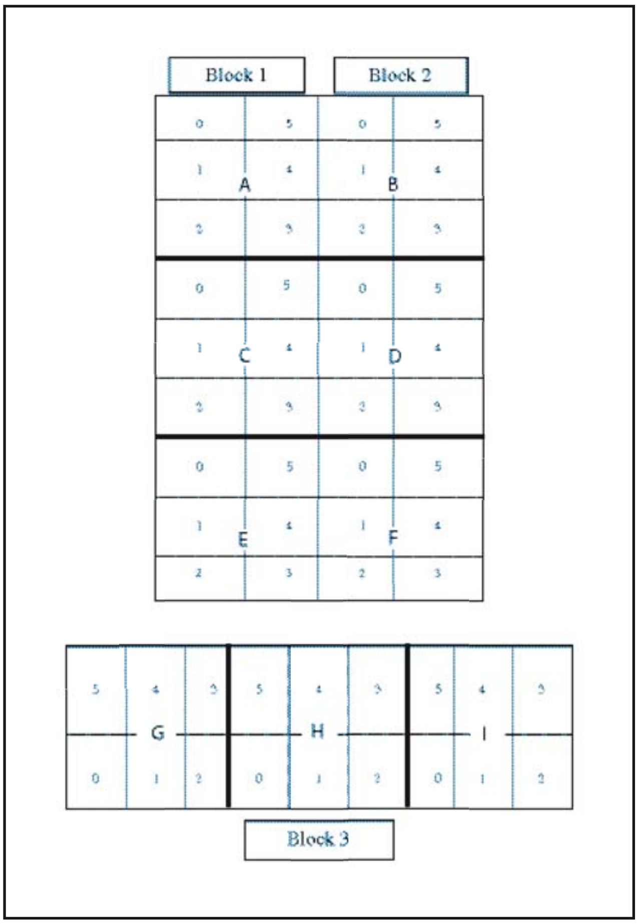

Figure 1: Layout of thinning treatments in the experiment at Aughrim forest, Co Wicklow.

Site 1

An experiment was laid down in a 2.7 ha section of a Coillte-owned stand located at Aughrim Forest, Co Wicklow, Ireland. The site was at an elevation of 300 m and was reasonably sheltered. It had a southerly aspect, with a slope ranging between 5^{o} and 10^{o}. The soil was a brown podzolic. A pure Sitka spruce stand was planted in 1965 and had an estimated yield class of 18 m^3 ha^{-1} yr^{-1}. The stand had been thinned in 1991, 1995 and 1999. The first thinning was rack and selective while the latter two were selective. Prior to the experiment the stand was due for clearfelling in 2009 and was to receive one more thinning prior to clearfell.

Nine 0.3 ha main plots were laid down in the stand (A-I, Figure 1). Within each of the main plots, six subplots (0-5; 20 x 25 m) were marked out, within which the diameter at breast height (1.3 m above ground level) of every tree was measured. Within three of the nine main plots (B, E and I) no thinning was carried out (Table 1). The mean basal area in these plots was approximately 34 m^2 ha^{-1}. In a further three the basal area was reduced to 29 m^2 ha^{-1} (D, A and H) while the remaining three plots were thinned to a basal area of 24 m^2 ha^{-1} (C, G and F). This latter thinning intensity represents the maximum reduction in basal area that this stand would be likely to withstand without windthrow occurring. A 0.5 ha section of the stand, approximately 50 m to the north of blocks 1 and 2 was clearfelled.

Following thinning in 2003 the experiment area was deer-fenced. The following species were planted in each of the nine plots: Sitka spruce, hybrid larch, western red cedar, oak, birch and beech. However, due to a combination of drought, hare damage and poor quality seedlings many of the seedlings died. A hare fence was erected around the perimeter of the experiment in September 2003 and all the seedlings were replaced with new stock (with the exception of the western red cedar) in 2004.

Table 1: Characteristics of the plots prior to and post thinning.

Plot	Pre thinning			Post thinning			
	Basal area	Stocking	Mean DBH	Basal area	Basal area removed	Stocking	Mean DBH
	m^2 ha^{-1}	trees ha^{-1}	cm	m^2 ha^{-1}	%	trees ha^{-1}	cm
B	35.40	493	29.45	35.40	0	493	29.45
E	34.43	490	29.01	34.43	0	490	29.01
I	34.37	427	31.70	34.37	0	427	31.70
D	30.37	547	25.46	28.97	4.6	470	27.61
A	34.37	473	29.68	29.10	15.3	387	30.25
H	35.07	427	31.99	29.07	17.1	340	32.71
C	29.20	490	26.71	24.10	17.5	373	28.85
G	32.30	403	31.60	25.31	21.5	300	32.49
F	34.07	520	27.65	23.93	29.8	297	31.60

Light levels

Pre- and post-thinning light levels beneath the canopy were assessed from hemispherical photographs. These were taken in the centre of each of the 54 subplots using a fisheye lens (Sigma 8 mm at F4) mounted on a digital camera (Nikon Co-olpix 995). The fisheye lens was attached to a self-levelling mount (Type SLM2, Delta-T Devices Ltd, Burwell, UK), which was screwed on top of a commercial camera tripod. The photographs were taken at a height of 1.3 m above ground level with an alignment marker facing north. By superimposing the annual solar track on the photographs, using specialised computer software, an estimate of the light levels transmitted through the canopy for a whole year were obtained. The images were analysed by Dr Sophie Hale, Forestry Commission UK, using Hemiview (Delta-T Devices, Cambridge, UK) computer software. The software produced measures of visible sky (also known as the gap fraction) and the proportion of diffuse light that was transmitted through the canopy to the photo-point (transmittance).

Precipitation and throughfall

Throughfall volume, pH as well as concentrations and amounts of ammonium, chloride, and sulphate were measured on two sampling occasions in May 2003. Polypropylene open funnels fitted with coarse-mesh nylon filters, leading directly into sample bottles, were used as precipitation collectors at ground level. Five collectors were used to collect precipitation in a clearfelled area directly adjacent to the test site. The throughfall collectors were made from lengths of polyvinyl chloride pipe driven into the ground with polyethylene bottles placed in the above ground sections of the woven pipe. Collection funnels were placed into the openings of the bottles, with coarse mesh nylon filters fitted over the funnels to prevent organic matter from falling into the collector bottles. Collectors were placed 2 m apart to form a 10 x 10 m grid within each main plot of block 2.

Ammonium was measured colourimetrically using the phenol-hypochlorite method, read on a Beckman DU 650 Spectrophotometer on the UV spectrum at 635 nm. Anion levels were measured using ion chromatography (IC). A Dionex 120 anion exchange column and conductivity detection, with PeakNet Version 6.20 SP2 Build 541 software (Copyright© 1992-2001, Dionex, Inc) was used. The throughfall pH was measured using a WTW Digital pH Meter.

Temperature

Soil temperature was monitored continuously using Gemini Tinytags (TGX-3080). Tags were buried at selected sampling points in the organic soil layer. Temperature data were downloaded and analysed using OTLM Software, Version 2.8 (Copyright© 1994-2002 Gemini Data Loggers (UK)). A separate estimate of the variation in soil temperature was made using a Delta-T data logger with multiple soil temperature probes. The Delta-T logger can record temperatures simultaneously at 30 different points.

Nitrogen mineralisation and nitrification

Measurements of nitrification in forest floors typically involve a number of in-field incubation techniques. These methods are considered superior to laboratory incubations because of their sensitivity to on-site environmental fluctuations such as temperature and moisture level. A number of methods can be used for field incubation. In this project the buried bag method was used to assess the rates of nitrogen mineralisation and nitrification. Incubation of soil in buried polyethylene bags was developed by Eno (1960) and has become a widely used method. The bags allow exchange of O_2 and CO_2 but prevent loss of liquid water and nitrate. The method therefore, while integrating temperature, may not be as sensitive to changes in soil moisture. Soil samples for the incubation were taken using a soil corer. The organic layer was placed in polyethylene bags which were reburied at the sample point. At the same time fresh soil was collected at each sample point and returned to the laboratory. Samples were processed and analysed for ammonium and nitrate content. Nitrogen was extracted using a KCl solution which was was analysed for ammonium and nitrate concentrations using flow injection analysis (Tecator 1984a and b). The soil incubated in the bags was collected after approximately one month and the nitrogen content measured as described. N-mineralisation was calculated, for both methods, as the amount of NH_4^+ plus NO_3^- present at the end of the incubation period, minus the amount present at the beginning of the incubation period.

Graphical Analysis

Contour maps exhibiting the spatial patterns of throughfall volume, pH, ammonium and soil ammonium were created for each plot using krigging. The spatial variation in ammonium is illustrated in Figure 2, together with the position of the trees within the plots.

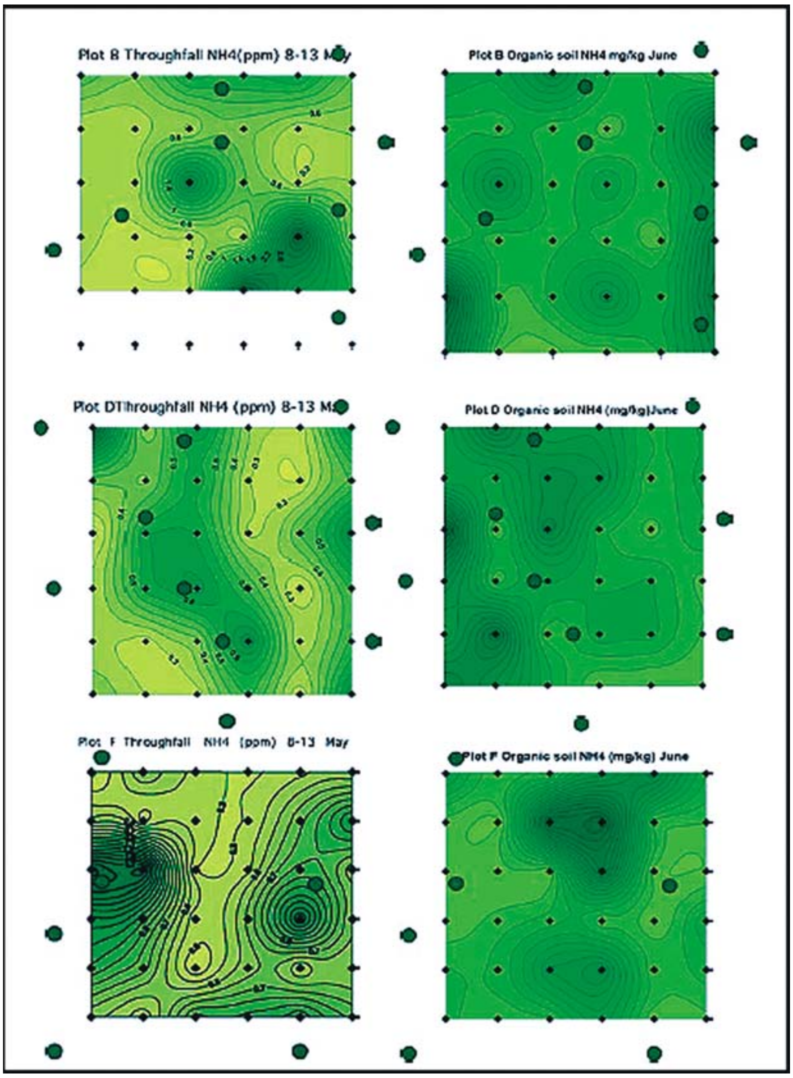

Figure 2: Distribution of NH_4-N in throughfall and soil organic horizons in relation to positions of trees (●). These maps were produced by krigging data collected from a sampling grid (•).

Site 2

A section of a 27-year-old Sitka spruce stand (estimated yield class 16 m^3 ha^{-1} yr^{-1}) adjacent to the stand described above (sub-compartment 13064C-1 in Brown Hill Property, Aughrim Forest) was selected to demonstrate how silvicultural management for continuous cover forestry differs from that for the clearcutting system. Specifically, the objective of this demonstration was to show thinning in a stand managed for continuous cover. The stand (20.8 ha) had been thinned once (rack and selective) and was due to be thinned again in 2002. A 1 ha section was marked for a crown thinning, while the remainder received a standard selective thinning. The aim of the crown thinning was to promote crown development on future parent trees, so as to encourage natural regeneration. Approximately 250 trees equally distributed throughout the plot were selected. Trees competing with parent trees were marked and removed during the thinning. All thinning (within and outside the plot) was carried out mechanically.

Site 3

A small experiment was laid down in two Sitka spruce stands in a private forest (owned by Robert Tottenham) in Co Clare. The stands were harvested by opening up two coupes (gaps) of about 20 m diameter in each. The objective was to determine the effectiveness of artificial seeding, surface scarification and small mammal exclusion (through fencing) on promoting gap regeneration. The three treatments were combined factorially, together with controls, resulting in eight treatments in all. These were set out in 1 m^2 plots in each gap, in April 2003. These will be monitored to record the level of seedling germination, as well as any natural regeneration that may occur in the no seeding controls.

Site 4

An experiment to examine the effect of shading on the early growth and survival of three conifer species was established at Thornfield, University College Dublin in April 2003. Seedlings of three species, Sitka spruce, western red cedar and hybrid larch, were planted in 3 litre pots and placed under four levels of shading (0%, 25%, 50% and 75%). The treatments were replicated three times in a split plot design (36 plots in total). During the first growing season the amount of photosynthetically active radiation (PAR), and the ratio of far-red to red light (FR:R) were regularly measured. In addition, the levels of chlorophyll fluorescence were measured on a sample of seedlings from each of the 36 plots on a monthly basis. Analysis of the fluorescence characteristics will provide a rapid and non-destructive method of detecting and quantifying seedling tolerance to shade. The height and diameter growth of the seedlings were assessed after the first growing season to indicate the impact of different levels of shade on the morphological characteristics of the seedlings. The impact of shade on biomass allocation was examined by measuring the shoot:root ratios in a sample of seedlings in April 2004. These measurements will be repeated after the 2004 growing season.

RESULTS

Site 1

Light levels

As the majority of seedlings were planted in spring 2004 no data on the height and survival of the trees are yet available. However, the impact of thinning on light levels in the stand was examined as was the relationship between the light levels and some stand characteristics. The light data generated from the hemispherical photographs have been analysed. Gap fraction in the subplots varied between 0.02 and 0.12 prior to thinning, while post thinning the maximum gap fraction was 0.17. Transmittance ranged from 0.01 to 0.13 prior to thinning, with a maximum value of 0.26 after thinning.

Regression analysis indicated that of the stand characteristics examined, gap fraction was most closely related to stocking density and transmittance with basal area.

Throughfall and temperature

Throughfall collections were sampled twice during May 2003 and are referred to here as Cycle 1 and Cycle 2. Spatial variation in volume and pH was evident in all plots for both cycles. These exhibit definite patterns in relation to the position of the trees. Volumes are always lower under canopy covered areas. pH was lower close to trees and the pH of throughfall was generally lower than that of incident precipitation.

Concentrations of inorganic N in throughfall were very low for both cycles, bordering on the limit of the analytical techniques used for this project. NH_4-N levels were notably low for Cycle 2, and NO_3-N was detectable in less than 5% of the samples. This may imply a low level of canopy enrichment or perhaps even a net uptake of inorganic N by tree surfaces during some periods. The chloride concentrations were higher under areas of canopy cover for all three plots in Cycle 1. Whelan *et al*. (1998) state that marine derived NaCl acts as an important source of cloud condensation nuclei, which can lead to high levels of Cl in incident precipitation. Sulphate contour maps also exhibited spatial patterns related to canopy cover, with higher levels of sulphate under canopy covered areas.

Soil nitrogen

Nitrate concentrations were lower than ammonium in both the mineral and organic layers, and the mineral layer had lower concentrations of both forms, with nitrate levels being almost undetectable (Table 3). There was considerable variation in the level of nitrogen between each sampling point.

Rates of mineralisation and nitrification

During the summer months of 2003, rates of nitrification and mineralisation were estimated in the three plots in one block (Table 4). The mean concentrations (mg kg^{-1} dry soil) of nitrate and the rates of nitrification (mg kg^{-1} day^{-1}) were low, and essentially undetectable in all three plots.

The mean rate of mineralisation was significantly higher in the plot with less canopy coverage (plot F) than in the plot with the highest level canopy coverage (plot B).

Table 3: Nitrate (NO_3^-) and ammonium levels (NH_4^+) (mg kg^{-1} dry soil) in the organic and mineral soil layers in Plot B in April 2003 (n=30).

Layer	NO_3^- mg kg^{-1}	NO_3^- mg kg^{-1}
Organic	4.28 (±2.79)	27.74(±14.45)
Mineral	0.69 (±0.78)	6.38 (±4.37)

Site 2

The number of trees removed from the crown thinned plot in Brown Hill was lower than in a contiguous 1 ha plot that been thinned using a rack and selective thinning However, there was a greater volume of boxwood and stake material in the crown thinned area which meant that overall the total volume removed in both areas was similar. In addition, it was noted that the amount of brash on the forest floor in the crown thinned plot was substantially less than that in the section that had received a standard thinning.

Site 3

There is little evidence of natural regeneration in the two stands examined in site 3. Of the sixteen plots that were not seeded no seedlings were present 1.5 years after the plots were established. Surprisingly, seedlings were only present in four of the sixteen plots that were seeded. These plots were located in a gap that had been created in a particularly moist part of the site. This would suggest that moisture availability may have been a factor in the survival of the seedlings and that only in this one gap was there sufficient moisture available. A preliminary examination of the data suggests that fencing and/or scarifaction had no impact on seedling numbers.

Table 4: Mean nitrate (NO_3^-) and ammonium concentrations (NH_4^+), nitrification and mineralisation rates in the organic soil layers under different thinning treatments in June 2003 (n=36). Mineralisation rates with the same superscript are not significantly different ($p \leq 0.05$).

Plot	Treatment basal area m^2 ha^{-1}	NO_3^- mg kg^{-1}	NH_4^+ mg kg^{-1}	Nitrification mg kg^{-1} day^{-1}	Mineralisation mg kg^{-1} day^{-1}
B	35.40	6.64	48.24	0.13	3.13^a
D	28.97	6.48	33.75	0.14	4.00^{ab}
F	23.93	6.75	44.74	0.18	4.74^b

Site 4

The height increments of the three species were greater under all levels of shade compared to the control (0% shade). In the case of hybrid larch and western red cedar, height increment peaked at 50% shade while for the Sitka spruce it peaked at 75% shade. In contrast the mean root collar diameter for the three species was significantly smaller for all three species at 75% shade compared to the control. In general the shoot:root ratios of all three species increased as shade levels increased with the shoot:root ratio of western red cedar significantly greater at 50% and 75% shade compared to the control.

DISCUSSION AND CONCLUSION

Preliminary data on the growth and survival of a number of broadleaf and conifer species under different levels of canopy cover in a mature Sitka spruce stand will be available at the end of 2004. However initial indications from the analysis of the light levels recorded beneath the canopies, and an examination of the current literature available on the light requirements of various species, suggest that it is likely that the amount of light available to seedlings will only be sufficient for the successful establishment of the most shade-tolerant of the species planted, i.e. beech and western red cedar. In contrast, results from the shadehouse experiment show that hybrid larch (light-demanding) and Sitka spruce (intermediate shade tolerance) are to date not being adversely affected by 75% shade. Data collected during the remainder of the project will elaborate on these findings.

The results from the Brown Hill study (site 2), although preliminary, are interesting. One of the main criticisms of CCF is that it is uneconomic, particularly in comparison with the conventional clearfell/replant systems. The earlier removal of more boxwood and stake material under the CCF system, as demonstrated here, could make this system more economically attractive. This benefit would depend on the comparative markets for pulp and stake material. The effect on brash would also need to be monitored further.

Even though there was considerable spatial variability in volumes of throughfall, pH and concentration of mineral components measured in each cycle, spatial patterns were relatively consistent for most components in each cycle. The results presented here confirm those of other studies (Hansen 1996, Whelan *et al*. 1998) in showing that the volume of throughfall generally increases while ion concentration and load generally decrease away from trees. Ion concentrations tended to be higher closer to a tree trunk, and tended to decrease with distance away from it. In all cases, mean concentrations and amounts of all ions measured in throughfall greatly exceeded those found in the precipitation collected in the adjacent clearfelled site. This concurs with many of the studies showing ion enrichment as precipitation passes through canopies of a wide range of species, including Sitka spruce (Parker 1983, Stevens 1986, Puckett 1990, Rodrigo *et al*. 2002). The average pH value for the nine plots was 3.9, which is generally considered too low for nitrification to operate efficiently. For example, Berg *et al*. (1997) found that below pH of 4.2 the process was severely inhibited.

Throughfall, temperatures, and rates of nutrient turnover (C and N) will continue to be monitored in the plots. This information coupled with information on light levels in the stand will contribute to our understanding of the factors determining the growth and survival of the tree species that have been planted.

ACKNOWLEDGEMENTS

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Forestry and Biodiversity in Ireland and a Case Study of the Hen Harrier (*Circus cyaneus*): BIOFOREST Project

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It has been estimated that, in Neolithic times, forest cover in Ireland was around 80%. However, since human settlement of the island, the majority of Ireland's native forests have been cleared as result of wood harvest and to make way for agriculture, or a combination. By the beginning of the 20th forest cover was just over 1%, and although large scale afforestation over the last half of the 20th century has seen forests recover to just under 10%, this is still a small fraction of Ireland's original forest cover, and is among the lowest of any country in Europe (IPCC 2001). The Irish government aims to increase this figure to 17% by 2030 (Department of Agriculture Food and Forestry 1996).

Many Irish habitats that have been more or less devoid of trees for centuries are now coming once more under closed canopy tree cover. Ireland's new forest plantations differ widely from native Irish woodlands in their constituent tree species. The most widely planted commercial species are not native to Ireland (Department of Agriculture Food and Forestry 1996). For these reasons, modern forestry in Ireland entails a profound change in the Irish landscape, the implications of which for Ireland's fauna and flora are still not well understood.

The BIOFOREST Project is a large-scale research project on the biodiversity supported and affected by plantation forests in Ireland. This project is funded by COFORD and the EPA, and is being conducted by researchers at UCC, TCD and Coillte. The project is divided into three main sub-projects:

1. Biodiversity assessment of afforestation sites,
2. Assessment of biodiversity at different stages of the forest cycle, and
3. Investigation of experimental methods to enhance biodiversity in plantation forests.

All study sites for these sub-projects have now been identified and visited (their location is shown in Figure 1). The project runs from 2001 to 2005, and there is still work ongoing on elements of each of these three sub-projects. However, the project has already had several outputs, and in this paper we summarise three of these:

- Output 1: Review of pre-afforestation biodiversity assessment;
- Output 2: Investigation of biodiversity over the forest cycle;
- Output 3: Study of Hen Harriers and afforestation.

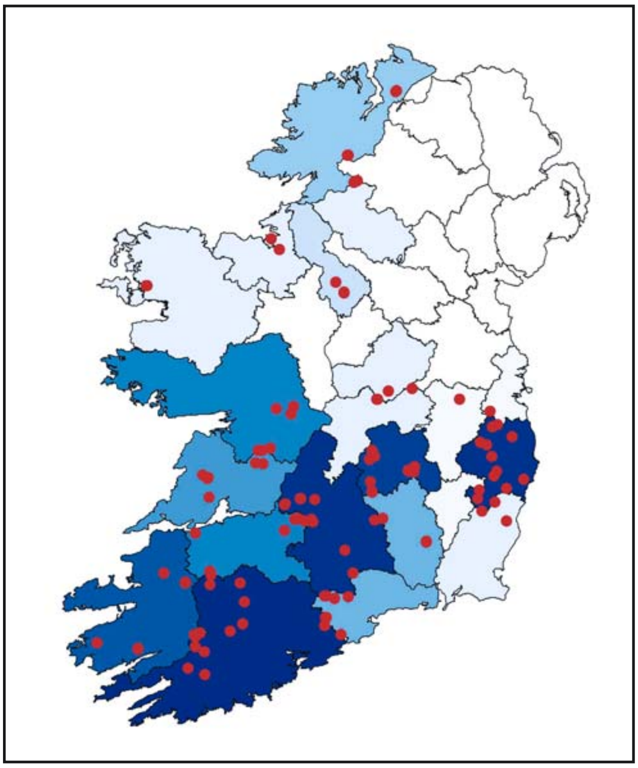

Figure 1: Location of all 116 BIOFOREST study sites. The red symbols indicate the location of the sites, and counties are shaded according to the number of sites in each (the darker the shade of a county, the more sites are situated therein).

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OUTPUT 1: REVIEW OF PRE-AFFORESTATION BIODIVERSITY ASSESSMENT PRACTICES

The aims of this element of the project were to review and evaluate the effectiveness of pre-afforestation biodiversity assessment in Ireland, and to identify best practice overseas which might be integrated into existing schemes in Ireland. In particular, we examined whether the procedures currently in place would reliably identify sites of high biodiversity value, where afforestation proposals should be deemed inappropriate or be required to incorporate measures aimed at mitigating the impact of planting on the existing fauna and flora. We reviewed information from several sources:

- the guidance published by the Forest Service and other governmental sources on biodiversity assessment and planting for afforestation in Ireland;
- consultations with personnel in the Forest Service, Dúchas (now the National Parks and Wildlife Service) and local authorities;
- consultation with over 200 individuals and organisations overseas;
- the nine Environmental Impact Assessments (EIAs) submitted for afforestation projects in Ireland, and 17 EIAs submitted for afforestation projects in the UK.

The results of this review, and the recommendations that followed from them, are described in detail by Gittings *et al*. (in prep. b). The following is a summary of the main recommendations:

- Monitoring of assessments should be made more effective. Among the measures that could be implemented to achieve this are the employment of ecologists by the institutions responsible for monitoring pre-afforestation biodiversity assessments, the training of those already involved in the monitoring process, and the greater involvement of existing expertise outside of these institutions.
- The strengthening of the ecological knowledge base in Ireland (through the development of Indicative Forest Strategies, Biodiversity Action Plans and nationally co-ordinated, taxon specific surveys) would greatly assist both those conducting biodiversity assessments, and those responsible for evaluating the quality of these assessments.
- External consultation and comment at all stages of the assessment process should be encouraged; particularly during the planning stages, and again when assessments are being monitored.
- Those carrying out biodiversity assessments should be properly trained in ecological survey methods, and should receive guidance from the appropriate authorities that, when followed, would enable them to produce assessments to an adequate standard.
- Survey methodologies and habitat classifications used in biodiversity assessments should be standardised, and all assessments should incorporate explicit descriptions of scoping, survey effort and methodologies (including annotated site maps). These steps will facilitate interpretation of assessments' findings, and evaluation of their adequacy.

OUTPUT 2: BIODIVERSITY OVER THE FOREST CYCLE

Forty-four study sites were selected, comprising three tree species compositions (pure Sitka spruce (*Picea sitchensis*), pure ash (*Fraxinus excelsior*), Sitka spruce/ash mix), and five age categories (5, 8-15, 20-30, 35-50 and >50 years). We surveyed plants, spiders, hoverflies and birds in each of these sites during the summers of 2001 and 2002, and also collected environmental, structural and management data from each site. We examined the relationships between biodiversity and tree species, forest growth stage and other environmental variation. Our results, and the recommendations that follow from these, are described in detail by Gittings *et al*. (in prep. a). Some of the recommendations from this paper, aimed at improving management of forestry plantations for biodiversity, are summarised here:

- We found some broad similarities in the diversity of species assemblages in different taxa across the range of environmental variation represented by our study sites. However, it is not generally possible to extrapolate from one easily surveyed taxonomic group in order to infer patterns of biodiversity in other taxa.
- Biodiversity indicators are generally not suitable for identifying sites of national or regional importance; but can be used to good effect to distinguish local areas of biodiversity and to assess the effectiveness of management in promoting biodiversity.

- Tree growth stage has a greater effect on biodiversity than tree species composition. Biodiversity tends to be highest in pre-thicket and mature plantation forests; however, the biodiversity of pre-thicket forests may depend to a large extent on pre-planting habitat.
- Although young forests established in improved grassland will often exhibit lower biodiversity than forests planted in other habitats, they will generally result in most positive long-term effect on biodiversity. Semi-natural habitats should not be afforested.
- Factors that may enhance biodiversity within plantation forests include the presence of scrub and open space within and around forests, well-developed thinning regimes and the retention of over-mature trees and large diameter dead wood.

OUTPUT 3: HEN HARRIERS AND FORESTRY

The Hen Harrier (*Circus cyaneus*) population of Ireland has been estimated at between 120 and 130 breeding pairs. Over the past 50 years, most of the upland areas where Hen Harriers exist have been heavily afforested. During this period, an initial increase in Hen Harrier numbers was followed by a population decline. Hen Harriers use young forests for nesting and foraging, but, generally speaking, do not use forests after canopy closure (O'Flynn 1983, Watson 1977). The value of young second rotation forestry to Hen Harriers is uncertain (Bibby and Etheridge 1993, Madders 2000), though they will use reforestation sites for nesting (Norriss *et al*. 2002, Petty and Anderson 1986). In the long term, afforestation of open Hen Harrier habitats does result in habitat loss for this species, as the canopy of most commercial forests remains open for only about a third of the forest cycle.

The Hen Harrier is an Annex 1 species in European Union (EU) law and, as such, specific measures are required to be implemented in order to safeguard the Irish population. The Irish government has recently been under pressure from the European Commission to meet its obligations under EU conservation directives, which include the designation of Special Protection Areas (SPAs) for Hen Harriers. As a consequence, candidate SPAs were identified quickly, without time for thorough liaising between those responsible for deciding these areas, and local farming and forestry stakeholders (the location of these areas, which will hereafter be referred to as Hen Harrier Indicative Areas or IAs, is shown in Figure 2). Although it is expected that restrictions on farming and forestry activities will be imposed in the IAs, scientific evidence that suggested restrictions would be either sufficient or necessary to conserve populations of Irish Hen Harriers is scanty or absent. The lack of consultation and certainty regarding the IAs has led to concern, both within rural communities and among conservationists.

The aim of this project is to increase our understanding of the Hen Harrier's habitat requirements, in order to inform discussion about Hen Harrier conservation in Ireland. This will help to ensure that the measures taken to protect Hen Harriers in Ireland are stringent enough to achieve this goal. At the same time, it will reduce the likelihood that unnecessary restrictions will impact adversely on agricultural and forest interests. We address this aim by examining how Hen Harrier distribution is related to forest cover and other environmental variables, identifying thresholds beyond which landscapes become unattractive to Hen Harriers, and predicting the effect of forest maturation on Hen Harriers in the IAs. The results of the project, and the recommendations following from these, are described more fully by Wilson *et al*. (in prep.).

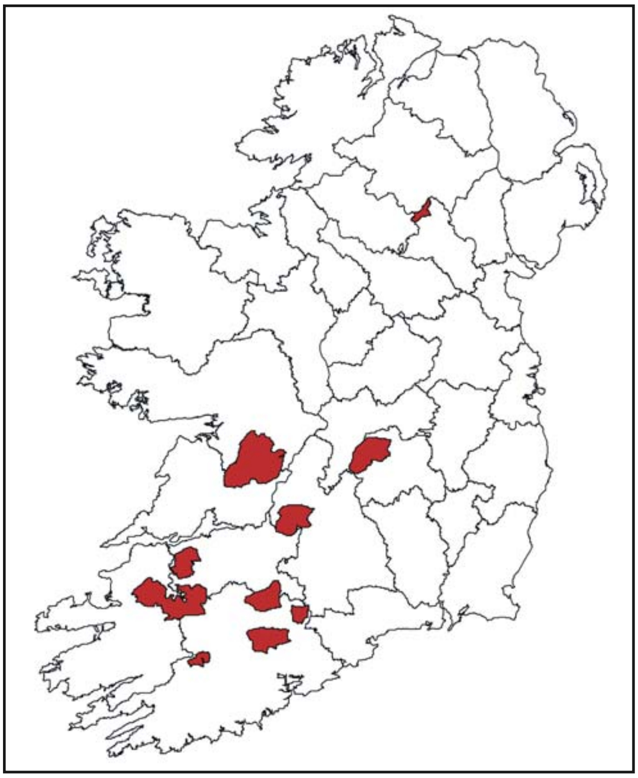

Figure 2: Location of the ten Hen Harrier Indicative Areas that have been identified by National Parks and Wildlife Service as being the areas that appear to support the highest densities and most stable populations of Hen Harriers in Ireland.

HEN HARRIER HABITAT PREFERENCES

Assuming a random distribution of Hen Harriers in the Indicative Areas, the land 500 m around Hen Harrier nests comprised:

- a HIGHER than expected proportion of coniferous forest (young and old), clearfell, bog and heath, and land between 200 and 400 m;
- a LOWER than expected proportion of mature broadleaves, grassland, roads and land below 200m

This suggests that Hen Harriers are distributed non-randomly with respect to the above types of landcover and altitude. Changes in the Hen Harrier's distribution in Ireland over the past 30 years reveal similar patterns.

Hen Harrier thresholds

Almost all Hen Harriers occur in areas with 30% or more suitable habitat cover (bog, wet grass, pre-thicket forestry). Due to forest maturation, the proportion of the IAs that is suitable for Hen Harriers will decrease substantially by 2015. This may cause a decline in the number of Hen Harriers in these areas. The extent and location of further afforestation in these areas is therefore a matter of considerable importance.

Recommendations

- Afforestation and agriculture should be 0regulated in the IAs to maintain a sufficient amount of habitat for Hen Harriers.
- Proposed land changes that would decrease the area of suitable habitat for Hen Harriers within 1 km to below 30% of total land cover are potentially damaging.
- Where possible, forestry should target improved agricultural land, and avoid semi-natural habitats.
- Large (>100 ha) contiguous areas of similar aged (within 14 years old) forestry should be avoided.
- Until further research is conducted, second rotation forests should not be regarded as equivalent in value to open habitat or young first rotation forests.
- Hen Harrier populations and habitat cover in the IAs should be monitored regularly. There is a particular need for a forest inventory to cover all forestry in these areas, with details of planting year and projected felling year.

Hen Harrier male in flight.
Copyright Peter Hadley, Manx Bird Photography

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We thank BirdWatch Ireland, the British Trust for Ornithology, Coillte, the Forest Service, the Irish Raptor Study Group, National Parks and Wildlife Service and numerous other individuals and organisations that provided information or access to sites, or have assisted us in other ways.

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PEnrich – A Study on the Impact of Current Forestry Operations on Water Quality in Ireland[1]

O.M. McCabe*, E.P. Farrell, J. Machava and P. O'Dea

INTRODUCTION

There has been much concern about water quality in Ireland in recent decades, especially in relation to phosphorus (P) loss from land to water. Since the introduction of the Phosphorus Regulations (Anon 1998), all sectors (agriculture, forestry and industry) have come under increased pressure to protect and improve water quality. Forestry operations – one of the potential risks to water quality - have been examined in many studies carried out in Ireland (Renou *et al*. 2000, Cummins and Farrell 2000, Cummins and Farrell 2003), including the recent catchment-based studies at Lough Leane and the Three Rivers Boyne, Liffey and Suir. Forestry activities and water quality are also being examined within the River Basin Districts studies currently underway throughout Ireland.

In the PEnrich study, the impact of forestry operations on water quality is examined - especially in relation to phosphorus behaviour. The main aims of the study are to monitor the impact of current forestry practices on phosphorus concentrations and loads in surface waters and to assess the efficacy of *Forestry and Water Quality Guidelines* in minimising phosphate loss.

There are a total of three study sites in this project. The first of these is an ex-agricultural site near Crossmolina, Co Mayo. Over the past fifteen years there has been a move away from poor mineral upland and peat soils towards the afforestation of land previously used for agricultural purposes. As the soils in such areas can be quite different to those that traditionally underwent afforestation, it is as yet unclear what impact forestry activities have on water quality at such sites. The study site at Crossmolina is typical of this type of site and of those that will undergo afforestation in the future. Water quality was monitored at this site before and after forestry operations to determine what impact this had on water quality.

At a second site in Co Mayo a surface runoff experiment was carried out. In this experiment, P loss from plots treated with granulated and ground rock P is compared to determine the most effective and environmentally friendly fertilizer to use, especially in light of recent concerns about the effectiveness of granulated rock phosphate.

Finally, a nutrient export coefficient, solely for forestry, in the Wicklow uplands will be determined. This site is along the Ballinagee River and is a sub-catchment of the Kings River Study area examined in the Three Rivers Project.

The Forest Service and Department of the Marine and Natural Resources issued the *Forestry and Water Quality Guidelines* to highlight potential risks associated with forestry operations and water quality. The guidelines outline good practice and precautions that should be taken by all those involved in forestry operations to protect water quality. The efficacy of these guidelines in minimising phosphate loss is examined in the PEnrich study and recommendations for amendments and/or improvements to these guidelines and to the *Code of Best Forest Practice* will be considered on the basis of our findings. In this paper, preliminary findings from each of the study sites will be presented.

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METHODOLOGY

1. Ex-agricultural site, Co Mayo

This study site located near Crossmolina, Co Mayo, is approximately 1.5 km from the shores of Lough Conn. The site covers an area of 3.5 ha and is isolated by watercourses on all sides. It received annual applications of NPK fertiliser until 2000 and has a poorly drained soil with a Morgan's P content of 14.2 – 19.1 mg l^{-1} in the upper layer (0-5 cm).

Sampling began at this site in June 2002, nine months prior to any forestry operations, thus enabling us to establish a baseline data of water quality at the site. The sampling programme was quite intensive - consisting of (i) weekly grab samples from various subsurface drains (ii) composite weekly samples at each of the drains/streams leading into the main drainage outlet and (iii) composite daily samples collected on an hourly basis from the main drainage outlet of the site using a Sigma 900 Max autosampler.

Samples were collected on a weekly basis and analysed for P fractions (total reactive P (only analysed since December 2003), dissolved reactive P and total P), cations (Mg, Ca, Fe, K, Na, Mn and Al), anions (SO_{42-}, NO_3^- and Cl^-), suspended solids, pH, conductivity, alkalinity and ammonia in the laboratories at UCD and Coillte. Flow readings for the main drainage outlet of the site were also recorded to enable us to quantify nutrient loading.

Forestry operations commenced in March 2003. This involved the installation of mound drains followed by planting a mixture of oak and Scots pine. Sampling at this site finished in June 2004.

2. Surface Runoff Experiment, Co Mayo

Surface runoff plots were established at the site in Ardvarney, Castlebar, Co Mayo, in spring 2003. Plots (9 x 3 m) were isolated on three sides using wooden planks. Runoff from each plot was collected in a pipe that drained into a tipping bucket to facilitate collection of a composite runoff sample each week. Treatments in this experiment were – (i) control (no fertilizer), (ii) ground rock phosphate, (iii) granulated rock phosphate.

Surface runoff samples were analysed for total and dissolved reactive P content each week or as often as runoff events occurred. Phosphorus loss from each of these treatments will be compared to determine which is the most effective and environmentally friendly source of fertilizer to use in similar forestry sites.

3. Ballinagee River, Co Wicklow

An intensive water-sampling programme has been underway in the Ballinagee River catchment in Co Wicklow since October 2002. Two autosamplers were located above forestry – WA and WH. Although, not originally planned, it was necessary to install an autosampler at WH as this was downstream of local housing and water quality of the Ballinagee River could be affected by the presence of septic tanks. A third autosampler was installed below forestry (WB).

Samples were collected on a time-proportional basis i.e. one sample hr^{-1} for each 24 hour period, giving a composite water sample for each day of the week. Samples were collected on a weekly basis and analysed for P fractions (total P, total reactive P and dissolved reactive P), cations (Al, Ca, Fe, K, Mg, Mn, Na), anions (Cl^-, NO_3^-, SO_4^{2-}), pH, conductivity, alkalinity and ammonia.

pH readings were recorded on-site as well as in the laboratory and were downloaded during weekly site visits. Flow measurements were also recorded for this catchment. Water depth measurements were recorded every 15 mins at WB and then converted to flow readings (m^3 sec^{-1}) using a rating curve. Flow readings for sites WA and WH were calculated on the basis of catchment area. Sampling finished at this site in June 2004.

RESULTS TO DATE

1. Ex-agricultural site, Co Mayo

High total reactive P (TRP) concentrations (molybdate reactive P in unfiltered samples) were observed for water samples collected from subsurface drains and streams/drains leading into the main drainage outlet of the site on many occasions prior to and post-forestry operations. TRP values often exceeded the 30 µgl^{-1} threshold outlined in the Phosphorus Regulations (Anon 1998) as the target for good water quality. This may be related to higher suspended sediment concentrations also observed on these occasions. While high TRP concentrations have been detected on many occasions since forestry activities began, these values do not appear to differ significantly from TRP concentrations measured before this period.

Table 1: Range and mean total reactive P concentrations (µg l^{-1}) in the main drainage outlet of the ex-agricultural site, Crossmolina, Co Mayo in 2003 (nd=not detectable).

Date	Jan	Feb	Mar 03	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Range	7.6-121.2	3.7-24.52	2.8-32.8	0.7-334.2	3.8-27.6	1.5-45.0	nd-31.7	nd-11.2	1.2-16.0	1.0-20.9	7.3-32.7	9.8-22.1
mean	22.6	11.9	8.1	20.8	9.4	8.4	10.1	3.5	4.8	6.7	16.1	14.3

In general, TRP concentrations of samples collected from the main drainage outlet of the site (autosampler collection point) were quite low before and after forestry operations. Prior to any forestry operations, TRP concentrations exceeded the 30 µg l^{-1} threshold on only two occasions. This recommended target value has been exceeded on four occasions since (19 March - 31 December 2003; Table 1). The most significant of these events was on 12 April when a TRP concentration of 334.2 µg l^{-1} was observed. There is no indication that this high TRP concentration is related to any increase in sediment loss at the time. TRP values observed in subsequent days were less than 30 µg l^{-1}. The significance of this event will be further investigated.

It seems that while TRP concentrations in streams and drains leading into the main drainage outlet of this site are often quite high, these values are diluted substantially as they move into this larger stream. Thus, TRP concentrations in surface water leaving this site are generally low.

Early indications are, that with the exception of one occasion, forestry operations at this site have not had any major adverse impacts on water quality. Other nutrient concentrations and loads have yet to be examined and this will give us a better understanding of water quality as a whole at this site.

2. Surface Runoff Experiment, Co Mayo

Preliminary findings from the surface runoff experiment indicate that TRP and DRP concentrations in surface runoff were high at this site. TRP concentrations often exceeded the 30 µg l^{-1} threshold, in fertilized and unfertilized plots. However, false high background P concentrations may have been observed due to contamination of water from insects trapped in the collection apparatus, especially during summer months (despite the use of filters). It is, as yet, unclear whether there was any significant difference in P loss between the different types of fertilizer used. Tree growth measurements to be recorded later in the year will indicate whether there is any difference between the different forms of fertilizer applied.

3. Ballinagee River, Co Wicklow

Preliminary findings indicate that total P (TP), total reactive P (TRP) and dissolved reactive P (DRP) concentrations of water samples collected at locations above and below forestry along the Ballinagee River were very low. In almost all cases in 2003, TRP (Table 2) and DRP concentrations were well below the 30 µg l^{-1} P threshold outlined in the P Regulations. However, on two occasions during this period (January and May 2003), this value was exceeded at sampling point WH. It is possible that this was due to contamination from farmyard waste or septic tanks nearby.

Table 2: Range and mean total reactive P concentrations (µg l^{-1}) of water samples above (WA and WH) and below (WB) forestry in the Ballinagee River in 2003 (nd=not detectable).

Month	Parameter	WA	WH	WB
Jan-03	Range	0-24.4	1.9-43.6	0-9.0
	Mean	*3.7*	*11.5*	*3.2*
Feb-03	Range	0-9.6	0.7-16.5	0-8.1
	Mean	*2.3*	*6.9*	*2.9*
Mar-03	Range	0-7.8	1.8-14.1	0-7.8
	Mean	*1.3*	*6.7*	*2.4*
Apr-03	Range	nd-11.4	0.8-14.7	nd-14.4
	Mean	*4.6*	*5.8*	*3.2*
May-03	Range	nd-4.5	0-57.4	nd-3.6
	Mean	*1.4*	*6.4*	*1.1*
Jun-03	Range	nd-3.4	nd-28.4	nd-28.6
	Mean	*1.0*	*4.7*	*2.4*
Jul-03	Range	nd-4.2	nd-9.9	nd-6.5
	Mean	*2.7*	*3.2*	*2.2*
Aug-03	Range	nd-8.0	1.9-13.6	0.6-4.8
	Mean	*3.5*	*5.0*	*3.0*
Sep-03	Range	nd-6.1	nd-9.7	nd-4.7
	Mean	*1.0*	*2.2*	*1.3*
Oct-03	Range	nd-9.8	nd-8.4	nd-5.0
	Mean	*2.5*	*3.2*	*2.1*
Nov-03	Range	nd-3.2	0.7-8.1	0.6-10.4
	Mean	*1.7*	*2.8*	*2.8*
Dec-03	Range	0.2-3.1	1.6-7.5	0.12-10.2
	Mean	*1.6*	*4.0*	*3.7*

DISCUSSION

Preliminary findings from this study indicate that while P concentrations in drains leading into the main drainage outlet of the ex-agricultural site at Crossmolina were often very high, these concentrations appear to have been diluted as they moved into the larger stream. While the Morgan's P content of soil in the study site was in soil P index 4, this value was not reflected in the P content of water in the main drainage outlet.

Prior to forestry operations, there were some concerns about one of the drains that had to essentially by-pass the buffer zone into a stream adjoining the main drainage outlet. This was essential in order to ensure that the site would not become flooded and inhibit plant establishment and growth. Results indicate that this did not appear to have any adverse effect on water quality at the site – perhaps in part due to the fact that weather conditions were particularly dry pre- and post- planting operations. Nonetheless, this is an important issue in terms of the *Forestry and Water Quality Guidelines* and should be considered carefully prior to commencing forestry operations at similar sites. In particular, careful consideration should be given to the site conditions (topography, drainage), soil types and prevailing weather conditions.

As yet it is unclear whether P loss or tree growth differed significantly between plots treated with ground rock phosphate and granulated rock phosphate. Traditionally, ground RP was used on all forestry sites, however in recent years there has been a move towards the use of granulated RP to reduce the risk of P loss to water following fertilizer application. However, there have been some concerns regarding the effectiveness of the latter - as the granules appeared to remain undissolved, even several months after spreading at some sites. Although this did not appear to be a problem at this study site, the high P content in surface runoff observed for all plots is a cause for concern. Heavy rainfall events shortly after fertilizer application would certainly have increased the risk of P loss. However, as suggested earlier, it is likely the high P concentrations observed were influenced by contamination from insects trapped in the samples.

There does not appear to be any significant differences in water quality - in terms of phosphorus concentrations between sites above or below forestry in the Ballinagee river. In almost all cases TRP and DRP concentrations were low and did not exceed the 30 µgl-1 threshold. P concentrations were sometimes slightly higher at site WH and it is likely that this was due to contamination from septic tanks. Nutrient loading for this site is currently being determined and will give a clearer picture of events in this catchment and about the impact past and present forestry activities have on water quality at this site.

In addition to the above, a literature review on alternative silvicultural techniques to clearfelling (group felling, continuous cover forestry) is being carried out. This will add to the findings of the PEnrich study in relation to the risks associated with forestry operations and the measures which need to be taken to ensure that water quality is protected.

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Sediment Release in Forest Catchments: Environmental Implications and Management

M. Müller*, M. Rodgers and J. Mulqueen

INTRODUCTION

One of the principal objectives of the study is to monitor the erosion effects, if any, of clearfelling and harvesting a 20 ha forest coupe on water flows in a peat catchment. This requires monitoring stream flows and solids in the water during about 10 representative storm events before and after clearfelling and harvesting the trees.

The study commenced in September 2003. Many sites were investigated before a forest coupe (lodgepole pine) of 20 ha was selected in the Burrishoole Catchment (Rough River), Co Mayo, after consultation with personnel from the EPA, Coillte and the Marine Institute. The Burrishoole Catchment (9°55'W 53°55'N) provides the unique opportunity to assess the impact of a variety of forest management practices on blanket bog on the long-term sustainability of an important salmonid fishery.

The first six months were spent defining the site and installing measuring and sampling stations upstream and downstream of the study coupe. The measurement and sampling devices included depth recorders, a tipping bucket rain gauge, data loggers, staff gauges and water samplers (Pictures 1 and 2).

Monitoring commenced in Spring 2004. H-flumes in a concrete surround were installed at two measurement stations during Autumn 2004 when low flows permitted; these will be used for the measurement of eroded bed material.

Picture 1: Data logger and staff gauge up stream.

Picture 2: Data logger and rain gauge down stream.

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Event-orientated suspended sediment sampling during flood events (high resolution sampling every 5 – 10 minutes) at both sampling locations has been carried out. As the sediment load is highest during the early part of a flood event it is absolutely essential to use triggered water sampling devices. The samplers are triggered either by water level or rainfall intensity via a data logger.

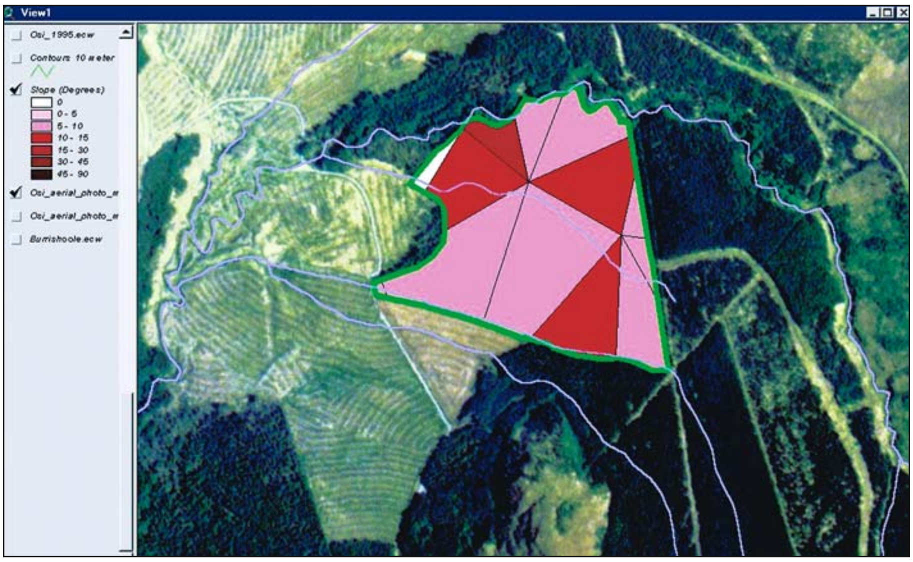

Figure 1: Slope analysis of felling coupe.

Data collection was limited due to the extremely long dry period in Spring and early Summer 2004. Coillte postponed clearfelling until Spring 2005 in order to collect characteristic winter storm flow and sampling data.

Catchment factors such as morphology, soils, quaternary geology, landuse (Table 1) and morphological stream units (Rosgen 1996) have been used to describe observed variability in run-off patterns. Also, aerial image analyses of the study area have been conducted using a Geographical Information System (McGinnity 2000). These data were supported by precipitation measurements and detailed morphometrical analysis of the felling coupe, including analysis of shape, slope (Figure 1) drainage density, bifurcation index and gradient.

Table 1: Morphometric data of study coupe.

	Forested Catchment (Nephin Beg East)
Area	20 ha
Highest point	240 m
Lowest point	150 m
Altitude range	90 m
Slope range	0° - 16°
Geology (Bedrock)	Quartzite, Schist, (Volcanics)
Quaternary sediments	Blanket Peat (95%), Sand and Gravels (5%) (metamorph.)
Drainage	1st order stream draining felling coup
Morphology	Well defined catchment within coup, concave, bowl shape
Precipitation and Hydrology	High rainfall area (over 2000 mm/year), Nephin Beg East (Rough river) catchment 'open' to westerly fronts. 'Spatiest' sub catchment within Burrishoole catchment.
Accessibility	Through forest roads

PRELIMINARY RESULTS AND DISCUSSION

Hydrological analysis of rainfall and flow data (pre-clearfelling)

The runoff hydrograph for the study stream draining the felling coupe is extremely irregular (Figure 2).

The large variation in run-off and yield factor in the catchment indicates a direct dependence on precipitation distribution during the research to-date. Flash floods are a common phenomenon. The discharge frequency curve of the stream is characterised by steep amplitudes and extremely fast falling crests. The total run-off (baseflow plus direct run-off) in the catchment during the period of the investigation is predominated by direct run-off (73%). This suggests that despite the dense forest cover the capacity for retaining water in the study coupe is poor. The low retention potential of the metamorphic rocks in this area, the declining compensation capability of the blanket bog and the high drainage density of the afforested site are likely to be the most important underlying factors.

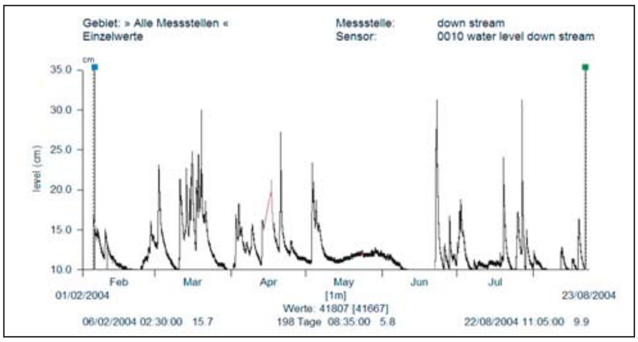

Figure 2: Hydrograph of the study stream (downstream station).

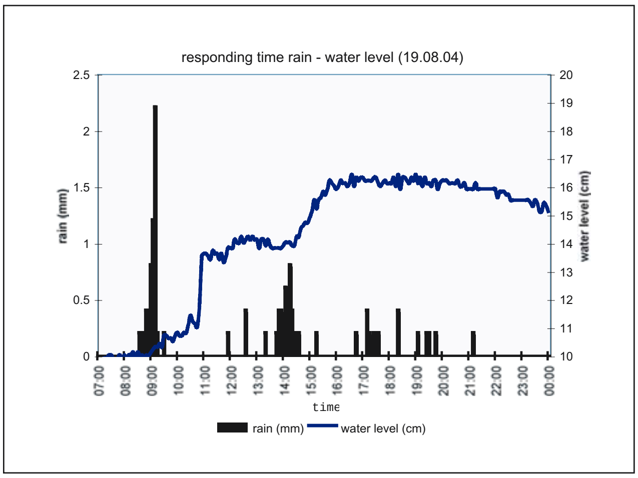

Figure 3: Response time under saturated conditions.

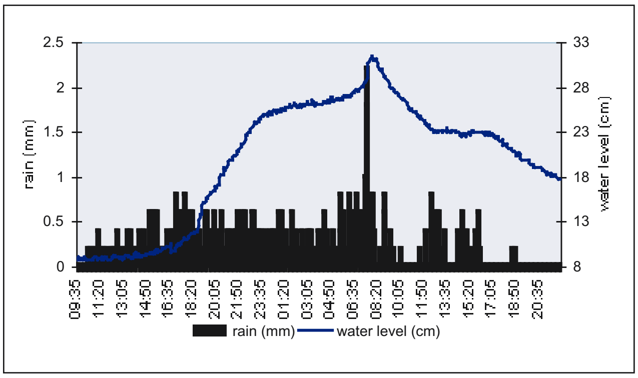

Figure 4: Water level and rainfall on 22.06.2004, with total rainfall for event (18 h) = 80 mm

Low dry weather flows (the study stream dried out for some time during Summer 2004) are a further indication of the poor storage capacity of the aquifers. No annual run-off pattern could be characterised for the study catchment as precipitation influenced flood events predominated. The hydrograph shows no obvious yearly flow pattern. Therefore, monthly mean flows are unsuitable to describe the flow regime of the study stream. Response times (precipitation → run off) are generally of a short nature. Under saturated soil conditions an almost immediate response (less than 15 minutes) was observed (Figure 3).

However, after longer dryer periods, as observed during summer 2004, a significantly longer response time has been noticed (Figure 4).

Suspended sediments (pre-clearfelling)

The suspended sediment loads and concentrations in the study stream - pre-clearfelling - were generally low, even during storm events. The concentrations of suspended sediments ranged from 3.6 mg/l during base flow conditions to 65 mg/l during storm events. During the heaviest storm event (80 mm rain in 18 hours), recorded in June 2004, a maximum suspended solid load of 10.6 g/s at a flow rate of 164 l/s was recorded.

This suggests that the study coupe is well buffered and therefore, erosion rates are very low. It will be interesting to examine the effects that clearfelling and harvesting will have on the water quality, flow and sediment load in the stream. It is hoped that buffer zones - designed in accordance with forestry guidelines - will settle out any sediment eroded from the clearfelled site.

CONCLUSIONS

The conclusions from the study to-date are:

- The study site has a low retention potential.
- The study stream is extremely spaty.
- The hydrograph of the study stream shows no obvious yearly flow pattern.
- When the soil is saturated there is a very quick response (precipitation → run off).
- The suspended solids concentration in the stream prior to clearfelling is very low.
- The suspended solid load in the stream prior to clearfelling is also very low.

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Some Observations of the Potential Use of the Sodium Dominance Index as an Indicator of Surface Water Acid Sensitivity in Forested and Non-forested Catchments

R.B. Lauridsen, J. O'Halloran*, R. Cruikshanks, M. Kelly-Quinn and P.S. Giller

INTRODUCTION

Acidification of surface waters has been one of the most widely studied environmental problems over the last decades (e.g. Bowman 1986 and 1991, AQUAFOR 1997, Hildrew and Ormerod 1995). The causes of acidification have been extensively reviewed and it is now clear that anthropogenically-mediated acidification occurs where atmospheric deposition of strong acid anions (SO_4^{2-} and NO_3^-), accompanied by H^+ and NH_4^+, exceed the buffering capacity of the soil, resulting in the leaching of Ca^{2+}, Mg^{2+} and Al^{3+}. There is a large body of data now demonstrating that in areas of high atmospheric pollution and sensitive geologies, plantation forests can exacerbate the effect and lead to surface water acidification and increase in Al^{3+} (Harriman and Morrison 1982, Ormerod *et al*. 1989 and 1993). While the deposition of acidifying ions has shown a decline by 40% in EEA membership countries (EEA 2000), there is still considerable concern about the impacts of acidifying ions on surface water quality and its associated ecology. The ecological consequences of acidification have been summarised by many workers (e.g. Edwards *et al*. 1990, Hildrew and Ormerod 1995) and impact across a number of scales from sub-physiological to global (Table 1).

In Ireland, a number of sites, largely in the west, east and southwest, have been identified as sensitive to acidification (e.g. Bowman and Bracken 1993, Allott *et al*. 1997, Kelly-Quinn *et al*., 1997, Giller *et al*., 1997, Giller and O'Halloran 2004). These studies raised a number of very important issues regarding forest development and sustainable water resources, which remain to be resolved.

In view of the ecological importance of soft-waters for salmonid production, it is important that measures are taken to avoid increased rates of acidification, particularly those relating to changes in land use. This necessitates the identification of acid-sensitive waters. The most commonly adopted indicators are pH and alkalinity. Low pH (<5.0) and low alkalinity (<10 mg l^{-1} $CaCO_3$) are indicative of low buffering capacity but they are extremely variable within any one catchment, depending on flow conditions and geology. Clearly, what is needed is a parameter that is both relatively stable and independent of season and flow. The contribution of

Table 1: Potential responses to freshwater acidification at different scales (after Hildrew and Ormerod 1995).

Scale of effect	Type of effect
Sub-physiological	Tissue metal concentrations in fish
Physiological	Physiological dysfunction and reproductive effects in aquatic vertebrates
Behavioural	Foraging times in birds and avoidance behaviour in fish
Individual	Change in body condition, growth and energetics in birds
Species populations	Presence/absence
Community	Altered community structure in invertebrates and aquatic plants Altered predator/prey relationships
Ecosystem	Altered quality of production and reduced decomposition
Landscape/ Biome	Cumulative responses across ecosystems (e.g. lakes and rivers)
Global	Cumulative responses across biomes and continents

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sodium to the sum of the major cations (Sodium Dominance Index) in river waters has been proposed by White *et al*. (1998 and 1999) as an indicator of the acid sensitivity of rivers of upland Scotland, particularly where sea salt inputs dominate the base cation composition. The extent of sodium dominance provides a quantitative indication of catchment weathering rate, incorporating the effects of diverse geological composition.

The ultimate goal of the WATERAC project jointly funded by COFORD and the EPA is to provide objective scientific information to evaluate the process of designating sites, to set out solutions and management tools to reduce the conflict between surface water acidification and forestry in Ireland. Scale again, provides a very useful framework. There are two scales, which we consider to be critically important in examining the acidification issue in terms of identifying sensitive catchments and in developing tools for amelioration:

1) Supra Catchment or Regional Scale. At this scale the objective is to identify sensitive areas to help plan forest development with minimum impact on water quality and ecology (e.g. fisheries). Because of Ireland's geographical position and prevailing weather systems, the deposition of acidifying compounds is low, although local scale ammonium deposition may be very important in the future (EPA 2000).
2) Catchment scale. At smaller scales, the efforts are largely focussed on preventing or militating against acidification and ensuring that acidification is not exacerbated locally (Hildrew and Ormerod 1995). This will lead, for example, to planting regimes being controlled in sensitive catchments where the riparian zone may be of high importance. This latter strategy fits well with the river basin district (RBD) concept set out in the EU Water Framework Directive.

OBJECTIVES AND TARGETS

The overall objective of the project is to help optimise the opportunities for sustainable forest management and to determine and contribute to management practices that could prevent or ameliorate impacts of forest operations on acidification of aquatic systems at different scales. This will be achieved through studies at two nested scales: Supra Catchment or Regional scale to identify sensitive areas and Catchment scale to investigate the effects of different land use.

Specific targets of the project are as follows:

i) to further test the utility of the Sodium Dominance Index (SDI) as a measure of sensitivity to acidification and as a tool for evaluating the impact of forestry on acidity of streams in an Irish context.,
ii) to determine biological indicators for and sensitivity grades within the index,
iii) assess the potential efficacy of buffer strips to ameliorate acidification in forested catchments on sensitive geologies.

METHODS

Extensive study

To test the utility of the SDI as an indicator of acid sensitivity an extensive study was carried out in 256 streams across a range of geologies across the Republic of Ireland (Figure 1). One water sample was collected during base flow condition from these streams, of which 57 were in forested catchments and

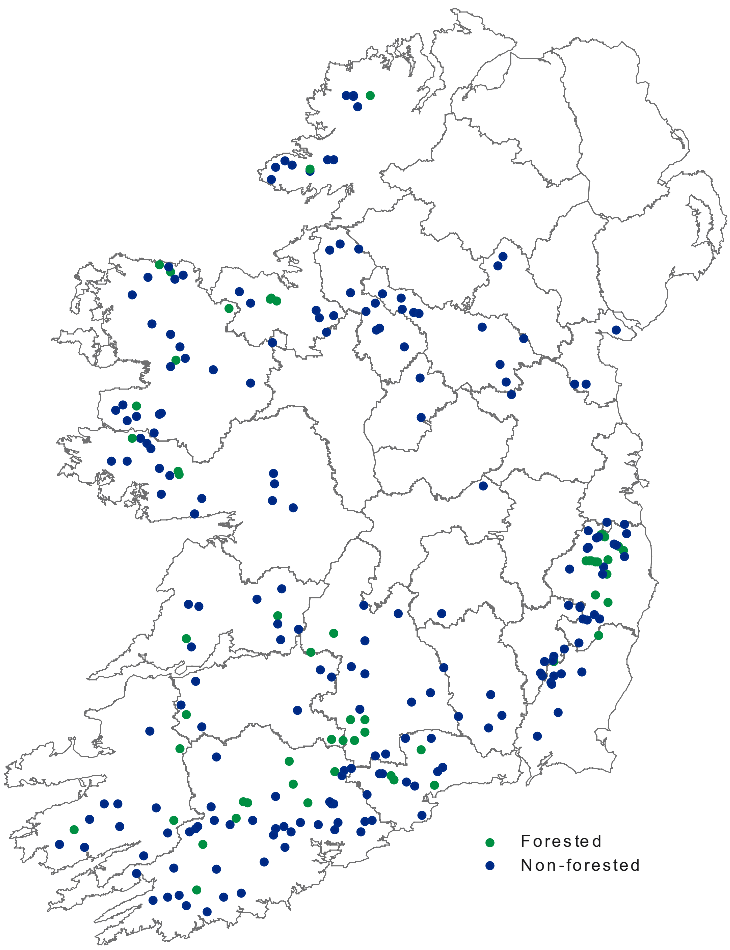

Figure 1: Distribution of extensive study sites across the Republic of Ireland.

the remaining in non-forested catchments. Our definition of a forested catchment was one in which more than 20% of the area comprised established plantation forest. Sites were selected from a pool of potential sites, which were deemed of good, to very good water quality (Q4-Q5 values based on EPA designation). Water samples were analysed for major cations (Na^+, Ca^{2+}, Mg^{2+}, K^+), pH, alkalinity, conductivity and total aluminium.

Intensive study

To further investigate the utility of the SDI as an indicator of acid sensitivity and to explore its temporal stability 65 of the 256 extensive streams were chosen for an intensive study. These sites were chosen to cover the full range of SDI-values and so that an approximately equal number of forested and non-forested site where represented within the different ranges. For the intensive study water samples were collected under both base and high flow conditions. In addition to the water samples, three 3-minute multihabitat kick samples were collected in both spring and autumn from the intensive sites to determine biological indicators for and sensitivity grades within the index.

Sodium Dominance Index (SDI)

The SDI was calculated as the relative contribution of sodium to the major cations (after White *et al*. 1999).

$$SDI(\%) = \frac{[Na^+]}{[Na^+] + [Ca^{2+}] + [Mg^{2+}]} * 100\%$$

Base cations (particularly Ca+) may be derived from weathering of sensitive geologies (e.g. limestone). Increases in their concentrations confer an increased acid neutralising capacity to the catchment, while the opposite is also true. As weathering rate (mmolC ha-1 yr-1) increases, SDI decreases. As such, SDI provides a quantitative value of weathering upstream of the sampling point. In previous studies it has been suggested that sites with SDI-values of more than 40% are acid sensitive (Kelly-Quinn et al. 1999).

Buffer strips

A literature review was undertaken to assess the potential efficacy of buffer strips to ameliorate acidification effects of forested catchments on sensitive geologies. The review revealed that there has been a small number of recent attempts to devise and implement methods of riparian management to ameliorate the effects of forestry on acidification (e.g. (Stoner and Gee 1985, Ormerod *et al*. 1993, Swift and Norton 1993, Weston 1995, Cowan 1998, Donnelly *et al*. 2003). These measures include various kinds of buffer strips, either of moorland vegetation or native broadleaf trees. Ormerod *et al*. (1993) assessed these approaches using an analysis of water chemistry and stream macroinvertebrates. The results indicated that buffers had little effect on aluminium concentrations. Catchments with pure conifers and no buffer strips had the lowest mean species richness. The main conclusions from this limited range of studies are that the approach does little to reduce acidification on its own, at least in highly acidified streams. However, the result implies that there may be beneficial effects of buffer strips in reducing bank erosion, generation of greater in-stream structural diversity and by acting as wildlife corridors in plantations (Ormerod *et al*. 1993, Naiman and Decamps 1997, Forestry Commission 2000).

RESULTS

In the extensive study we found that high SDI values (>40%) and therefore presumably acid sensitive sites were mainly located in the west, east and southwest, the same areas that has previously been identified as sensitive to acidification (see Figure 2). Comparing the SDI-values obtained from the extensive study and the underlying geology of the catchments a significant relationship was identified (Figure 3). Catchments with relative fast weathering geologies like limestone were associated with low SDI-values, whereas catchments consisting of slow weathering geologies like granite were associated with high SDI-values. The extensive study also revealed that the SDI was inversely related to pH as well as alkalinity, during base flow conditions, and there did not seem to be any difference in the trends between forested and non-forested sites (see Figures 4 and 5).

Preliminary results from the intensive study show some temporal variation of SDI with flow (Figure 6). With few exceptions SDI-values increased with flow, however for most sites these increases where small. Interestingly there was a tendency for the forested sites to have a higher degree of variation between SDI-values at high and base flow conditions (Figure 6).

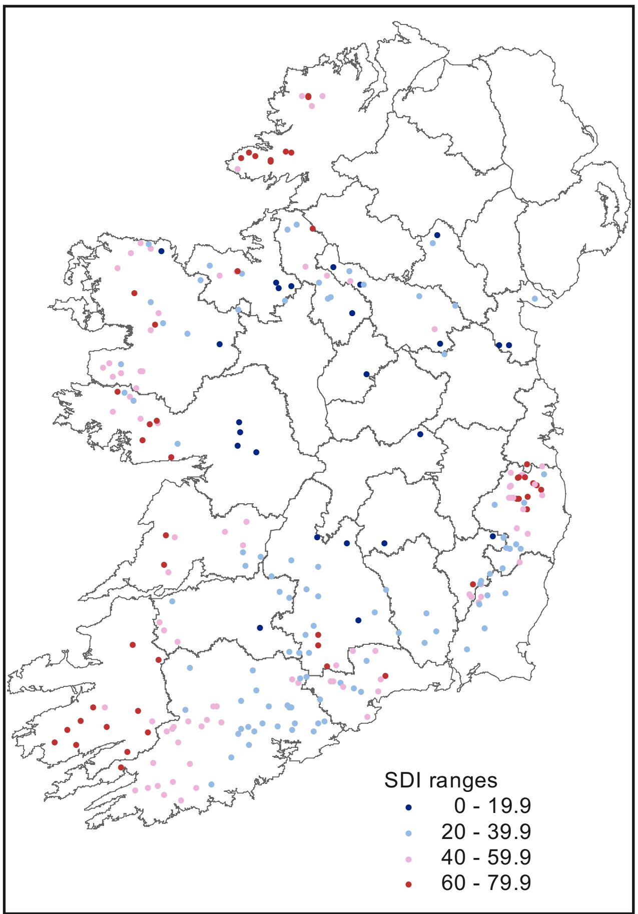

Figure 2: SDI results from the extensive study across the Republic of Ireland.

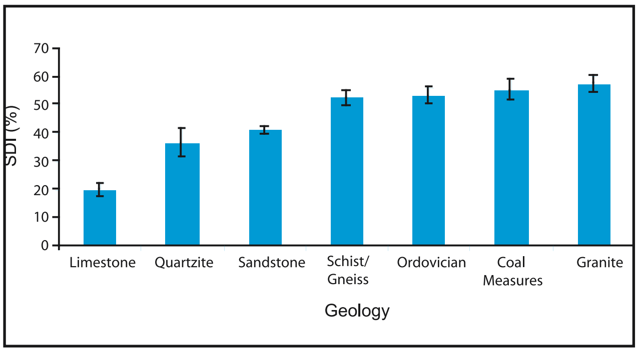

Figure 3: Mean SDI-values from the extensive study for the different types of underlying geology with SE.

Preliminary results from an analysis of a sub-set of the fauna samples collected at the intensive sites indicate that the macroinvertebrate communities are somehow related to the SDI. The macroinvertebrate abundance was inversely related to the SDI with fewer individuals caught per kick sample with increasing SDI-values (Figure 7). Also the macroinvertebrates community structure appears to be linked to the SDI. For example, the proportion of Ephemeroptera to Plecoptera in the samples decreased with increasing SDI-value (Figure 8).

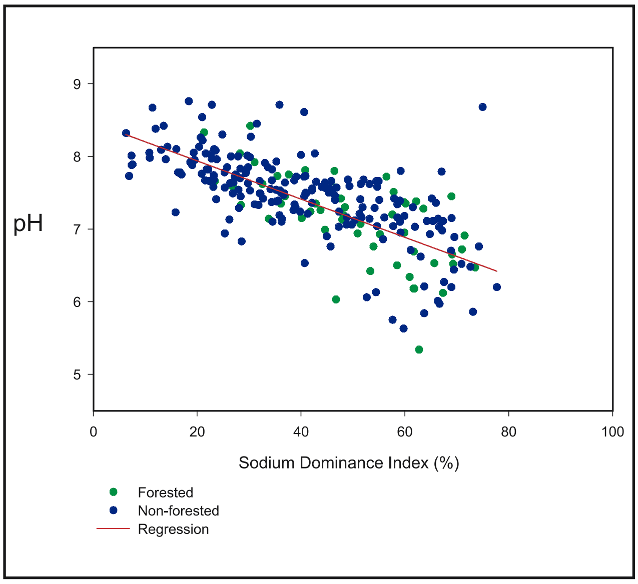

Figure 4: SDI-values for the extensive sites depicted against the pH. R^2 = 0.47.

DISCUSSION

The general conclusion from the literature review on ameliorating effects of buffer strips on acid runoff from forested catchments was that there is little evidence to support such a mitigating effect (Stoner and Gee 1985, Weston 1995, Cowan 1998). However, most studies concluded that there are other substantial positive effects of buffer strips e.g. reduced bank erosion and reduced nutrient and pesticide runoff (Swift and Norton 1993, Gril *et al.* 1997, Harris and Forster 1997). Another reported

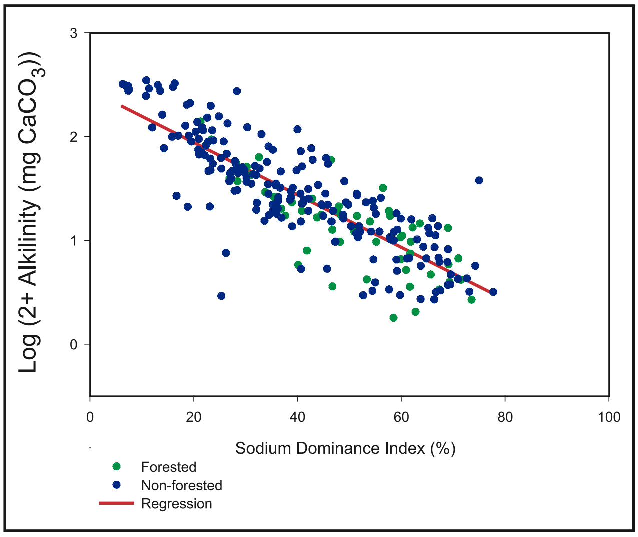

Figure 5: SDI-values for the extensive sites depicted against the alkalinity. R^2 = 0.70.

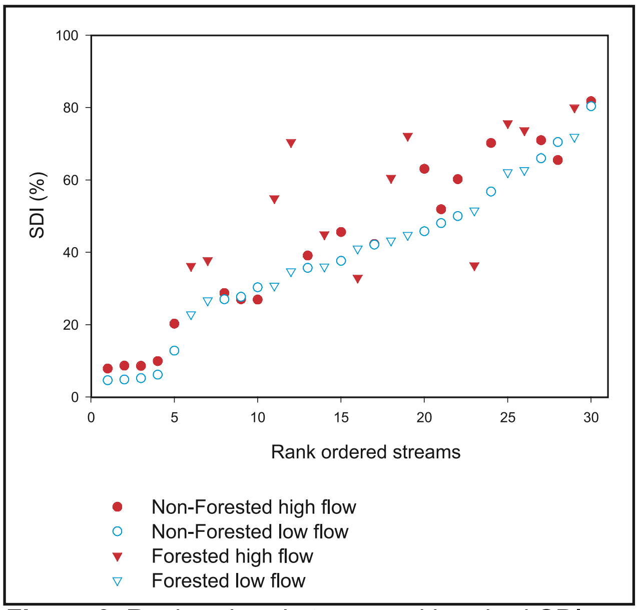

Figure 6: Rank ordered streams with paired SDI-values from samples collected during high and base flow conditions.

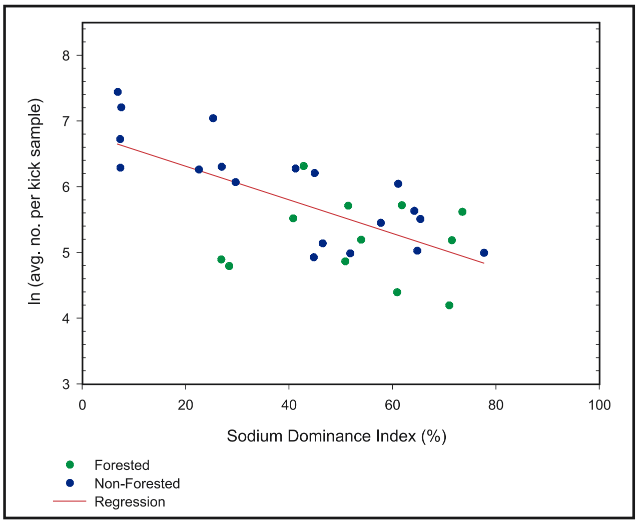

Figure 7: Macroinvertebrate abundance displayed against the respective SDI-values. Abundance displayed as ln to mean number of individuals caught per kick sample (n=6). $R^2 = 0.45$.

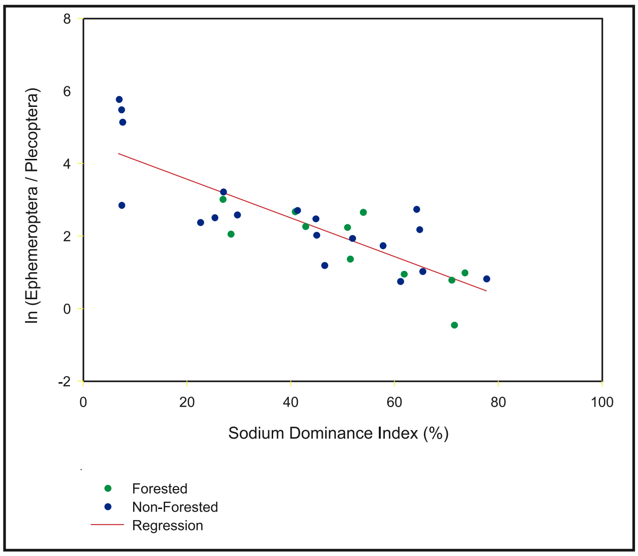

Figure 8: Proportion of Plecoptera to Ephemeroptera in fauna samples. $R^2 = 0.68$.

change with clearance of bank side conifers and plantation of broadleaf buffer strips is increased light input and significantly increased nutritional value of the allochtonous input, both factors contributing to increased in-stream productivity. There is also evidence to suggest that broadleaf buffer strips lead to increased in-stream structural diversity, increasing both habitat and biodiversity (Ormerod *et al*. 1993). Broadleaf buffer strips within monoculture coniferous plantations would also enhance terrestrial biodiversity and might act as wildlife corridors. However these structural and ecological changes are all areas that together with water pathways and chemical processes through buffer strips need further investigation to be fully understood.

The majority of the high SDI values from the extensive study were located in the west, east and southwest and therefore in line with previous studies on acid sensitive areas in the Republic. The correlation between SDI-values and the underlying geology looks to be the main explanatory factor behind this, however other factors like high sea salt deposition in coastal areas may also contribute to this association (White *et al*. 1999). However, the inverse correlations found between SDI and both pH and alkalinity at base flow conditions does imply that the SDI might be a useful indicator of acid sensitive waters. Temporal variation of the SDI with flow seems to be limited for most sites, though the preliminary data indicate that the SDI is subject to more variation with flow at the forested sites. More detailed analysis of the chemical data collected will hopefully enable us to understand this issue in more detail. In any case, the preliminary data indicate a large degree of stability with flow, which provides robustness for variation of conditions during sampling.

It is well known that macroinvertebrates are sensitive to hydrochemical parameters such as low pH and high aluminium concentrations. The observed shift from a communities dominated by Ephemeroptera to one dominated by the more acid tolerant Plecoptera with increasing SDI-values has previously been associated with increased acidity of streams (Friberg *et al*. 1998). Thus, the apparent link between SDI-values and macroinvertebrate communities further strengthens the support for the index to work as an indicator of acid sensitivity. However, these are preliminary data and a more detailed analysis of the faunal data may reveal further patterns in faunal composition associated with the SDI.

Whether a cut off at 40% sodium dominance is appropriate to classify streams as acid sensitive still needs further study and hopefully a more detailed analysis of the data collected as part of the WATERAC project will help explore this topic further. The temporal fluctuation in SDI with flow and between-site variation in this temporal fluctuation needs to be researched in more detail. However, at this point of the project it seems that the SDI could be a useful tool when trying to identify new areas for afforestation and further research should enable us to get a better understanding of the variation of the index encountered with flow and land use.

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Soil Carbon – The Forgotten Pool

K.A. Byrne*, G. Saiz, V, Blujdea, K. Black, B. Osborne O. O' Sullivan, O. Schmidt, J. Dyckmans, B. Tobin, J.J. Gardiner, M. Nieuwenhuis, S. Dolan, B. Reidy, T. Bolger and E.P. Farrell

INTRODUCTION

The United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol (KP) is the first global policy attempt to reduce greenhouse gas (GHG) emissions, in order to mitigate the effects of global climate change. Under the terms of the KP, countries have reduction commitments that need to be reached during the first commitment period, 2008-2012. Under the European Union burden sharing agreement Ireland is committed to limiting its GHG emissions to 13% above 1990 levels. To help countries meet these targets and minimise the economic impact of reducing energy requirements, the KP allows carbon (C) sequestration by forests to be used to offset GHG emissions, but places strict limits on its use. C stock changes that occur in each commitment period, as a result of afforestation, reforestation and deforestation since 1990, may be used to offset emissions. Forest management can also be used, although in Ireland's case the maximum that can be claimed is 50,000 t C yr^{-1} during the first commitment period (see Byrne and Green 2004). The UNFCCC and the KP requires the development of GHG inventory for Irish forests. Such an inventory needs to account for C stock changes in above-ground biomass, below-ground biomass, litter, dead wood and soil organic matter. While guidance is provided by the *Revised 1996 IPCC Guidelines for National Greenhouse Inventories* (Houghton *et al.* 1997) and the more recent *IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry* (Penman *et al.* 2003) there is a need for nationally specific data in order to best reflect national circumstances and to reduce uncertainty. It is in response to this need that the CARBiFOR project was initiated.

Soils are an integral component of both the global C cycle and the forest C cycle. Forest soils can contain significant amounts of C. Globally soils are estimated to contain 466 Gt C, while vegetation is estimated to store 2011 Gt C (Bolin *et al.* 2000). Forests account for 77% of vegetation C and 39% of soil C. Given that the atmosphere contains c. 750 Gt C it is clear that changes in the size of the forest C stock have the potential to significantly alter atmospheric CO_2 levels. C is added to the soil through litterfall, fine root turnover and harvest residues. C is lost from the soil as CO_2 through heterotrophic respiration (decomposition of organic matter) and autotrophic respiration (maintenance respiration by tree roots and soil organisms). The soil will act as a C store as long as the rate of C input to the soil exceeds the rate of C loss. Accounting for the changes in soil C stock in forests requires an understanding of all aspects of the soil C cycle and how it changes with factors such as stand age, rotation length, species, soil type and environmental conditions.

CARBIFOR

The CARBiFOR project (Carbon Sequestration in Irish Forest Ecosystems) was established in 2001 and has an overall objective of providing data to determine C budgets, spanning the entire life cycle of Sitka spruce forests. In pursuance of this the project aims to determine:

- C stocks during stand development
- Changes in biomass expansion factors during stand development
- C fluxes during stand development
- C budgets for the selected forests.

The study is located in a chronosequence of Sitka spruce at Dooary Forest, Co Laois. The chronosequence covers four forest sites varying in age from 9 to 47 years. All stands are first rotation

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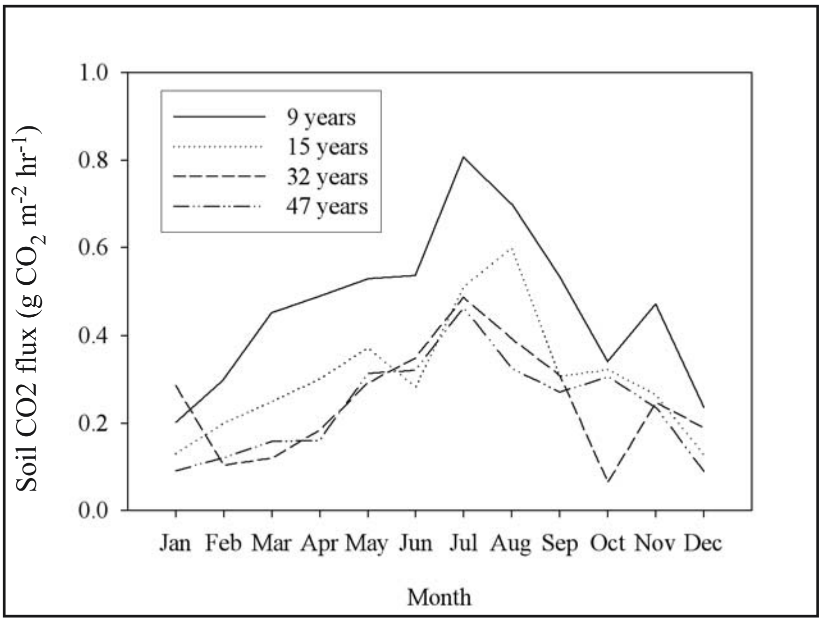

Figure 1: Average soil CO_2 emissions during 2003 in a chronosequence of Sitka spruce stands.

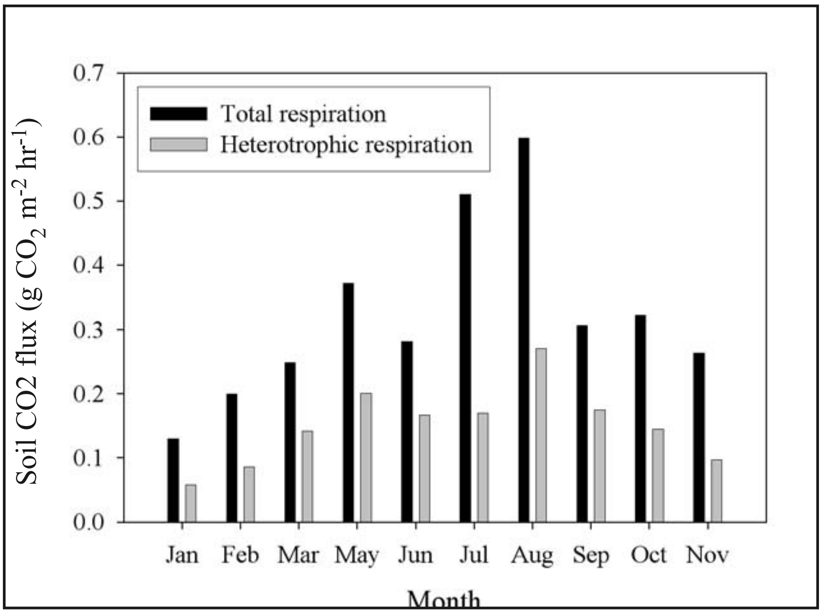

Figure 2: Contribution of heterotrophic respiration to total soil respiration in a 15-year-old Sitka spruce plantation during 2003.

and the principal soil types are gleys and podsols. The project includes a broad range of studies (see also Black *et al*. this volume) and this paper describes the approach to studying soil C and presents some preliminary results.

The soil component of CARBiFOR had the following specific objectives:

- To measure the spatial and temporal variation in soil CO_2 emissions.
- To quantify the contribution of heterotrophic and autotrophic respiration to total soil CO_2 emissions.
- To determine the relationship of soil CO_2 emissions with soil temperature and soil moisture content.
- To measure soil C stocks and test the applicability of the CENTURY model to predict changes in soil C stocks.

SOIL CO_2 FLUXES

Methods

Soil CO_2 emissions were measured using portable chambers at a number of sites throughout 2003. Soil temperature and moisture content were monitored during soil CO_2 emission measurements. Total soil CO_2 emissions were partitioned into heterotrophic and autotrophic respiration by comparing CO_2 emissions between undisturbed areas of soil and the soil surface enclosed by stainless steel pipes (16 cm diameter) inserted 30 cm into the forest floor/mineral soil. In addition, litterfall was measured at all sites and fine root biomass regularly assessed.

PRELIMINARY RESULTS

Preliminary results show that soil CO_2 fluxes vary seasonally (Figure 1) and are well correlated with soil temperature. Furthermore, total soil CO_2 emissions were limited during times of drought or soil water saturation. Soil CO_2 fluxes indicated a definite trend over the chronosequence where young stands emitted greater amounts of CO_2 than the older ones (Figure 1).

The different respiration components that make up the total soil CO_2 flux were quantified separately to assess their relative importance in relation to the overall emission. Both autotrophic and heterotrophic respiration varied seasonally (Figure 2). This was mostly explained by seasonal changes in soil temperature.

CONCLUSIONS

Work is ongoing to develop a model to explain the relationship of soil CO_2 emissions with soil moisture and temperature. Further work will quantify the spatial variation in soil CO_2 emissions and the role of fine root turnover in soil CO_2 emissions. The applicability of the CENTURY model for simulating soil C stock changes will also be assessed.

The CARBiFOR project will greatly increase understanding of soil C cycling in Irish forests. This knowledge will assist in the development of integrated budgets for C sequestration in Sitka spruce forests on mineral soils. Furthermore, this information will improve the accuracy of assessments of C sequestration in Irish forests and of the contribution of forests to Ireland's commitments under the Kyoto Protocol.

ACKNOWLEDGEMENTS

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Irish Forests - A Dynamic Carbon Store

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INTRODUCTION

As signatories to the Kyoto Protocol European countries are required to reduce their collective greenhouse gas (GHG) emissions to at least 5% below the 1990 level over the first commitment period from 2008-2012. Under the EU burden-sharing agreement Ireland's target is to limit its growth in emissions to 13% above 1990 levels. As a result of the rapid growth of the Irish economy over the past decade, current GHG emission levels are 37% above the 1990 level (EPA). Under the terms of the Kyoto protocol carbon sequestration by forests may be used to offset greenhouse gas emissions. For the first commitment period carbon stock changes in Kyoto (Article 3.3) forests must be estimated for deforestation, reforestation and afforestation activities since 1990. Assuming the business as usual scenario, it is estimated that the contribution of forests activities relating to Article 3.3 may account for 27% of the required reduction (13.05 Mt CO_2 equivalents per year) in national emissions for Ireland to meet its Kyoto target (Byrne and Milne, unpublished data).

Whilst standardized carbon inventory methodologies have been developed to estimate the carbon stock and storage capacity of forest ecosystems (see Houghton *et al*. 1997), there is a clear need for reported values to reflect national circumstances. The primary objective of the CARBiFOR project is to provide data on carbon stocks and sequestration rates spanning the entire life cycle of the major forest type in Ireland. This project cluster was designed specifically to provide improved estimates, based on meteorological and inventory methods, of above-ground and below-ground carbon (C) stocks and sequestration rates for afforested Sitka spruce stands, grown on wet mineral gley soils.

Inventory methods, based on species and region-specific biomass models, may be suitable for carbon accounting reports, but these methods should be cross-validated using a 'full C accounting' procedure to estimate losses associated with disturbance and land use change, which cannot be determined using conventional biomass or soil C stock estimates. From a 'full carbon accounting' perspective, ecosystem flux measurements by eddy covariance (Aubinet *et al*. 2000) can be used to verify, at a stand or local scale, changes in carbon stocks, emission factors or default values used to compile carbon budgets for a particular land-use category.

OVERALL APPROACH

The sites representing the Sitka spruce chronosequence were located in five different Coillte forests in the Portlaoise area (~52º 57' N, 7º 15' W). Selected stands (9 to 45-year-old trees) are representative of the typical yield class (18-20 m^3 ha^{-1} yr^{-1}) for Sitka spruce growing on wet mineral soils in Ireland (Table 1). An additional 14 year-old-stand, of yield class 24 was used for eddy covariance measurements, and validation of inventory-based estimates. Total height (H), height to crown and diameter at breast height (DBH) of individual trees from four sampling plots per site were recorded over a period of one week in July 2002, and this was repeated in June 2004.

Estimates of annual changes in soil C stocks were based on measurements of litter C inputs and soil C content in stands of different ages. The inventory data for biomass and soil C stock changes, at the 14-year-old Dooary site, were cross-validated with eddy covariance measurements of C sequestration over a two year period.

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Table 1: Summary of the Sitka spruce chronosequence in 2002.

Forest	Age yr	Yield class $m^3\ ha^{-1}\ yr^{-1}$	Stocking stems ha^{-1}	Mean DBH cm	Mean Height m	Crown to height ratio	LAI* $m^2\ m^{-2}$
Baunogue	9	18-20	2,300	5.4	3.8	0.08	4.5
Clontycoe	14	18-20	2,366	10.8	5.8	0.13	7.8
Dooary	14	20-24	2,400	13.6	7.6	0.41	10.5
Glenbarrow	25	18-20	1,133	22.8	14.9	0.56	8.2
Dooary	30	18-20	1,083	25.2	17.6	0.59	7.2
Cullenagh	45	18-20	730	31.4	21.0	0.61	6.5

* Leaf area index (LAI) was determined using a previously described allometric relationship (Black *et al*. 2004)

BIOMASS AND SOIL CARBON STOCKS

Development of biomass models

As forest inventories are traditionally based on the estimation of timber volume (V), biomass expansion factors (BEFs), carbon content ($C_{(m/m)}$) and density (D), are required to convert volume to total biomass C. For the purpose of this study, BEF is defined as the ratio of aboveground biomass to total stem biomass ($t\ t^{-1}$)

Biomass C stock = $V \times D \times C_{(m/m)} \times BEF$ (1)
($t\ C\ ha^{-1}$)

The estimation of an annual increment in biomass C stocks requires an estimate of annual timber volume increment (VI):

Annual biomass C increment = $VI \times D \times C_{(m/m)} \times BEF$ (2)
($t\ C\ ha^{-1}\ yr^{-1}$)

The traditional definition of BEF (the ratio of total biomass to merchantable timber volume) may not be suitable for calculation of C storage by all forest ecosystems because of the exclusion of younger stands with significant C reserves but no merchantable timber (DBH < 7 cm). Consequently, the application of models to younger stands can lead to large errors when predicting forest biomass. To incorporate younger stands into current biomass estimates, BEF should be redefined as the ratio of total biomass to growing stem biomass. For Sitka spruce, BEF values can vary from 1.4 to 5.0 for a selected chronosequence depending on age, yield class and stand growing stem biomass (Figure 1). Therefore, biomass inventories may require the development of stand and species-specific BEF values. A possible alternative would be to use species-specific biomass functions based on allometric algorithms derived from forest inventories over a rotation cycle to estimate total forest biomass increment. The calculation of biomass carbon stocks based on biomass functions and carbon content would eliminate the errors associated with the estimation of stem wood growth rate, BEF and specific wood densities when calculating forest carbon stocks.

Allometric algorithms were developed using total biomass data, obtained from trees harvested from the selected chronosequence. Sensitivity analysis of these biomass models suggest that the most accurate and least variable estimate of total stand biomass was obtained when both DBH and tree height were used as predictors of stand biomass C stocks.

Biomass C stocks varied from 20 t C ha^{-1}, in the 9-yearr-old stand, to 205 t ha^{-1}, in the 45-year-old

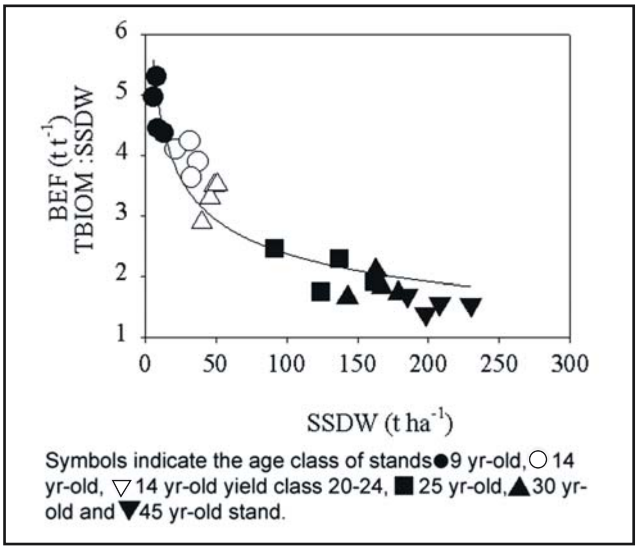

Figure 1: The curvilinear relationship between stand growing stem biomass (SSDW) and BEF, expressed as the ratio between total biomass and growing stem biomass, using data from the Sitka spruce chronosequence. All stands were yield class 16-20 unless stated differently. (From Black *et al*. 2004).

stand (Figure 2). The older stands exhibited a greater coefficient of variation in biomass C stocks due to larger differences in stand density, when compared to the younger stands. A comparison of estimates of C stocks using both the BEF or biomass function approach, suggests that the largest variance and errors of predicted estimates occurred when the BEF method was used. The average annual biomass C stock increment, over the chronosequence, was 4.1 t C ha^{-1} yr^{-1} (Figure 2), but this was lower in very young and older stands after thinning.

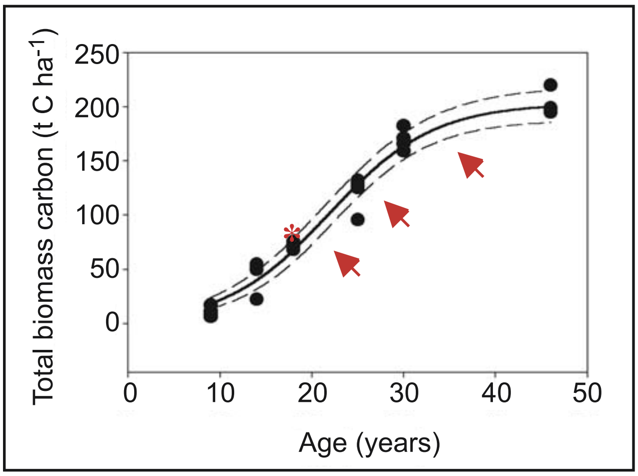

Figure 2: Changes in total biomass carbon stocks with stand age (Black *et al*. unpublished data). The solid line represents a sigmoidal function depicting the change in biomass C as a function of stand age (r^2 = 0.96). The broken lines represent the 95% confidence limits. The age of the 14-year-old, yield class 24 stand was rescaled to 18 years (*) to account for developmental differences in biomass increment associated with a different yield class. The arrows indicate when stands were thinned. Stand biomass C stocks were estimated using allometric biomass models.

Soil carbon stocks

Conventional chemical methods currently used to determine changes in soil carbon are based on mass balance estimates of carbon in the various soil fractions. For this purpose, soil organic matter (SOM) is divided into three pools; an active SOM consisting of microbial biomass and metabolites (turnover of 1-5 years); a slow SOM, consisting of partially stabilized organic matter having an intermediate turnover rate (20-40 years); a passive SOM, which is the most recalcitrant pool with the longest turnover rate (200-1500 years). The ability of forest ecosystems to store C in soils depends on the deposition and accumulation of a highly lignified and recalcitrant C pool. Analysis of the amount of different C pools in soils from various sites show that the total soil C stock was 109 t C ha^{-1}, for a non-forested site, compared to 175 t C ha^{-1}, for a 45-year-old stand (Figure 3). The largest increment in soil C stocks (~2.4 t C ha^{-1} yr^{-1}) occurred in the 15-year-old stand, where litter input was higher. Changes in litter inputs with stand age were associated with differences in leaf area index (LAI, Table 1 and Figure 3).

Data obtained from the analysis of SOM in the different stands and isotopic labelling experiments will be used to parameterise a soil model (CENTURY) to predict changes in C stocks in afforested mineral gley soils.

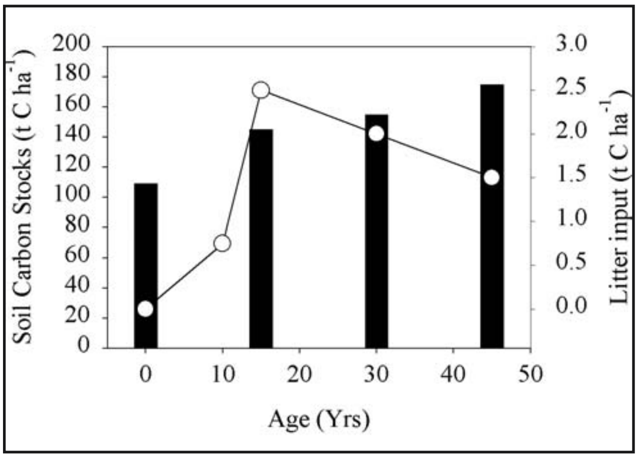

Figure 3: Changes in soil carbon stocks (black histograms) and litter inputs (white symbols) with stand age (Reidy *et al*. unpublished data).

FULL CARBON ACCOUNTING

The net exchange of carbon by a forest ecosystem over a given period of time is termed net ecosystem productivity (NEP). NEP captures a variety of processes and feedbacks associated with C metabolism by vegetation and soils, including gross primary productivity or photosynthesis (GPP), and total ecosystem respiration (Figure 4).

Eddy covariance has been used to continuously measure the exchange of CO_2 between the atmosphere and a 14-year-old forest since February 2002. The NEP or net annual uptake of C for this stand was 8.9 and 8.3 t C ha^{-1} yr^{-1}, for 2002/3 and 2003/4 respectively (Figure 5). Seasonal variations in NEP, GPP and total ecosystem respiration were associated with changes in temperature and irradiance (Figure 5 A, B). This suggests that NEP may be limited by GPP as a result of low temperatures and reduced light levels during the winter months (Figure 5 A, B).

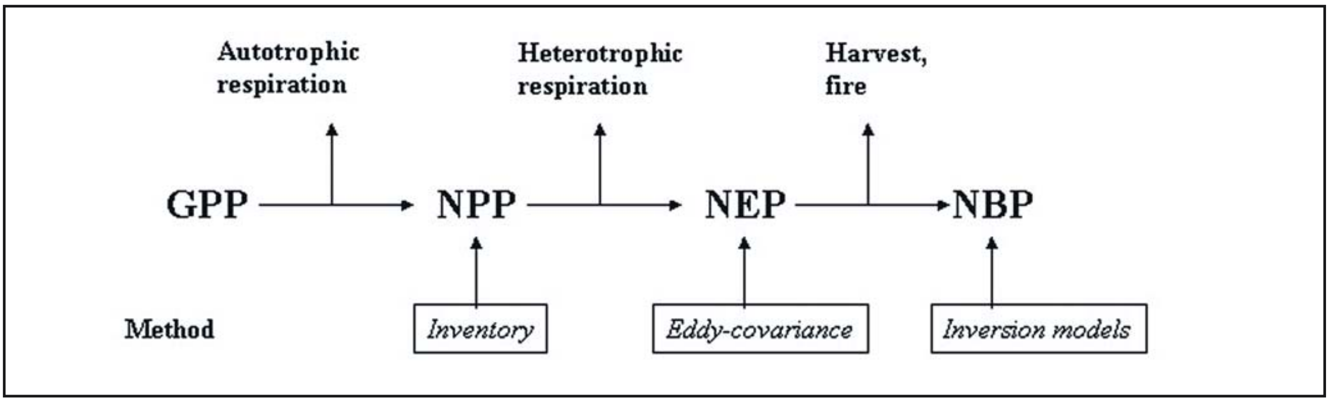

Figure 4: The relationship between different components of ecosystem exchange and associated observation methods (from Ehman *et al*. 2002). Gross primary productivity (GPP) is the C flux due to photosynthetic processes. Net primary productivity (NPP) is measured as biomass increment and associated biomass losses, representing GPP minus losses due to autotrophic respiration. Net ecosystem productivity (NEP) is the net uptake (positive) or loss (negative value) for the entire ecosystem as measured by eddy covariance, which accounts for losses associated with heterotrophic respiration. Net biome productivity (NBP) represents the total uptake or loss of C over for a particular land use type, including NEP changes predominantly associated with harvesting or thinning.

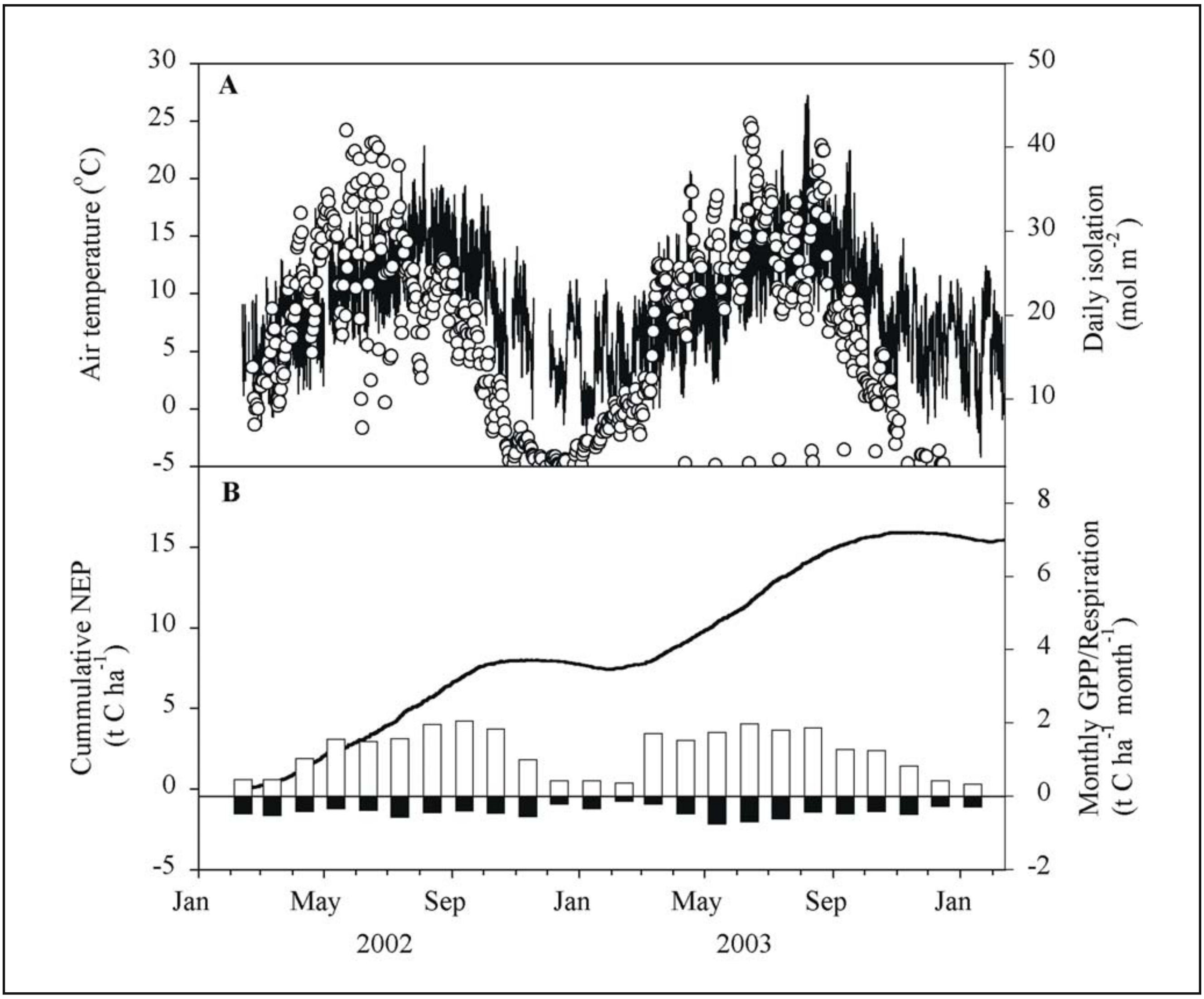

Figure 5: Annual and seasonal variations in (A) air temperature (solid black line) and daily isolation (integrated daily irradiance; white symbols), and (B) cumulative NEP (solid line), monthly GPP (white histograms) and monthly ecosystem respiration rates (black histograms; Black *et al*. unpublished data)).

VALIDATION OF INVENTORY AND EDDY COVARIANCE ESTIMATES OF NEP

Theoretical considerations

Although annual NEP can be estimated using either eddy-covariance or inventory techniques, both methods have potential errors due to systematic biases of unknown magnitude.

If annual losses of C from the ecosystem, via heterotrophic respiration, are known, NEP can be calculated using an inventory approach;

$$NEP = NPP + R_h \quad (3)$$

Where R_h is heterotrophic respiration due to microbial decomposition of soils, dead root material, coarse woody detritus (CWD) and respiration by consumers;

$$R_h\ (total) = R_{h\ (soil)} + R_{h\ (CWD)} + R_{h\ (consumers)} \quad (4)$$

Net primary production was estimated using the following:

$$NPP = \Delta B + D_{total} + H \quad (5)$$

where, ΔB is the change in living biomass, D_{total} is the sum of above (litterfall) and below-ground detritus production and H is related to herbivore removal of biomass. Above-ground litterfall is measured as the annual loss of live shoots or branches. Below-ground detritus is defined as all C transferred from roots and mycorrhizae to the soil as exudation and mortality. The estimation of ΔB in practice relies on allometric relationships between tree biomass and DBH and/or height. The change in living biomass was estimated using allometric algorithms for live biomass only, to account for potential changes in standing CWD.

Heterotrophic respiration

A soil heterotrophic respiration model ($R_{h\ (soil)}$), including litter in the O horizon, was developed based on *in situ* and soil core measurements. Heterotrophic respiration or decomposition of the litter and soil C appeared to contribute a large part of the NEP carbon balance (Table 2). However, the model only accounted for 61% of the observed variation in the measured respiration rates (data not shown). Analyses of the soil respiration data suggested that the decomposition of C in soils is reduced during rainfall events and periods of high soil moisture content (Figure 6). This may be associated with a

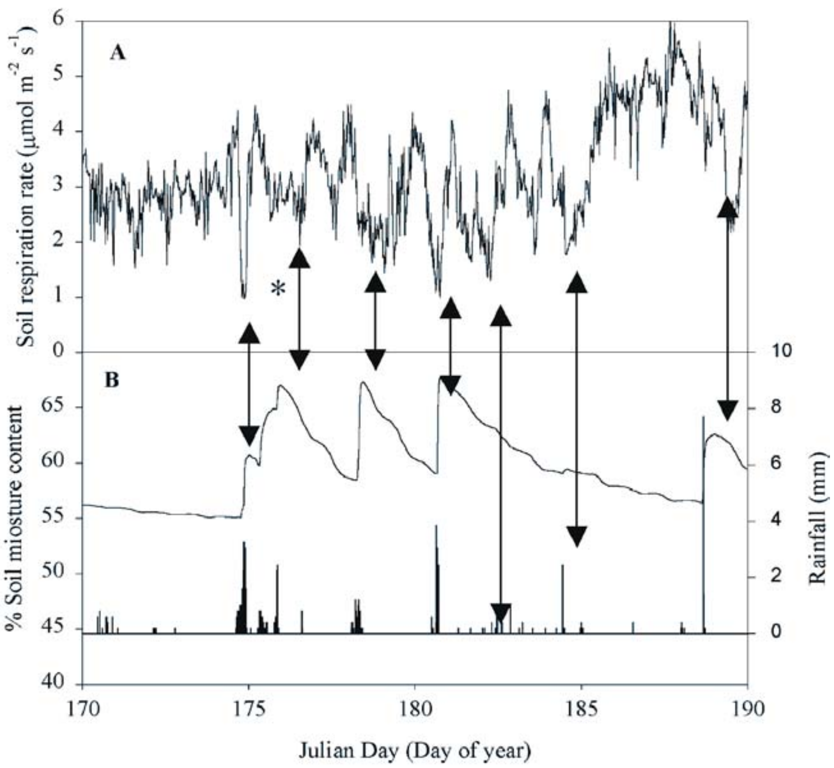

Figure 6: Changes in soil respiration rates (A), soil moisture content (solid line, B) and rainfall (histograms, B) during June/July 2004. The arrows indicate where respiration rates decline during and after rainfall events due to changes in soil moisture content (Black *et al.* unpublished data).

reduction in CO_2 diffusion out of and influx of O_2 into wet gley soils, which would decrease $R_{h\ (soil)}$ rates under those conditions. The $R_{h\ (soil)}$ model is currently being improved to account for diffusion processes and variations in the amount of active versus recalcitrant SOM.

Estimates of $R_{h\ (CWD)}$, based on the decomposition of total standing CWD as a function of temperature, suggests that 9% of the annual C pool in standing CWD was decomposed (Table 2). This is consistent with other studies, which show that 5 to 10% of the standing CWD is decomposed every year (Janisch and Harmon 2002, Ehman *et al*. 2002).

Cross-validation

The annual uptake of C by the forest, based on ecosystem inventory estimates, for 2002/3 and 2003/4 was 8.4 and 7.8 t C ha^{-1} yr^{-1}, respectively. For the same time period, eddy-covariance estimates of NEP were 8.9 and 8.3 t C ha^{-1} yr^{-1}, which was 5.9% and 6.4% higher than the inventory based estimates (Table 2).

We suggest that the lower inventory estimates of NEP, compared to flux assessments, may be associated with unaccounted C fluxes including fine root production/turnover, below ground losses and herbivory. Conversely, an over estimation of eddy covariance estimates are possibly due to unaccounted soil organic matter (SOM) losses associated with run off. Despite these differences, uncertainty and error analysis for both inventory and flux based methods suggest that there was no statistical difference between the two procedures.

It is evident from these initial studies that there are numerous unknown variables associated with the estimation of NEP based on inventory methods at the stand level. These include the inability to fully account for standing CWD changes, litterfall associated with current annual growth, herbivory

Table 2*: A comparison of inventory and eddy covariance based estimates of annual NEP. Heterotrophic models were based on temperature and moisture functions. The inventory NEP values were calculated using the live biomass increment method as this had a smaller error of estimation. Values represent a mean and cumulative standard error with 95% confidence limits.

	2002/3		2003/4	
t C ha^{-1} yr^{-1}	**Value**	**±SE**	**Value**	**±SE**
Inventory				
Biomass increment (DB)	10.5	1.9	10.3	2.2
Total living biomass	10.5	1.9	10.3	2.2
Fine roots	ND		ND	
Losses (D)	0.19	0.7	0.22	0.6
Litterfall	0.19	0.07	0.22	0.06
Belowground	ND		ND	
Herbivory	ND		ND	
Heterotrophic respiration (Rh)	-2.23	1.07	-2.7	1.21
Soil Rh	-2.14	1.1	-2.54	1.2
¶CWD Rh	-0.1	0.03	-0.09	0.03
Consumers	ND		ND	
NEP (NPP + Rh)	8.45	2.2	7.8	2.5
†Eddy-covariance	8.9	0.45	8.3	0.42

¶ CWD loss based on estimated decomposition rates of total standing CWD

† Estimation of error for annual eddy covariance was based on a 5% cumulative uncertainty (Goulden *et al*. 1996)

*Black *et al*. unpublished data

losses, fine root production/turnover, as well as potential errors associated with the eddy covariance measurements.

Age related changes in NPP

Despite the lack of information for a full accounting estimate of NPP, we assessed the potential changes in C sequestration in the different experimental stands by assuming that biomass increment was the predominant process governing NPP and that herbivory losses were negligible. These preliminary assessments suggest that changes in NPP of different aged stands may be associated with differences in leaf area index (Figure 7), interception of light and the efficiency with which absorbed light is utilised in assimilating C.

Implications of findings in relation to:

National forest inventory and biomass estimates

Both DBH and height should be measured in repeat surveys and used as predictors for biomass stocks and changes.

The calculation of biomass carbon stocks based on biomass functions and carbon content would eliminate the errors associated with the BEF method when calculating forest carbon stocks.

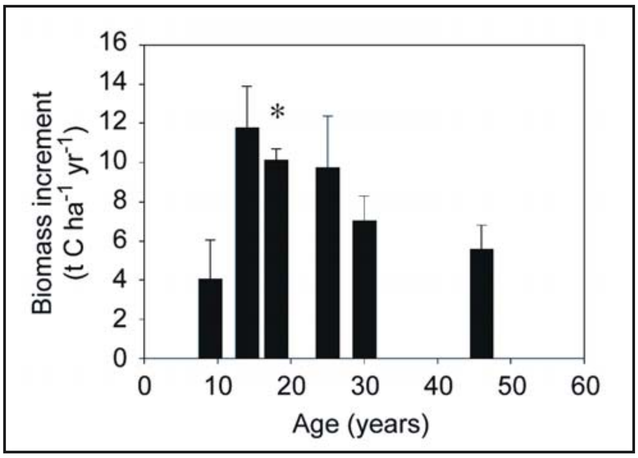

Figure 7: Age related changes in biomass increment. Estimates of the change in stand biomass were based on allometric models using inputs from 2 years of survey data. The age of the 14-year-old, yield class 24, stand was rescaled to 18 years (*) to account for developmental differences in biomass increment associated with a different yield class (Black *et al*. unpublished data).

The greatest error in estimating biomass C stocks and stock changes in older stands is associated with variations in stand density.

Although there have been significant advances in the development of biomass stock models for Sitka spruce, alterations in BEF and/or variations in the functions used for biomass estimations on other soil types and other species is required.

There is good agreement between eddy covariance and inventory-based estimates of C sequestration at the stand level. However, more information on soil respiration, litterfall, and fine root turnover from different aged stands and soil types are required to provide verifiable values.

The sequestration potential of national forests

Based on inventory methods, the average C sequestration rate, over the entire life cycle of the selected chronosequence of Sitka spruce, was estimated to be 5. 7 t C ha^{-1} yr^{-1} (Figures 2 and 3). This value is significantly higher than a previously reported average estimate of approximately 3.36 t C ha^{-1} yr^{-1} (Kilbride *et al*. 1999), based on the model developed by Dewar and Cannell (1992). The higher average sequestration rate reported in this study was due to the inclusion of soil C stocks and the use of improved biomass models. Our results suggest that the BEF value used to calculate carbon stocks for Irish forests was underestimated in the report by Kilbride *et al*. (1999), particularly for younger Sitka spruce stands. The use of a single BEF value of 1.3 may result in an ~ 2 to 4-fold underestimation of current carbon stock changes for sites afforested since 1990.

The chronosequence approach can be used to determine changes in biomass and soil C stocks over time (Figures 2 and 3). However, changes in C stocks may be more difficult to measure in highly organic soils, such as peat soils or podsols, because of the high background soil C content (Mencuccini *et al*. 2002).

The soil water properties and type of soil may be an important determinant of decomposition rates of organic matter in forest soils. In wet mineral soils, decomposition may be slower due to the inhibition of respiration at high soil water contents (Figure 6). In contrast, more C may be lost via decomposition processes in dry or well-drained forest soils.

Inter-annual variation in NEP, for the 14-year-old Dooary stand, were associated with changes in temperature and light levels. The lower NEP during the winter months was predominantly due to the short day length, with the lower temperatures having a smaller effect.

Changes in the potential sequestration rates in younger or older stands (Figure 7) are associated with differences in LAI, absorption of light by the canopy and changes in the conversion efficiency of absorbed light into fixed C. Therefore, the implementation of alternative planting and thinning practices may have a significant impact on the C sequestration potential of afforested stands.

The estimated annual NEP values (~8 t C ha^{-1} yr^{-1}, Figure 5) for the 14-year-old Dooary site are similar, but slightly higher, than those reported for a Scottish Sitka spruce stand of a similar age (Carboage, CarboEurope cluster, unpublished data). This may be partially due to the lower productivity of the Scottish stand (yield class 18-20), which is located on a podsol soil.

It is also evident from our results and reports from the Scottish project (Carboage, CarboEurope cluster, unpublished data), that 8 t C ha^{-1} yr^{-1} may be the upper limit of annual NEP for Sitka spruce stands, under current climatic conditions and with typical or current management practices. However, it is plausible that sequestration rates may be potentially higher in faster growing stands of yield class of 26 or 28.

Based on studies on Scots pine, NEP may be substantially lower following clearfelling and replanting, due to the higher decomposition rates (source of C) in harvested stands (Kolari *et al*. 2004). It has been shown that C losses associated with clearfelling may be equivalent to the sum of C sequestered over the first 20 years of the second forest cycle following replanting (Carboage, CarboEurope cluster, unpublished data). These losses may be minimised by partial clearfelling and replanting, continuous cover forestry or minimum soil disturbance following clearfelling.

In addition to accounting for changes associated with stand age, there is a need to incorporate an analysis of the effects of disturbance, particularly those related to management practices (e.g. thinning), and land-use change, such as transition from grassland to forest.

A major short-fall in accounting for forest ecosystem C balance during land-use change is the exclusion of ecosystem processes, associated with under-storye vegetation changes during canopy development, in current inventory-based NEP estimates. This is compounded by the lack of information on baseline estimates of C balance prior to afforestation. The net change in ecosystem sequestration potential due to land-use change to forestry would depend on the forest species, soil type and type or land-use activity prior to afforestation.

Although much progress has been made regarding our understanding of C cycles in forest ecosystems, many issues relating to belowground compartments remain poorly understood. Fine roots are a key component, because they are the major source of soil organic matter (SOM) and influence both microbial activity and decomposition processes (Jessens *et al*. 2002). In addition, limited information on the influence of fine root production and turnover on NPP introduces a significant error in the estimation of current NEP-based inventories. Our current estimates of NPP may be severely underestimated, based on the suggestion that fine root production may represent up to 30% of NPP (Jessens *et al*. 2002).

ACKNOWLEDGEMENTS

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PractiSFM: Multi-Resource Inventory and Decision Support System for Sustainable Forest Management

F. Barrett*, M. Nieuwenhuis and M. Somers

INTRODUCTION

During the last 30 years, traditional forestry objectives aimed at sustained yield management have been replaced with those of Sustainable Forest Management (SFM). SFM is a more holistic forest management system and requires that forest resources are managed in ways which will ensure their integrity, productive capacity, resiliency, and biodiversity and satisfy national economic, environmental, and social values. The framework for SFM has been developed in the context of the Ministerial Conference on the Protection of Forests in Europe. Resolution L2 of the Lisbon conference sets out Pan-European Criteria, Indicators and Operational Level Guidelines for Sustainable Forest Management (Anon 1998). These have been given expression in the Irish context by the National Forest Standard (Anon 2000) and its accompanying Codes and Guidelines. Developing multi-resource inventory protocols and decision support tools to help Irish forest owners manage their woodlands according to this new paradigm is the main goal of the PractiSFM project.

METHODOLOGY

Development of a Multi-Resource Forest Inventory Protocol

Gathering forest inventory data is an expensive and time-consuming process. The challenge when developing a multi-resource forest inventory protocol is to prescribe methodologies that achieve a balance between being practical and cost-effective, while producing credible and useful data for SFM.

The Irish National Forest Standard (Anon 2000) identifies criteria and indicators for sustainable forest management. Local measures for many indicators are recommended. How these indicators should be incorporated into SFM practices and into the PractiSFM inventory methodologies needed to be addressed. Evaluation of methodologies for estimating deadwood, canopy cover, terrain classification, various species habitat suitability, adjacency to water bodies, landscape sensitivity and amenity values was carried out in Ballycurry Estate. Through a combination of research and widespread consultation, these methodologies were refined and compiled into a single field sheet to produce a practical and effective multi-resource forest inventory protocol.

Species (e.g. deer) cover and food habitat suitability models were developed using information from the literature together with expert knowledge. Functions modelling the decay of deadwood in the forest over time were evaluated and the most appropriate model (Eriksson and Lindhagen 2001) was incorporated into the PractiSFM Decision Support System.

Development of a Decision Support System for Sustainable Forest Management

Forest management planning requires an evaluation of the cumulative effects on the forest, of current and future management decisions. To evaluate large data sets over long time scales, and to develop, present and compare alternative forest management regimes, computer-based simulation and optimisation are essential. A Decision Support System or DSS is a particular type of computer-based system or tool that allows forest managers to do their job more effectively; that is, managing a wide range of forest values in a sustainable and holistic manner (Bonnell and Pittman 1994).

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The PractiSFM Decision Support System comprises a series of a customised Microsoft Excel^{TM} based modules that allows forest managers to project the development of a forest under a range of management strategies over a 10-year period. The PractiSFM DSS relies on both timber and non-timber inventory data, collected using the conventional and newly developed multi-resource inventory protocols.

MAIN FINDINGS

Software modules have been developed for validating and summarising the raw timber and non-timber inventory data collected in the field. The Forestry Commission static and Irish dynamic yield models have been integrated into the PractiSFM program and are used at the individual stand level to generate silvicultural treatments, such as thinning, clearcutting or selective harvesting, to standard or user-defined specifications. In this way the raw inventory information is processed to generate stand statistics and silvicultural treatments, and to produce potential stand management options that can be used in tactical and operational management decision-making at the forest level (Figure 1).

The user can run 10-year strategy simulations for the entire forest by selecting and changing management options for each stand, until happy with the outcome. After each simulation, reports in tabular, graphic and map format are produced by the PractiSFM DSS on a wide range of variables These include: harvest volumes and values (by assortment, by period, by species), discounted periodic values, conifer and broadleaf age-class distributions at the start and end of the planning period, retention area statistics, deer habitat ratings, deadwood volumes, terrain classification statistics and aquatic and landscape sensitivity values for thinning and clearfell areas, and operational hours for harvesting and planting (Figure 2).

Visual tools have been incorporated into the program to help the user appreciate the wide variety of information available when formulating forest management strategies with PractiSFM. An interactive map interface has been developed to allow the user to interact with the program, to visualise the spatial impact of particular management scenarios and to refine and reselect management options for different stands. A goal analysis module produces a graphic display of sliders, with which the user can

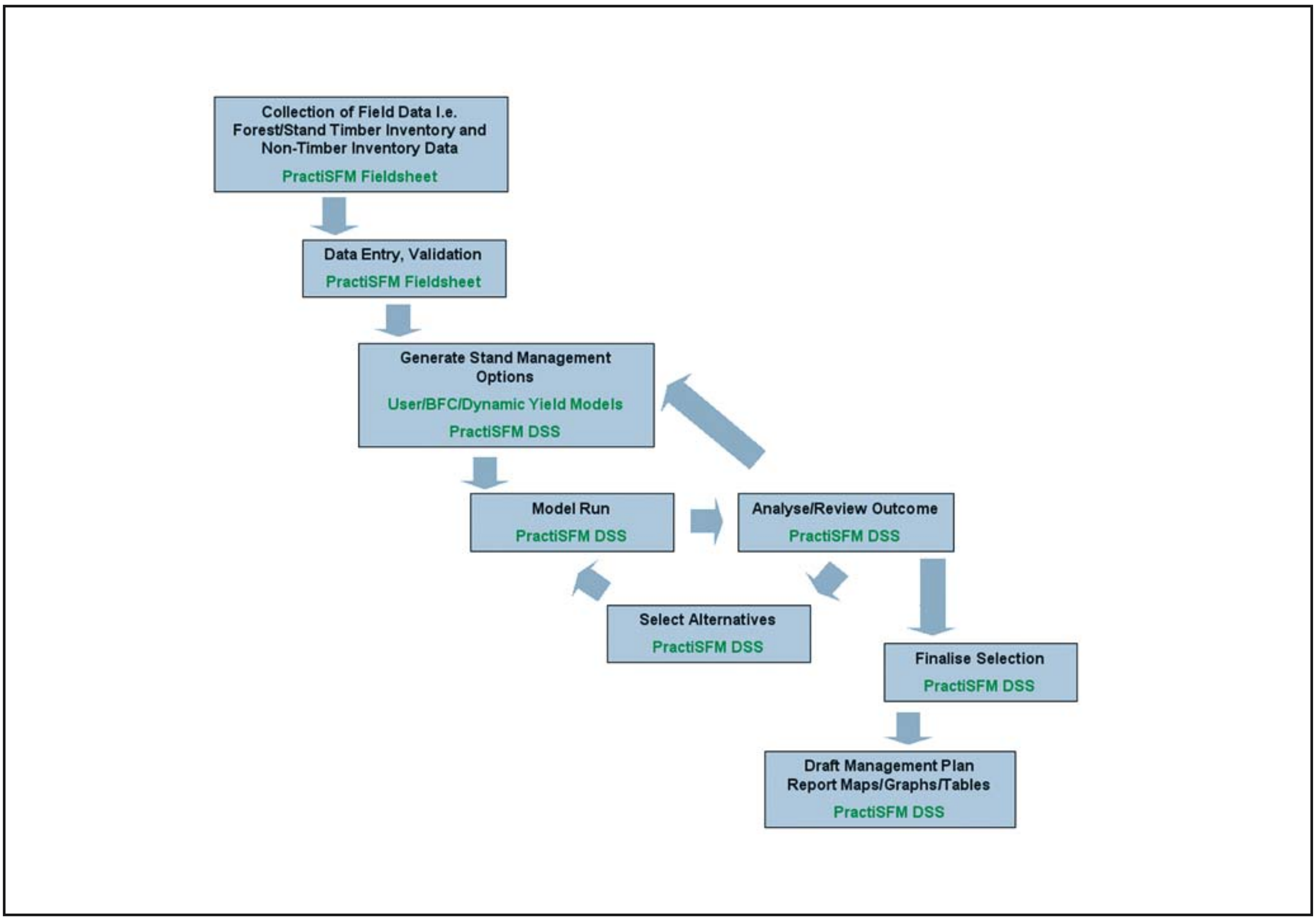

Figure 1: The PractiSFM System, from the collection of inventory data to the drafting of the forest management plan.

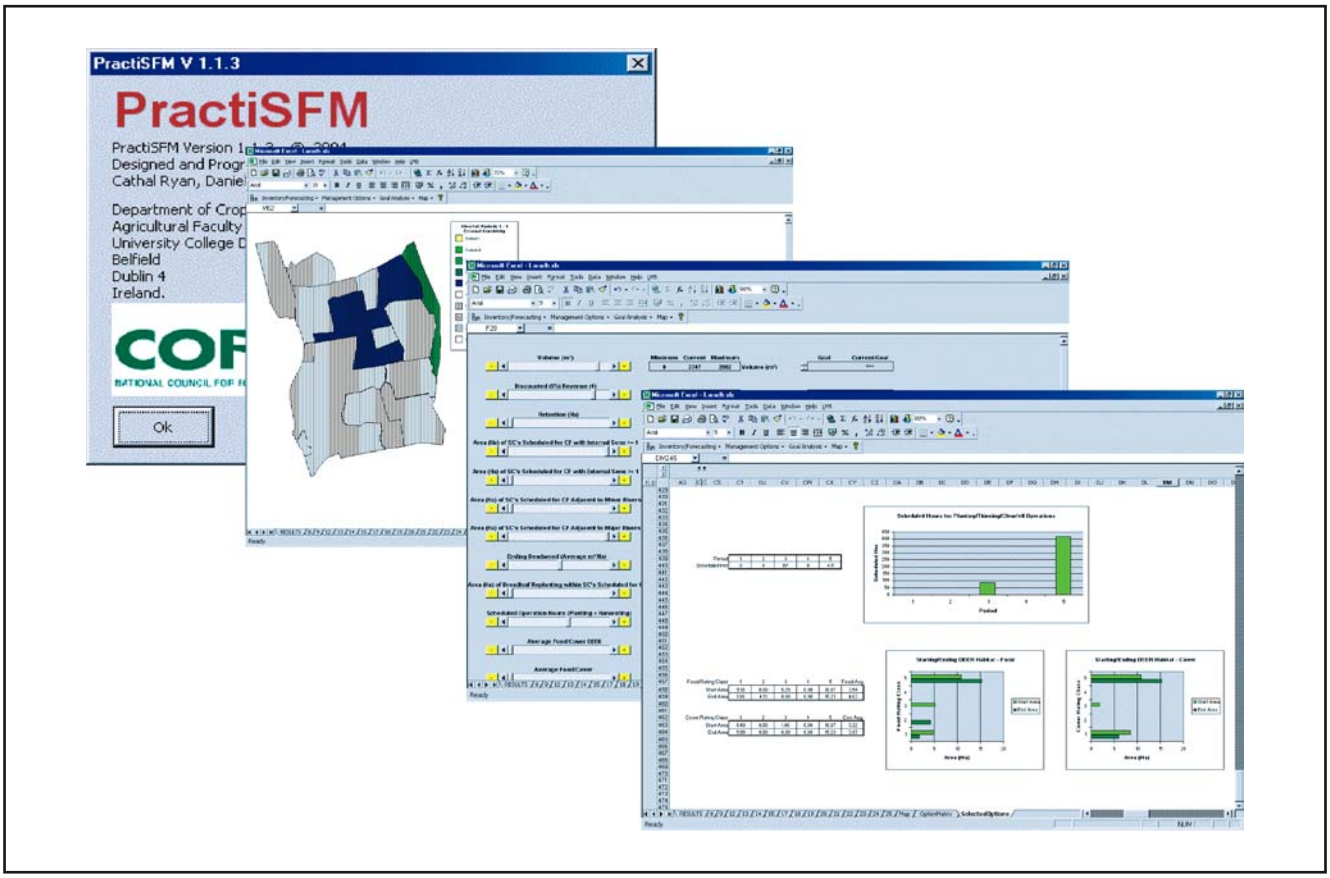

Figure 2: PractiSFM Decision Support System screen shots (Title Screen, Map Based Interface, Goal Screen, Graphic and Tabular Output Screen).

visualise the minimum, the maximum and the current values of a number of timber and non-timber variables. This goal analysis module allows the user to set specific goals and monitor how far the predicted timber and non-timber results at the end of the ten-year planning horizon deviate from these goals. The module also makes the relationship and trade offs between different variables clear, for example how revenue will decrease and the age-class distribution will change if more stands are designated for retention rather than for clearfelling.

CURRENT AND FUTURE DEVELOPMENTS IN THE PRACTISFM PROJECT

The development and refinement of the multi-resource inventory protocol and the specifications used for the PractiSFM DSS are under constant review. A number of presentations to professional foresters, consultants (PTR, SWS, Green Belt, Woodlands), academics and to the Forest Service, were held to showcase the ideas behind and work on the PractiSFM project, and have yielded useful feedback on required further developments and on the practicality of PractiSFM. In addition, final year UCD forestry students have been successfully using the PractiSFM DSS to produce sustainable forest management plans for Ballycurry Estate as part of their studies towards their Forestry degree.

A number of forest sites of varying size, site type, species composition and ownership have now been inventoried according to the PractiSFM multi-resource inventory protocol. These data will be processed using the tools in PractiSFM DSS to determine the strengths and weaknesses of the system as an aid to SFM for a range of site and forest complexities. The degree to which the PractiSFM meets the current requirements under forest certification schemes will also be assessed.

The analytic hierarchy process (AHP), a well-know technique in multi-objective planning, was developed to aid decision-making in a structured and organised manner. Recent studies have applied to the AHP to both environmental resource and forestry based decision problems (Pukkala and Kangas 1993, Kangas and Pukkala 1996, Kangas 1999). AHP and its variants provide the objective mathematics to process the inherent subjective personal preference data of an individual or group and to improve decision-making based on this processed information

(Saaty 2001). Future work will concentrate on integrating AHP decision making techniques into the PractiSFM system to produce a more formalised means of selecting and weighting the criteria used when prioritising management options for each stand in the forest. The inclusion of mathematical optimisation (Goal Programming) and heuristic optimisation techniques within the PractiSFM DSS is also being considered.

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Value Maximisation Through the Integration of Pre-harvest Stand Valuation, Cross-cutting by Harvester, and Sawing Pattern Selection in the Sawmill

M. Nieuwenhuis[*], I. Browne, T. Dooley and T. Layton

INTRODUCTION

The maximisation of product value recovery from timber resources in the sawmilling industry is a multi-phase optimisation process that has not attracted the same attention in research circles as the cost minimisation and volume maximisation elements of the overall quest for profitability.

The first element of a research project, investigating this process of maximising value recovery, has been successfully addressed (Malone 1998, McHugh 1999, Nieuwenhuis 2002, Nieuwenhuis and Malone 1996 and 1999, Nieuwenhuis *et al*. 1999, 2000, 2001 and 2004). The development of stand inventory, valuation and optimal cross-cutting procedures was successfully completed in a COFORD and Palfab Ltd. co-funded research project during 1995-1999 and is included in this paper to give a complete overview of the research carried out.

The second element of the overall optimisation process consisted of an investigation of value and volume recovery in the sawmill. The relationships between recovery and combinations of log type and cutting pattern were investigated, and the development of a value maximisation module for in-mill log/pattern selection was initiated (Browne 2003, Nieuwenhuis *et al*. in press).

The development of an optimal information chain between forest and mill and vice versa was identified as an important element in the integration of the decision-making processes. For this purpose, an investigation into the accuracy and usefulness of the production information produced by the harvester is being carried out as the third element of the study. The second and third elements are part of the OptiVal project currently being undertaken by UCD and Palfab Ltd. and co-funded by COFORD and Palfab Ltd.

BACKGROUND

The breakdown of a stem into sawn products consists of a three-dimensional optimisation process. In the shortwood system, this decision process is spatially and temporally divided into two stages:

- the cross-cutting decision at the stump;
- the selection of a cutting pattern for each log in the sawmill.

In order to make the overall process an optimal one, these two decisions have to be integrated, as the final solution will be dependent on the optimal combination of the two. In addition, the selection and valuation procedure of the trees to be purchased and utilised in this production process, together with demand restrictions and inventory control procedures for the mix of final products, should also be part of this integrated decision-making process.

Individual elements of the process have been investigated in many countries and solutions have been suggested. The only fully integrated 3-D model that has been developed and implemented in sawmill operations was the IDEAS (Integral Decision Effect Analysis System) decision-support system by Reinders (1989). However, this system was designed for a tree-length processing facility, where both the temporal and spatial elements of the decision-making process are concentrated at one point. This system also does not take the stand evaluation and selection decisions into account.

The stand inventory, valuation and optimal cross-cutting procedures developed previously as part of this research produce information on the potential

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value of a stand pre-harvesting. However, during the harvesting process, actual data on assortments produced and log dimensions cut is being generated by the harvesters. An investigation of the accuracy of this information and the usefulness of it in terms of sawmill optimisation is being carried out in order to be able to develop an optimal information chain between forest and sawmill and vice versa. If the results of this investigation are positive, the harvester information can then be used as input in the sawmill recovery optimisation decision-making procedures, while production information from the mill can be fed back into the harvester computer to identify priority assortments and log dimensions. This information can also be used in the valuation of standing timber and in the cross-cutting simulator.

RESEARCH OBJECTIVES

The objective of this research project is the development of an integrated decision support system for the maximisation of value recovery in the sawmilling production chain (Figure 1). This will be accomplished by the integration of the developed optimal stand inventory, valuation and cross-cutting procedures (Element 1) with in-mill inventory control, saw pattern selection, and value optimisation procedures (Element 2), made possible through the use of the information technology available on modern harvesters in the development of the optimal information chain (Element 3).

METHODS

In order to value a stand, an integrated optimal cross-cutting and sawing pattern selection strategy has to be established. The value and demand for the end products in the mill determine the value and priority of the log sizes that should be considered during cross-cutting. Stand information (tree size, taper, size distribution, etc.), together with the log assortment information (small end diameter (sed), length, value, priority) is then used to 1) value the standing timber; and 2) to decide on the harvesting and cross-cutting strategies.

In the mill, for each log size a number of cutting patterns can be used. Depending on the demand for certain end-products and the availability of the different log sizes, different cutting patterns can be selected for a specific log type. However, volume recovery is also a critical parameter. If possible, a cutting pattern producing maximum recovery will be selected. Demand for certain end products and restrictions on the supply of logs of different sizes (and qualities) may make it necessary to deviate from this ‘optimal’ pattern in order to produce the required output of the specified products.

The maximisation process will be constrained by both the potential availability of the different log types (depending on stand characteristics and cross-cutting decisions) and by the market demand for the different potential end products.

An integral part of this second phase of the research is also, therefore, the design and development of the information chain, i.e. the linkage of the mill optimisation system with the timber inventory, valuation and cross-cutting optimisation procedures. In this the harvesters with their computer and communication systems can play an important role. The end result will be a fully integrated decision-support system, allowing for the optimal use of the timber resource. This means that the optimal mix of end products (that the market demands) will be produced from the stands that are best suited to the production of the logs from which those end products are cut in the mill.

RESULTS

The three elements of the study are outlined in this paper. The first is the completed development of a pre-harvest inventory and valuation procedure which uses cross-cutting simulation. The second element deals with in-mill processes, focusing on the development of relationships between dimensions of log input and volume and value recovery. The final element deals with an investigation of the accuracy of the information on log numbers and assortment dimensions as produced by the harvesters and the use of this information in the development of an optimal information chain linking forest and mill.

Element 1: Value maximisation of standing timber

Prior to the purchase and harvest of a stand of timber, sawmills require information regarding not merely the total volume of timber in the stand, but also the volume, number and size classes of different types of logs that could potentially be harvested from the stand. This type of information will greatly assist timber procurement and production planning and will enable mills to identify the best stands to purchase

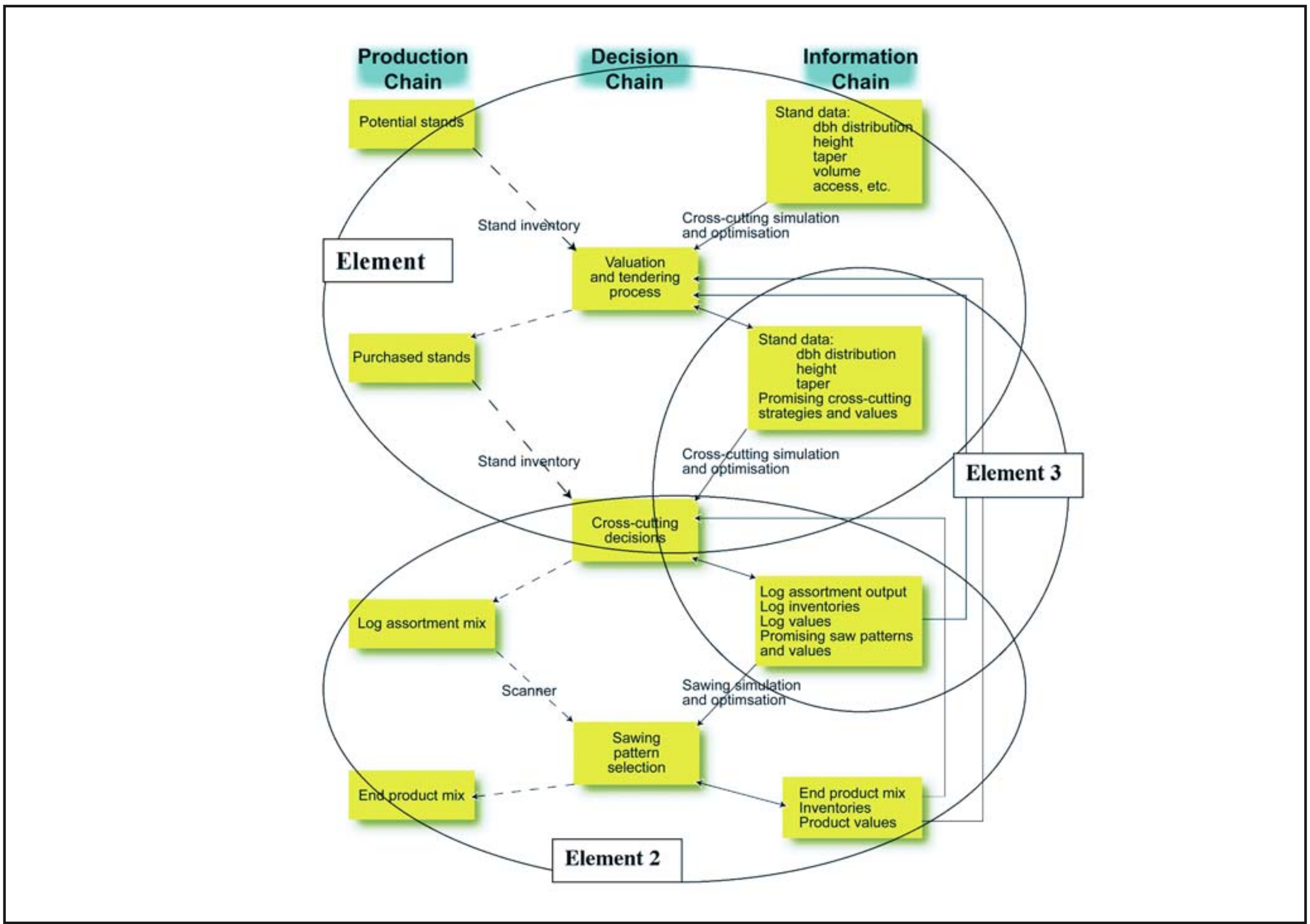

Figure 1: Schematic overview of the production chain, the required information chain and the resulting integrated decision chain. Superimposed are the three study elements.

and subsequently the best combination of logs to produce in each stand in the course of the harvesting operations. A system was produced, incorporating pre-harvest measurement and analysis procedures, to provide the timber procurement manager of a sawmill with accurate pre-harvest estimates of these stand parameters.

Stem profile measurements, consisting of observations of diameter and height, were taken from five Sitka spruce (*Picea sitchensis* (Bong.) Carr.) stands scheduled for clearfell. Four taper equations were selected for evaluation. Performance ranking, based upon values of bias and standard error of estimate, revealed an eight-variable taper equation to be best overall. Eight dbh-height models were chosen from the literature for preliminary testing. The three models that generated estimates of tree height with the least bias and minimum standard error of estimate were further investigated. Further data collection for validation purposes took place in the Cork/Kerry region, involving additional diameter and height measurements on trees at two Sitka spruce clearfell sites, one Norway spruce (*Picea abies* (L.) Karsten) clearfell site and at a Sitka spruce thinning site.

The Kozak taper equation performed consistently well using the data from the two Sitka spruce clearfell sites and the Norway spruce clearfell site. The analysis using data from the thinning site showed that the accuracy of upper stem diameter estimates was generally more variable. The investigation to find the optimum sample size required for the estimation of tree height concluded that a combination of the Curtis diameter-height equation, using simple random sampling and a sample size of 10 trees provided the best combination of accuracy and efficiency.

An interactive computer program was developed to simulate the process by which stems are cross-cut into logs. The program simulates cut-to-length harvesting and produces forecast estimates of yield for each log-type in terms of the volume and number of pieces in each of a series of small-end diameter categories. Results produced by the completed pre-harvest inventory and cross-cutting simulation procedure were compared with results obtained using a dynamic programming algorithm, which represented the theoretical optimal log output. This comparison produced similar results to those found in the earlier tests, with high levels of accuracy for the estimates produced by the cross-cutting simulation program using data from Sitka spruce and Norway spruce clearfell stands, and acceptable results for the sawlog component of a Sitka spruce thinning.

The system developed and tested in this element of the project provides the wood procurement manager of a sawmill with an efficient means of gaining a comprehensive insight into the yield potential of standing timber lots. It represents a valuable aid to improve timber procurement and production planning and, ultimately, to the successful operation of the company as a whole.

Element 2: The Impact of Log Dimensions on Volume and Value Recovery

The successful running of a sawmill depends on the ability to achieve the most profitable combination of throughput and value recovery. Traditionally, sawmills have relied upon the experience and skill of the operators in order to convert sawlogs into products that the markets require. However, their decisions are not always optimal, mainly because the operator cannot logically take account of all the important factors that affect the optimal conversion of a log. Today, sawmills use optimisation techniques to maximise yields from logs, and, as harvest volumes in Ireland continue to expand rapidly, the need for improved optimisation techniques increases even further because of competition on world markets.

Analysis of log type in terms of volume/value recovery and product out-turns is an important aspect of the development of optimisation techniques in the sawmill. Typically the breakdown of a stem into sawn products consists of a three-dimensional optimisation process. In the short-wood system, this decision process is spatially and temporally divided into two stages. In order to make the overall process an optimal one, these two decisions have to be integrated. The focus in this part of the project moved away from the forest and towards the sawmill. The objective of this research was to start the development of a decision support tool for the mill-based aspects of the harvesting and processing production chain. The objective targeted was to analyse and model, in detail, the relationship between log size and volume/value recovery and product out-turns.

Initially a number of preliminary research tasks were carried out to establish the availability and accuracy of data sources. Scanner performance, reliability and output were investigated through a series of tests. The main aspect of the research in this element of the study involved the investigation of the impact of log size on product volume and value recovery. In order for this to be possible, the reporting capabilities of the production control computer system had to be investigated. A number of preset report formats were available and some of these were used during the data collection stage. A test was carried out to establish the accuracy of the reporting process. This test showed very small and insignificant differences in the volumes calculated manually and those produced by the computer. Data for visual and statistical analysis were subsequently obtained from the computer system in the mill. The completed and validated data sets were then used for statistical analysis. It was concluded that diameter had no influence on recovery. Relatively high recovery rates were being achieved for all log lengths and to increase these rates further, a detailed investigation into the relationship between log size, sawing patterns and product volume and value will be needed. Highly significant relationships were found between the dependent variables output volume and output value and subsets of the independent variables diameter, diameter squared, number of logs, log length and log size, for some of the length classes but not for others. The statistical models produced in this research will form a building block for the decision support system as set out in the objectives of this project. These models will allow the sawmill manager to predict potential volume and value out-turn for a wide range of log sizes.

Element 3: The usefulness of harvesting head measurement information for production chain optimisation

The potential for harvester head measurement systems to produce reliable information on assortment numbers, sizes and volumes cut has been the subjects of previous research (PTR, 2000). This has indicated that these systems are capable of producing highly accurate results and that their accuracy is more a function of correct calibration and maintenance than of the quality of the timber being harvested. The information produced by these harvesting heads, if of sufficient accuracy, can be used in the sawmill to decide on cutting pattern selection and value recovery maximisation, based on customer demand and inventory volumes. And ultimately, the information can be used to confirm or change the (optimal) range of assortments being produced in the stand, completing the information chain between forest and mill and vice versa.

The program used in this study for calibrating the harvester heads originates in Finland but is currently used as the standard for calibrating harvester head measurement systems in Ireland. Access to the program was provided and a familiarisation process took place on how to use the program with a Pomo callipers. The first calibration tests were carried out at the end of 2003 and subsequently eight further calibration tests have been performed. The calibration tests were carried out roughly every 4 to 5 weeks, but if the operator felt that the accuracy of the harvester's measurement equipment was decreasing or when a serious breakdown of the harvester head occurred, extra calibrations were carried out. The harvester's volume measurements for a felled stand (or sales proposal) were compared to the volumes recorded at the weighbridge. So far, volume data from harvesting operations in four stands, varying in size between 2,000 m^3 and 6,800 m^3, recorded by the harvester and at the weighbridge, have been collected. Volume data from more stands will be added to this data set before a detailed analysis. A preliminary analysis has shown that harvesting head measurements differed by an average of 12% from weighbridge values before regular calibrations were carried out. Calibrating the harvester regularly reduced these differences to between 5% and 6%. It was also noted that there was a difference of less than 2% between the percentage distribution values of total volume into each assortment class (sawlog, pallet, pulp, etc.) as recorded by the harvester and weighbridge.

A more detailed study on the accuracy of the harvester head in measuring lengths, diameters and volumes is underway. Length and volume data for nine runs of 7 or 8 stems were taken. After calibration was carried out, the difference in volumes between the callipers and harvester decreased for both log (i.e. sawlog and pallet) and pulp volumes. This reduced difference remained in place for a longer period for the log volumes than for the pulp volumes. For the nine runs, the average difference between the total log volumes of the 7 or 8 trees as measured with the callipers and as measured by the harvester was about 3%, while the average difference between the pulp volumes as obtained using the callipers and as recorded by the harvester was circa 6%. In both cases, the volumes as measured using callipers were greater than the harvester volumes. The investigations aimed at determining how long the accuracy can be maintained before calibration is required are continuing. A small preliminary study on accuracy levels of the harvesting head measurement system and on the impact of calibration has been completed and identified a strong relationship between calibration intensity and the accuracy of the harvester head measurements (Kennedy 2004).

CONCLUSIONS

The three elements of this research project, when brought together, will form the core of an integrated decision-support system for the sawmill production chain. The availability all along the production chain of all data needed for the decision chain to perform optimally will be the most important integrative aspect of the system. This means that data from the pre-sale inventory, from the cross-cutting simulator, from the harvester, from the sawmill scanner, from the process computer and from the sawmill inventory and sales systems, will be available at any stage in the decision chain, allowing for the optimal linkage of the forest, the harvester, the mill, and the customers. At the current stage of research, the most important building blocks for the decision-support system have been produced. Putting the blocks together, filling in some missing links, and cementing it all together by way of a user-friendly interface, to form a cohesive structural system will require further work. It is hoped that this system building work can be carried out with the co-operation of the current research and funding partners.

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Dynamic Modelling of the Growth and Yield of Conifer Species in Ireland

P. Purser*, L. Broad and T. Lynch

INTRODUCTION

Reliably constructed growth models that permit growth and yield forecasting are crucially important for management of forest plantations. Silvicultural and economic planning at the stand and forest estate level are contingent on being able to forecast growth accurately at the stand level. For the case of the single-species even-aged stand, models range from rather primitive to sophisticated forms. Multiple species stand models are currently under-developed from a theoretical viewpoint.

There are a profusion of methods that have been developed to represent forest growth. Fortunately these can be classified using a relatively small number of criteria that convey the essential differences. García (1988b) terms models static when they assume that stands are managed to some totally prescribed pattern over the rotation. Within a European context the Forestry Commission’s (FC) Management tables (Johnston and Bradley 1963) are the best known example. The Johnston and Bradley approach is postulated utilising Eichhorn’s rule - that total volume production is dependent on top height and not the rate of top height growth (Joyce and OCarroll 2002). Dynamic models, on the other hand, do not assume prescribed management regimes and therefore can be used to forecast a wider range of management practice. These models rely on modelling incremental changes in the variables of interest over time. The corresponding yield is then obtained by integrating or summing the incremental changes. García, (op. cit.) introduced ideas from systems theory into a forestry context, to describe how a forest stand evolves over time. This requires:

(1) An adequate representation of the system (stand variables) at any point in time - the so called state of the system; and

(2) Estimates of the rate of change of state, and of the current value of any external control, variables.

Using such a framework the central elements of differing yield prediction systems can be compared. To illustrate, models based on individual tree position maintain a more detailed state description compared with those that operate at the stand-level. From a practical forest management viewpoint, a growth model must provide the requisite forecasts without too much in the way of operating overheads. This requirement has led to most modern growth models being developed at the aggregation level of a forest stand. Forest level prediction is then made through aggregating stand level predictions.

MODELS

The development of stand level growth models proceeded by adopting the state space modelling methodology advocated by García (1984). That is, a small number of stand variables such as top height, basal area and stocking were chosen to represent the stand. Future states of the stand can then be determined from the current state, provided any future actions such as thinnings are detailed. The variables included in the state allow the subsequent calculation of quantities of interest such as, stand volumes, log assortments and thinning reductions. Thus, a stand volume equation is employed to estimate stand volumes; an assortment generator predicts proportions of stand volume found in various log categories; and a thinning equation calculates basal area or stocking reductions during any possible thinning.

The flexibility of dynamic models in representing stand management scenarios comes at the price of maintaining sufficient mensurational data to form the state vector (i.e. starting point) for growth projection.

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The alternative of ensuring that establishment and subsequent management takes place to a prescribed pattern, so that a static yield model can be employed, places considerable restrictions on how stands can be managed. There may be a large opportunity cost associated with the deployment of static yield models, strict adherence to them restricts the decision set available to managers.

Further, dynamic growth models are readily utilisable within stand or forest level optimisers that seek optimal economic management decisions under changing cost and revenue structures.

DATA SOURCE FOR DYNAMIC MODELLING

Data on which dynamic models are based come from Coillte's network of permanent sample plots. These plots have been subjected to periodic measurement of top height, basal area, stocking and volume from the early sixties to the late nineties. Data from several hundred plots and many locations are available for Sitka spruce and lodgepole pine, the range of plots is less for Norway spruce, Douglas fir and Scots pine.

Silvicultural treatments applied within the research plots vary from thinning levels up to 50% removal at first thinning and initial stocking levels of 4,500 to 600 stems per hectare.

Only a small number of these plots now remain.

The models should give adequate projections within the range of data used in model construction. In Ireland, permanent sample plot data in thinned stands ranged from the time of first thinning forwards. For un-thinned stands the permanent sample plots were first measured at around age 20. The permanent sample plot database maintained by Coillte contains no early growth information that could be used in the construction of early growth models - further data acquisition could address this gap.

The frequency of permanent sample plot measurements is also worth considering. In many instances plots have been measured on an annual basis. Although this does provide further information for yield modelling a better procedure would be to measure more plots at less frequent sampling intervals. When conducting annual measurements the sampling measurement errors will tend to be larger in magnitude, compared with the increments on basal area and height, than when a longer sampling interval is used. A practical procedure would be to measure plots in thinned stands both immediately before and after a thinning, and at clearfelling. For plots in un-thinned stands, a sampling strategy can be more flexible, with the adoption of a sampling interval in the range 3-5 years. Fortunately, the techniques employed to construct the growth projection component models do not require that fixed sampling intervals be employed. Within a forestry context, many practical reasons exist as to why plot sampling intervals might not be fixed.

TEST OF DYNAMIC MODEL PROGRAM

Between October 2003 and May 2004, a test of the Sitka model was carried out by Coillte with part funding from COFORD. The purpose of the test was to check the accuracy of volume prediction from the Sitka spruce model program. A sample of 100 stands in 13 sites forest centres was selected. At each site, a plot was established within which highly precise estimates of top height, basal area, stocking and volume were measured. The measured volume estimate was compared to that derived using the model. For the 100 sites measured, the model showed a slight bias in favour of greater predicted volume. The level of bias was 8%, which indicates a strong capacity for the model to estimate standing volume in non-research stands.

The data collected as part of this test is being incorporated into the existing data in order to further upgrade the model and eliminate, as far as possible, the observed bias.

RECOMMENDATIONS

The fitted models typify growth found in Coillte's permanent sample plots (research plots). In thinned stands, the model is applicable beyond the time of first thinning. In un-thinned stands, the model is appropriate for use after approximately age 20.

Dynamic models are more suited to an interactive style of stand management than prescriptive management regimes documented in static yield models (e.g. Forestry Commission (FC) tables). Further, they are readily utilisable within computer software that seeks to find economic optima for stand and forest level management problems.

Forest management teams wishing to deploy these models should ensure that their mensurational systems provide the requisite stand variables for projection; i.e. basal area, stocking and top height. Ongoing re-measurement of these variables is also valuable. It serves as a basis for validation of projections and provides an updated starting point for further projections and site quality assessment.

DEVELOPMENT OF A USER-FRIENDLY SOFTWARE PACKAGE FOR DYNAMIC YIELD MODELS

This project, termed 'Dynamic Yield' is being undertaken by Purser Tarleton Russell, Ltd. with the aid of funding from COFORD. The objectives of the project are:-

- To gain a consensus, through consultation and user-testing, on the functionality and interface required by potential users from a dynamic yield model software package.
- To develop the software package accordingly.
- To produce a user-friendly manual to accompany the software.
- To introduce the software and manual to the Irish forest industry at training workshops.
- To operate the package, the forest manager will be asked to input best estimates of age, top height, basal area or mean diameter and stocking. Thinning ages, assuming a thinning regime for the stand, must also be entered (cycles may be fixed or variable). Thinning type may be set at systematic or selective. There is also a facility to enter timber prices for different tree sizes.

Output from the program will include a complete yield model for the stand of timber in question. All volume estimates will include assortment categories to conventional top diameter limits. In future years, based on reassessment of basal area, top height and stocking and any amendments to the management plan, a revised replacement model may be drawn up.

The availability of the dynamic modelling package in CD-ROM form to all forest owners and foresters will revolutionise the way in which plantations are planned and managed in Ireland.

Timber Fencing - The Road Ahead

R. Lowe*, M. Lynn and M. Bourke

INTRODUCTION

A study was carried out to determine the durability of one hundred 20-year-old timber posts removed from a fence-line on the Naas by-pass roadway.

The study focused on:

- Species identification;
- Assessment of condition;
- Preservative retention;
- Mechanical properties;
- Soil testing to determine leaching of preservative.

Species was determined by a visual examination of freshly sawn cross sections and planed longitudinal faces. The sample comprised 51 pine (*Pinus sylvestris*), 43 Douglas fir (*Pseudotsuga menziesii*) and four larch (*Larix decidua*) posts. The latter two species were grouped together in the subsequent analysis.

Each post was examined for evidence of decay and rated according to a 5-point scale (I.S. EN 252:1989). All of the posts scored 0 for the portion above the ground, meaning that no significant decay was evident. It is generally accepted that the parts of a timber post in ground contact have higher levels of moisture and fungal colonisation: the results supported this contention as 14% showed signs of 'slight attack' while just 3% were found to have evidence of 'moderate attack' at ground level. No posts were rated above level 2, indicating their generally good condition. after 20 years in service.

To determine the level of retention of preservative, samples were removed from the upper end, at ground level and from the below ground portion of each post, An elemental metal loading of 3.81 kg m^{-3} is currently recommended for CCA used in fence posts with a 'desired service life' of 30 years. Pine posts rated well against this criterion, with 84% having above the threshold. Although the Douglas fir and larch group had relatively low levels of the preservative chemicals, due to the difficulty in treating these species, they are known to have a higher level of natural durability, these posts were also generally in sound condition.

Ultimate bending strength of the posts was determined by testing to destruction in four-point bending on a 'Dartec' machine. The modulus of rupture was calculated based on maximum load. The mean value for the pine group was 27.05 N/mm^2 with a ranked 5th percentile of 16.12 N/mm^2. The equivalent values for the Douglas fir/larch group were 29.7 N/mm^2 and 13.64 N/mm^2, respectively.

Soil samples from the area surrounding the bases of each of 10 posts were tested to determine the extent of leaching of preservative chemicals. The posts had originally been pressure treated with a copper/chromium/arsenic (CCA) based preservative. It was found that there was a slight elevation of the level of copper and arsenic present in some of the soil specimens closest to the posts.

OBJECTIVES

The object of the research was to determine the condition of timber fence posts, which have been *in situ* for over 20 years. This involved an evaluation of the structural integrity and level of decay of the posts, which were supplied and erected in conformity with RC25 Standard requirement of the time. A sample of 100 posts from an approximate total of 8,000 was removed from the ground and tested at the Wood Technology Centre at the University of Limerick.

Assessment of condition of posts

I.S. EN 252:1989 uses a 5-point scale to categorise the level of decay evident on stakes being used in

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Table 1: Decay ratings used in I.S. EN 252:1989

Rating	Classification	Definition of condition
0	No attack	No change perceptible by the means at the disposal of the inspector in the field
1	Slight attack	Perceptible changes, but very limited in their intensity and their position or distribution: changes which only reveal themselves externally by a change in colour or by very superficial degradation, softening of the wood being the most common symptom, to an apparent depth of the order of 1 mm.
2	Moderate attack	Clear changes to a moderate extent according to the apparent symptoms: changes which reveal themselves by softening of the wood to a depth of approximately 2 to 3 mm over all or part of the test piece from the ground level zone and below.
3	Severe attack	Severe changes —marked decay in the wood to a depth of 3 – 5 millimetres over a wide surface (for example soft rot or other type of decay over all the surfaces of the specimen at the ground line zone or below) or by softening to a greater depth (10 –15 mm) over a more limited surface area, e.g. white rot over a few square millimetres
4	Failure	Impact failure of the stake in the field.

long term trials of preservative effectiveness. A notional average is calculated for the full set of posts. This scale was used to classify the level of decay evident on the posts. Table 1 lists the ratings and defines the classifications:

The posts were rated according to the IS scale. All of the posts scored 0 for the portion above the ground, meaning that no significant decay was evident. It is generally accepted that the parts of a timber post in ground contact have higher levels of moisture and fungal colonisation: the results supported this contention as 14% showed signs of 'slight attack' while just 3% were found to have evidence of 'moderate attack' at ground level. No posts were rated above level 2, indicating the generally good condition of the timber. Thus, for the sample a mean of 0 was found for the above ground part of the posts, while the ground contact parts had a mean score of 0.2.

Depth of penetration of preservative

Thin cross sections were removed from each post at above ground level, at ground level and below ground level. The radial depth of penetration of preservative was determined using a Rubeanic acid test (BS 5666-2:1980). A grid was used to measure the depth of penetration at each face. The results are summarised in Table 2.

Preservative uptake in the pine was much greater than in the Douglas fir/larch group. In some cases,

Table 2: Uptake of CCA preservative in Scots pine, Douglas/larch timber posts.

Statistic	Douglas fir/larch	Pine	Average
	Radial depth of preservative penetration mm		
Mean	5.07	15.80	10.61
Minimum	3.04	4.75	3.04
Maximum	8.58	36.25	36.25
Standard deviation	1.23	7.43	7.66
Coefficient of variation	24.3%	47%	72.2%

almost the full crosssection of the pine posts was impregnated with preservative. This confirms the known difficulty in treating Douglas fir and larch, particularly the heartwood portions.

Preservative retention

The posts were originally treated with a CCA type 2 chemical formulation, prior to installation. According to BS 4072:1999, type 2 CCA preservatives contain nominal proportions of the following chemicals: 45% Sodium dichromate dihydrate, 35% Copper sulphate pentahydrate, and 20% Arsenic pentoxide dihydrate, in formulations based on hydrated salts. Samples were taken, by collecting saw-dust from cuts made across the face of each post, at above ground, ground level and below ground level. Level of preservative retention was assessed using BS 5666:3 1991. The prepared sawdust samples were divided into two parts (0.5 g and 5 g respectively). The moisture content of the 0.5 g portion was determined using a rapid moisture analysis machine. The 5 g portion was placed in a 250 ml conical flask to which 50 ml of sulphuric acid solution was added, followed by 10 ml of hydrogen peroxide solution. The flasks were heated at 75°C in a water bath for 30 minutes, with occasional swirling to mix the contents of the flask. The solution was filtered into a second conical flask and thoroughly washed with 100 ml of distilled water. The filtrate and washings were boiled until the evolution of oxygen ceased and all the hydrogen peroxide was decomposed. The solution was then cooled to room temperature and transferred to a 250 ml one-mark volumetric flask, 25 ml of sodium sulphate solution was added and made up to the mark with water to give the test solution. A portion of this solution was analysed using the atomic absorption spectrometric (AAS) method.

The concentration of the elements was determined in mg/l. Based on these values, the percentage by mass of the elements of interest (As, Cr and Cu) present in the wood, was calculated. The dry salt retention was calculated by reference to the density of each sample and is expressed in kg m^{-3} in Table 3.

The BWPA manual on wood preservation (1999) gives recommendations for retention levels of preservatives to comply with various ‘Desired Service Lives’ (DSL). For fence posts with a DSL of 30 years, retention of 10.6 kg m^{-3} is recommended, based on salt type preservatives. The equivalent elemental metal loading is 3.81 kg m^{-3} for the type of preservative used in the posts under examination.

The pine posts rate well against this criterion, with 43 of the 51 (84%) having above the threshold. When compared to the recommendations for a 60-year service life (19 kg m^{-3} gross = 6.8 kg m^{-3} elemental), six of the pine group show levels above this threshold. In spite of the apparently low values of the preservative salts in the Douglas fir/larch group, the posts are in good condition as shown by the examination of decay. Douglas fir and larch are known to have a high levels of natural durability.

Species identification

Under current standards a number of softwood species are permitted for use as timber fence posts used in Ireland, including Douglas fir, larch, lodgepole pine, and Scots pine. It is believed that most of these were represented in the original fencing contract. An examination of the full batch was made to determine the species of individual posts. A portion of the surface of each post was planed to allow visual examination of longitudinal grain. Of the 100 posts removed 51 were pine (*Pinus sylvestris*) posts, 43 Douglas fir (*Pseudotsuga menziesii*) and 4 larch (*Larix decidua*). Subsequently post number 96 went missing, while number 33 was damaged in the course of removal from the ground. The total sample was therefore 98 posts.

Mechanical properties

Posts measured 2 m long with a nominal cross-section of 100 x 100 mm. The top of the posts were pointed at installation to facilitate rainfall runoff, while the bottom was cut square. Nails, which had been used to attach the original fence rails, were still present in many of the posts, when delivered to the University of Limerick laboratory. Where possible

Table 3: Preservative metal (As, Cr and Cu) retention in timber posts after 20 years service life.

Statistic	Douglas fir/larch		Pine		Average	
	kg m^{-3}	% by mass metals	kg m^{-3}	% by mass metals	kg m^{-3}	% by mass metals
Mean	2.89	0.640	5.07	1.18	4.03	0.923
Minimum	1.24	0.271	2.06	0.40	1.24	0.271
Maximum	4.92	1.267	8.54	1.93	8.54	1.930
Std. dev.	0.98	0.235	1.47	0.35	1.68	0.405
Coeff. of variation	33.9%	36.7%	29%	29.7%	41.7%	43.8%

these were removed prior to mechanical testing. The posts were tested at full size according to clause 11 of IS EN 408: 1995, 'determination of bending strength'. This stipulates 4-point bending, based on a span of 18 times the height of the test piece (1800 mm in this case). All posts were tested to failure on a Dartec universal test machine. The load was applied at a rate of 0.15 mm/s at points set to one third of the span, (600 mm). Data were recorded of the load and deflection as the tests progressed.

The maximum load was recorded and used in the equation from clause 11.3 of I.S. EN 408 ($f_m = a F_{max}/2W$, where $W=bh^2/6$) to calculate the modulus of rupture (MOR) of each post. The results are summarised in Table 4.

Values for the full set of posts are given in the first column. The Douglas fir and larch results were grouped as Df-L, while the pines are titled P. As described in the 'species identification' section, the proportion of species was split roughly equally between Douglas fir/larch and pine groups (47 Df-L, 51 P). From the modulus of rupture results it can be seen that there is greater variability in the Douglas fir/larch group than in the pine group of posts.

Density calculation

Density values were calculated to allow a comparison of physical properties. Cross section specimens were removed, used to determine moisture content by the oven dry method and density was calculated based on volume at test and oven dry weight. In order to simplify comparison at the reference moisture content of 12%, Table 5 summarises the results.

Soil testing

Ten post surrounds were selected at random for soil analysis. Samples of soil were taken immediately around the base of the post, and at 500 mm and 2000 mm distance from it. The samples were placed in plastic bags, numbered and dispatched to the laboratory.

Table 4: Strength properties of timber posts following 20 years service (N/mm^2).

Statistic	Douglas fir larch	Pine	Average
	N/mm^2		
Mean	29.70	28.34	27.05
Minimum	7.04	7.04	14.38
Maximum	53.20	53.20	42.07
Std. dev.	9.78	8.54	7.05
Normal 5 percentile	13.61	14.28	15.46
5th percentile (ranked)	13.64	14.30	16.12
Coeff. of variation	32.9%	30.1%	26.1%

Table 5: Density of fence posts at 12% m.c.

Statistic	Douglas fir/larch	Pine
	g ml^{-1}	
Mean	0.514	0.484
Minimum	0.392	0.376
Maximum	0.702	0.651.
Std. dev.	0.069.	0.064
Coeff. of variation	13.5%	13.4%

Small portions (30 to 60 g) were removed from each soil sample, placed on numbered sheets of paper and left to air dry in the laboratory. A number of samples were progressively weighed to determine the rate of drying. The laboratory had an ambient temperature of 20ºC, with relative humidity in the range 65-73%.

Chemical treatment

The process outlined by Rowell (1994) was used to leach the metals present in the soil samples. After a number of days drying, each specimen was sieved through a 2 mm mesh on a mechanical shaker and the material passing was ground using a mortar and pestle. This was placed in a numbered plastic bag. From each of the above specimens, a sample of 1.2 g was removed and placed in a boiling tube. To each was added 15 ml of digestion acid, consisting of a mixture of nitric and hydrochloric acid and then left to stand over-night. The boiling tubes were then placed in a heating block on a hot plate, heated to 50ºC for 30 minutes and subsequently to 120ºC for 2 hours. These were then allowed to cool. Each specimen was made up to 60 ml with 8.8% HNO_3 solution, and filtered to a volumetric flask. The solutions were analysed using an atomic absorption spectrophotometer (AAS).

Concentration of As, Cr and Cu in soil samples

The results of the chemical analysis of the solutions were used to calculate the concentration of the elements in the respective soil samples.

Table 6 gives a summary of the concentrations of the elements in mg/kg of soil for the 10 posts sampled. The locations from which the samples were taken are described as:

100 = soil from around the post
500 = 500 mm from post
2000 = 2,000 mm from post.

Comparisons were made with the background levels of the elements copper, chromium and arsenic recorded for soils in this country, based on recent a study by Teagasc (McGrath and McCormack 1999). To assess the statistical significance of the results of this study, an analysis of the data on chemical concentrations in the soil was performed, using SPSS software, in three steps:

1. The data were shown to have a normal distribution.
2. Analysis of variance (ANOVA) was carried out with the hypothesis that metal concentration (dependent variable) was significantly related to distance from the post. The resulting F values were significant ($p \leq 0.001$) for copper and arsenic, which were then compared.
3. Mean concentrations of copper and arsenic at the three locations were compared within each element comparison used using Duncan's post hoc test.

The conclusion was that, the soil concentration of arsenic and copper of samples taken from 500 mm and 2000 mm was significantly less ($p \leq 0.05$) than samples taken adjacent to the posts.

It can be concluded that there is a slight elevation of the level of copper and arsenic present in some of the soil specimens closest to the posts. At 500 mm

Table 6: Effect of distance from fence posts on the concentration of preservative metals in soil.

Average distance from post mm	Statistic	Cu	Cr	As
		mg/kg		
100	Minimum	14.5	10.0	3.5
	Maximum	84.0	31.0	14.0
	Mean	41.55	17.6	5.5
500	Minimum	16.0	9.0	1.0
	Maximum	38.5	33.5	5.0
	Mean	21.9	14.9	2.0
2000	Minimum	16.5	9.0	1.5
	Maximum	32.0	32.5	4.0
	Mean	22.7	17.9	2.0

and further away from the posts, the values appear to be at background levels. All of the chromium values and all but one of the arsenic values were lower than the mean concentration found in the Teagasc study (McGrath and McCormack 1999).

CONCLUSIONS

Each post was examined for evidence of decay and rated according to the 5-point scale. All of the posts scored 0 for the portion above the ground, meaning that no significant decay was evident. The sections around and below ground level ground are subject to more extreme conditions and in total, 14% showed signs of 'slight attack' involving 'superficial degradation to a depth of the order of 1 mm'. Just 3% of the total were found to have evidence of the level 2 category, 'moderate attack'. No posts were rated above level 2, indicating the generally good condition of the timber

The current level of the active ingredients of the preservative chemicals used to treat the timber (CCA) was particularly high in the pine posts. Douglas fir and larch had lower levels, but these are more difficult to treat, at the same time have greater natural durability. These properties are borne out by the findings of this study. It would appear that most posts have suffered very little degradation over the years in service and are likely to continue to perform their function for many years to come. The findings highlight the value of a properly controlled pressure treatment regime for softwood intended for use in the challenging environment of ground contact.

While strength properties are not a requirement of the fencing standard, the test results show that the timber retains bending strength values in the range that one might expect to encounter in material used in construction.

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REPOTIM: The Development of a Hybrid Fibre Reinforced Polymer Timber Beam Using Irish Grown Sitka Spruce

G. Raftery* and A. Harte

INTRODUCTION

Timber is a very attractive construction material for many reasons. It is a renewable resource, recyclable, relatively inexpensive and has an excellent strength to weight ratio. It is also architecturally attractive and is resistant to many of the chemicals destructive to steel and concrete. However, wood also possesses weaknesses as a construction material: anisotropy, inhomogeneity and wide variations in mechanical properties. The use of Irish grown Sitka spruce (*Picea sitchensis*), which is the most planted species in Ireland, is limited mainly to low load applications in domestic construction due to its low strength and stiffness values. In order to increase the structural use of the species, its structural properties must be enhanced. This may be achieved by reinforcing with a stiffer material.

In recent times, there has been considerable interest in the use of fibre-reinforced plastics (FRPs) for the enhancement of the structural performance of timbers. Advantages of FRPs include their low-weight, ease of handling and corrosion resistance. This innovative technology applied to local wood species has been the subject of much research, particularly in the United States and to a lesser extent in Europe with regard to the development of added value products. The application of FRP technology to the enhancement of the structural performance of Irish-grown Sitka spruce opens up considerable opportunities for the more widespread use of this softwood in the construction industry.

Structural glue laminating is an effective method of eliminating or controlling naturally occurring strength reducing defects such as knots, warp, wane, and checks that regularly appear in larger size members. The beams manufactured using this process are among the most versatile of engineered wood products and are used in residential, commercial and industrial construction. Shapes can vary from straight long span beams with a high degree of dimensional stability to complicated curved arches. However, no commercial glue-laminated manufacturing plant currently exists in Ireland despite several companies being involved in the importing and distribution of glue laminated beams. The current standard glulam grade that is consistently manufactured by the established glulam manufacturing plants on the continent and throughout Scandinavia is GL28c [EN 338, 2003]. This is a combined lay-up with outer laminations comprising C30 grade timber and inner laminations of C24 grade. The most common structural grade produced by Irish grown softwoods is C16 grade, also known as Regular Structural Grade (RS). By judiciously positioning carefully calculated percentages of the FRP material in the cross section of RS glue laminated Irish grown timber beams, it is envisaged that an alternative option can be offered to achieve equivalent stiffness values to that provided by imported glue-laminated beams.

In this paper, the structure of a three-year project REPOTIM (REinforced POlymer TIMber), which is still in its first year, is discussed. Findings from preliminary desk studies, which have highlighted appropriate reinforcing techniques and materials as well as potentially compatible adhesives, are discussed. The initial theoretical studies, which precede and are designed to direct the experimental programme, are presented. This includes a brief background to the theoretical models together with the analytical results determined from both singly and doubly reinforcing a glue-laminated section throughout the entire length. A discussion of the advantages and disadvantages for the production of a commercial FRP-glulam beam manufactured from Irish-grown Sitka spruce is presented.

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KEY ACTIONS

The REPOTIM project has a three-year programme. The work programme is segregated into subsidiary phases as outlined below:

(1) Evaluation of state-of-the-art and literature review

(2) Background research and data collection of reinforcements and adhesives

(3) Theoretical analysis of reinforced glue-laminated beams

(4) Numerical modelling of process conditions

(5) Adhesive bond testing of FRP-wood interface

(6) Short term static testing of short span beams

(7) Short-term static testing of long span beams

(8) Creep testing of FRP reinforced beams.

The initial phases of the project concentrate on evaluating previous methods to reinforce timber, assessing the reinforcement and adhesive properties available in order to enable comprehensive experimental design. Theoretical analyses are being undertaken to direct the experimental programme. A numerical analysis is also to be executed to verify process conditions. The experimental programme is currently underway. This paper concentrates on the findings of the first three phases of the programme.

STATE OF THE ART OF THE REINFORCEMENT OF TIMBER MEMBERS

Initial attempts directed at the reinforcement of wooden members focused on the available materials that could be utilised. A study was undertaken by Mark (1961) to analyse the mechanical interaction between bonded-on aluminium plates on the top and bottom of a wooden core. Sliker (1962) attempted to utilise aluminium sheets, which failed though debonding. Steel reinforcing bars were employed by Lantos (1970) to reinforce laminated wood beams in flexure. Spaun (1980) investigated the benefits of fibreglass reinforcement sandwiched between Western hemlock cores and Douglas fir veneers. Bulleit (1983) published a report reviewing all previous work executed on the reinforcement of wood and discussed the possibilities of reinforced wood being introduced as a commercial product.

As more efficient manufacturing technologies for processing FRPs have developed with the passage of time, and an increasing acceptance of FRPs in the construction industry, several researchers have developed a strong interest in the reinforcement of wooden members. Van de Kuilen (1991) illustrated that a considerable increase in stiffness and ultimate bending moment could be achieved by using glass fibre reinforced polyester sheets. Gardner *et al*. (1994) tested the bond interface between pultruded FRP and yellow-poplar with three adhesive types. Testing was executed for both ambient and saturated conditions. Tingley (1996) discussed the optimisation of the alternative material properties of wood and FRP technologies and the advantages of a hybrid beam. Belperio and Grad (1999) experimented with carbon fibre sheets above the bottom lamination of a glue-laminated beam in order to enhance its flexural properties. It was illustrated that significant increases in strength and stiffness could be obtained for small area fractions of reinforcement. Gilfillan *et al*. (2001) executed the only published study to date on FRP reinforced Irish-grown Sitka spruce and demonstrated that this low strength wood can be significantly enhanced in flexure by the addition of carbon fibre reinforcement. However, it was determined from undertaking an economic analysis that the composite carbon fibre Sitka spruce beam did not compare satisfactorily to an unreinforced section in terms of stiffness. Gentille *et al*. (2002) described a test programme and analytical model that investigated the reinforcement of sawn timber beams by means of GFRP bars positioned in routed out grooves close to the tensile face. Alam *et al*. (2004) compared steel and both CFRP and GFRP materials as reinforcement in varying geometric configurations to vertically reinforce LVL beams. It was reported that alternative modes of failure and flexural stiffness were associated with the different reinforcing materials. Micelli *et al*. (2004) increased the flexural behaviour of glue-laminated beams by using bonded-in CFRP rods. Svecova (2004) investigated the shear and flexural strengthening provided by bonded in GFRP bars.

BACKGROUND RESEARCH OF REINFORCEMENTS AND ADHESIVES

A rigorous review has been executed in order to determine suitable materials that are both readily accessible and commercially attractive before commencement of the experimental regime. This phase comprised enquiries to both national and international companies, reviewing forwarded literature and evaluating the information from documented textbooks.

A critical examination of the range of manufacturing processes available to produce the FRP material was undertaken. A range of techniques are currently commercially available in which the primary mechanical strength of the composite is provided by glass, aramid, carbon or graphite fibres bonded together in a thermoplastic or thermoset resin which transfers the loads to the fibres, provides shear strength and protects against corrosion resistance. The fibres can vary in form from mats, chopped strands and continuous or woven rovings. The processes assessed included hand lay up, spray up, vacuum bag, pressure bag moulding, autoclave moulding, resin transfer moulding, pultrusion, profile extrusion, sheet moulding compound and the continuous laminating process. The pultrusion process was found to be the most suitable for the current application for a number of reasons. This cost effective process can be operated continuously, allowing for the production of straight, constant section profiles. The method produces little waste material and ensures that the FRPs are manufactured with an exceptional strength to weight ratio. Detailed descriptions of the process are provided in Gutowski (1997) and Crawford (1987).

The mechanical properties of pultruded carbon, aramid and glass fibres (E-grade) in an epoxy resin, a pultruded glass fibre reinforced polyurethane thermoplastic (FULCRUM) and C16 grade Irish-grown Sitka spruce are given in Table 1.

While the carbon/epoxy and aramid/epoxy composites have higher tensile moduli and higher tensile strengths than the glass/epoxy and Fulcrum composites, nevertheless, the significant cost difference between these materials makes the glass fibre reinforced materials more cost effective in terms of reinforcing effect. While it would be possible to increase the tensile modulus of the glass fibre reinforced composites by increasing the fibre volume fractions, it was concluded, after consultations with a series of pultruding companies, that this option was not financially viable due to the set-up costs involved for such a short non-standard production run.

A study was directed towards the bonding with suitable adhesives for the wood-wood interface and the wood-FRP interface. A range of wood glues comprising resorcinol formaldehydes, phenol-resorcinol-formaldehydes, urea-formaldehydes, melamine-urea-formaldehydes, melamine-formaldehydes, polyvinyl acetate emulsions, isocyanates and conventional wood glues were assessed. A detailed account of these glues and a list of their applications is provided by the USDA (1999). A phenol-resorcinol-formaldehyde (PRF) is selected for adhesive bonding of the wood laminations because of its high strength characteristics, outstanding durability under conditions of severe exposure, reasonable cost and its long storage life. This glue primarily consists of a liquid resin in

Table 1: Mechanical properties of reinforcements and C16 grade Sitka spruce.

Source	Material	Density	Tensile Modulus	Tensile Strength	Flexural Modulus	Flexural Strength
		[kg m^{-3}]	[GPa]	[MPa]	[GPa]	[MPa]
Exel Oyj [2004]						
	Carbon/Epoxy	1500-1600	80-400+	1500 - 3000+	N.A.	N.A.
	Aramid/Epoxy	1300	70-75	800 - 1500	N.A.	N.A.
	Glass/Epoxy	1900-2000	38-46	800 - 1200	N.A.	N.A.
Rotafix [2004]						
	Fulcrum	1910	46	1000	45	1150
Gilfillan [2001]						
	C16 Sitka Spruce	449	9.7	35	11.5	36.3

(N.A. – Not Available)

alcohol-water solution, and is used in conjunction with powder or a liquid hardener that is mixed thoroughly into the resin at a prescribed resin/catalyst proportion before application. It has the capabilities to resist intermittent or continuous exposure to moisture, cold or boiling water immersion, moist or dry heat, mould or fungus attack and most organic solvents and develops joints that are stronger than the wood itself (Borden Chemicals 2004).

Numerous structural adhesives have been surveyed for the adhesive bonding of the wood-FRP interface. It is essential to the project that in the event of failure, a high percentage of wood failure occurs, when the FRP debonds. Otherwise the stiffening effect of the more expensive FRP is lost. The categories assessed consisted of the above stated structural wood glues, polyesters, acrylics, cyanoacrylates, epoxies and polyurthanes. There is no general agreement in the published literature as to the most appropriate adhesive for use in the wood-FRP interface. Neste Oy Chemicals (2000) identified PRF as being suitable for the application. However, other research attempts, such as Gilfillan (2001) and Alam (2003), selected more expensive two-part epoxy adhesives, the latter using a low modulus epoxy adhesive that possesses thixotropic and gap-filling properties. A programme of shear bond tests is currently being executed to qualify the most appropriate glue type. The selection process is based on performance, ease of application and economics.

THEORETICAL ANALYSES

The third phase of the project involves the analytical determination of the additional stiffness and strength characteristics that can be achieved by providing varying percentages of reinforcement both in the tensile and compressive zones of the beam. These analyses were implemented using a classical mechanics of materials approach.

A Transformed Section Analysis is utilised for the determinations of the stiffness. A series of Stress Block Analyses, are executed to determine the ultimate bending strength of the composite sections. Separate analyses where contrasting assumptions of total elastic or total plastic behaviour above the neutral axis of the beam section are carried out.

The beams comprise laminations of C16 grade Irish grown Sitka Spruce with reinforcement layers of pultruded glass fibre reinforced polymer. Two different beam lengths are considered for both the stiffness and strength analyses, a short span beam of 3240 mm (180 x 65 mm Section Size) and a full-sized span of 6480 mm (360 x 90 mm Section Size). These dimensions were chosen so that they would comply with EN 408: 2003 and are representative of the beams to be used in the experimental testing programme. The values used in the study for the Young's modulus in tension and compression are 9.68 GPa and 8 GPa respectively, as tested and reported by Gilfillan *et al*. (2000) for Irish Sitka spruce. In these initial analyses, the ultimate tensile strength was taken as 35 N/mm^2 and the ultimate compressive strength was taken as 30 N/mm^2 (Gilfillan *et al*. 2000). The FRP material is assumed to have a tensile modulus of 46 GPa and a compressive modulus of 35 GPa. The ultimate tensile and compressive strengths of the FRP material are taken at 1000 MPa and 440 MPa respectively.

Determination of stiffness

A series of Transformed Section Analyses (TSA) are utilised to determine the theoretical location of the neutral axis and the percentage increase in stiffness that is obtained by the composite beam, with varying percentages of reinforcement, compared to a non-reinforced beam.

Using this analytical technique to evaluate the behaviour of the composite beam, the reinforcing FRP material and wood in compression is converted into an equivalent area of the tensile wood material by manipulation of the modular ratios, n_i. The modular ratios were consequently determined as follows:

$$n_1 = \frac{E_{frp}}{E_{wt}} \qquad n_2 = \frac{E_{wc}}{E_{wt}}$$

n_i= modular ratios
E_{wt} = Elastic Modulus of the wood in tension
E_{wc} = Elastic Modulus of the wood in compression
E_{frp} = Elastic Modulus of the FRP

The location of the neutral axis can be calculated by:

$$y_n = \frac{\Sigma(a_i y_i)}{\Sigma a_i}$$

y_n = Location of the neutral axis
y_i = Distance from the beam soffit to the centroid of the constituent part *i*
a_i = Area of transformed section of constituent part *i*

The stiffness E_cI_c of the composite beam can be calculated by manipulation of the parallel axis theorem to determine the moment of inertia of the transformed section.

$$E_cI_c = E_{wt}\,[\sum_i(I_i + n_i a_i [y_i]^2)]$$

I_i = Moment of Inertia of the area for constituent part i

I_c = Moment of Inertia of the transformed section

By analysing the composite beam using a TSA, the following assumptions are made: a perfect bond is assumed to exist at the interface of the two materials, i.e. no slip is permitted, the contribution of the glue line to the stiffness is neglected both in the epoxy adhesive between the FRP reinforcement and in the phenol resorcinol adhesive between the wood-wood laminations, plane sections remain plane and the composite beam is assumed to exhibit linear elastic behaviour throughout the depth of the beam section, so that Hooke's law for uniaxial stress can be applied.

Determination of ultimate bending strength

Values for the ultimate bending moment are determined by means of a series of Stress Block Analyses assuming that all materials are ultimately loaded and act in equilibrium. The force and moment equilibrium equations are expressed as:

$$\Sigma F = 0: \int_{wt}\sigma_{wtu}dA + \int_{wc}\sigma_{wcu}dA + \int_{frpc}\sigma_{frpcu}dA + \int_{frpt}\sigma_{frptu}dA = 0$$

$$\Sigma M = 0: \int_{wt}\sigma_{wtu}y_i dA + \int_{wc}\sigma_{wcu}y_i dA + \int_{frpc}\sigma_{frpcu}y_i dA + \int_{frpt}\sigma_{frptu}y_i dA = M_u$$

Where ΣF represents the summation of forces, ΣM represents the summation of moments, σ_{wcu} is the ultimate compressive stress of wood, σ_{wtu} is the ultimate tensile stress of wood, σ_{frpcu} is the ultimate compressive stress of FRP and σ_{frptu} is the ultimate tensile stress of the FRP. The ultimate bending moment is determined from the moment equilibrium equation. The behaviour of the timber in compression at the ultimate load lies between two extremes - fully linear and fully plastic. The fully linear approach will give a lower limit on the ultimate strength while the fully plastic model will give an upper limit. The actual behaviour will be determined during the experimental programme. The approach as used by Belpiero (1999), which involves the assumption that all the wood above the neutral axis exhibits fully plastic behaviour, is shown diagrammatically in Figure 1. Both the wood material and the FRP below the neutral axis are taken to behave linear elastically.

ANALYTICAL RESULTS

Using the theoretical models presented above, the stiffness and ultimate moment carrying capacity of both the short and full-sized beams are determined.

Determination of Stiffness

The results in Tables 2 and 3 are theoretically deduced from the TSA and correspond to the short span and full sized beams, respectively.

It can be seen from Table 2 that with just 1% reinforcement positioned on the extreme tension fibres of the wood a 13% improvement in stiffness is achieved over an unreinforced beam. By increasing the percent reinforcement in the tension zone, the stiffness increases accordingly. The neutral axis, relative to the soffit of the beam, is seen to decrease as the tensile reinforcement increases from 1% to

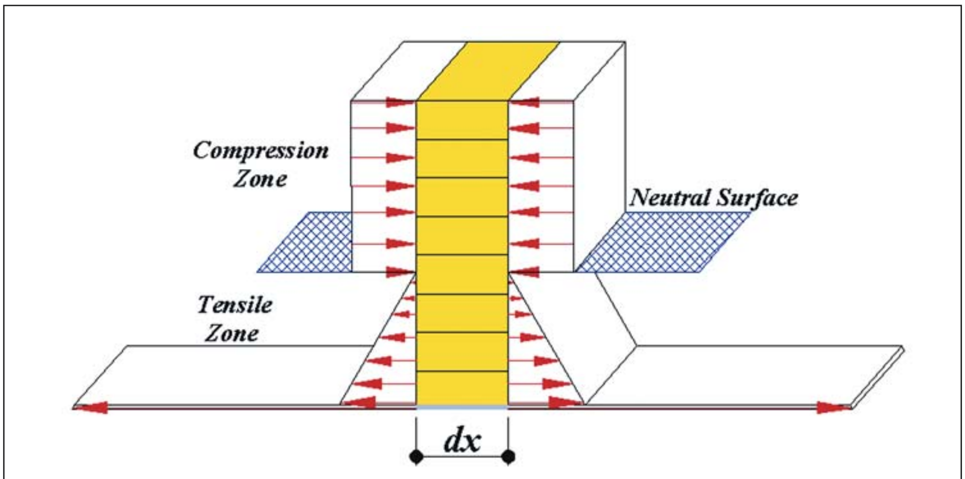

Figure 1: Assumed ultimate stress distribution with plastic compression behaviour in FRP reinforced glulam.

2.5%. From the study executed, the largest shift in the neutral axis occurs for the 2.5% tensile reinforcement where no compression reinforcement is utilised. Compression reinforcement further enhances stiffness characteristics. This is evident from the results as a 45% increase in stiffness is obtained when using 2.5% reinforcement in tension and 1% reinforcement in compression.

In Table 3, the reinforced full size beams show an increase of 13% in stiffness with 1% FRP reinforcement placed on the soffit of the beam as was found for the smaller sized beam. A 2% tensile reinforcement and 1% compressive reinforcement obtains the highest increase in stiffness of 39% and also the greatest shift of 10mm in the neutral axis position for the arrangements analysed.

Table 2: Transformed section analysis: Short span beams.

Reinforcement Cross/Section					
Tension %	**Com-press-ion %**	**EcIc (N/mm^2 x 10^9)**	**% $(E_cI_c)_o$**	**N. A. Position (mm)**	**N. A. Shift (mm)**
0	0	277	0	85.7	0.0
1	0	314	13	83.0	-2.8
2	0	347	25	79.5	-6.2
2.5	0	362	31	76.0	-9.7
1	1	352	27	82.9	-2.8
2	1	387	39	80.5	-5.2
2.5	1	402	45	79.5	-6.2

Table 3: Transformed section analysis: Full aize beams.

Reinforcement Cross/Section					
Tension (%)	**Com-press-ion (%)**	**EcIc (N/mm^2 x 10^9)**	**% $E_{co}I_{co}$** (%)	**N. A. Position (mm)**	**N. A. Shift (mm)**
0	0	3072	0	171.4	0.0
0.5	0	3284	7	168.5	-2.9
1	0	3482	13	165.9	-5.5
1.5	0	3668	19	163.4	-8.0
1	0.5	3694	20	165.9	-5.5
1.5	0.5	3885	26	163.4	-8.0
1.5	1	4098	33	163.5	-7.9
2	1	4283	39	161.4	-10.0

Determination of Ultimate Bending Moment

The results of the stress block analyses are presented in Tables 4 to 7. The ultimate moments for varying percentages of reinforcement are determined firstly assuming a linear elastic model for the timber in compression and then using a fully plastic model. As stated previously, the actual behaviour is expected to be partially linear and partially plastic so these analytical results provide lower and upper bounds on the actual behaviour.

The linear elastic model results given in Tables 4 and 5 show that large increases in ultimate moment are possible even with small percentages of reinforcement. With 1% tension reinforcement, the ultimate moment carrying capacity of the short span beam increases from 11.3 kNm to 18.8 kNm which corresponds to a 66% increase. Using 2% tension and 2% compression reinforcement, an ultimate moment of 37.8 kNm is possible, corresponding to a 233% enhancement in strength over the unreinforced beam. Similar increases in strength are found for the full size beam.

Tables 6 and 7 show the equivalent increases in ultimate moment which can be achieved if the timber in the entire compression zone is plastic. As can be seen in Table 6, the unreinforced short span beam has an ultimate moment capacity of 14.1 kNm using this model compared to 11.3 kNm for the linear elastic model of Table 4. Again, the strength values are found to increase significantly with increasing percentages of reinforcement. For the short span beam, 1% tension reinforcements increases the ultimate moment to 23.7 kNm compared to 18.8 kNm

Table 4: Stress block analysis: Elastic assumption, short span beams.

Reinforcement Cross/Section			
Tension (%)	**Com-pression (%)**	**M_{ult} (kNm)**	**% $(M_{ult})_0$ (%)**
0	0	11.3	-
1	0	18.8	66
2	0	21.7	92
2.5	0	21.5	89
1	1	25.3	123
2	1	30.1	166
2.5	1	30.9	172
2	2	37.8	233

for the linear elastic model. With reinforcement levels of 2% each in tension and compression, the ultimate moment is 43 kNm compared to 37.8 kNm using the linear elastic approach. The full size beam results in Table 7 shown comparable results.

Both of the models used show that strength enhancements of in excess of 200% are possible by using both tension and compression reinforcement. Using only tension reinforcement, increases of between 89% and 116% can still be obtained.

POTENTIAL IMPLICATIONS OF RESEARCH

Though at a preliminary stage of the project, the implications that this research project could have on the engineered wood products industry in Ireland depend significantly on the products commercial viability. A number of influential factors exist, as diagrammatically illustrated in Figure 2 below.

The obvious advantages of the engineered wood-FRP composite beams, as illustrated by the theoretical analyses, will be enhanced stiffness and ultimate bending moment characteristics in contrast to unreinforced beams. Previous research has highlighted that the mode of failure in reinforced beams, even by incorporating small percentages of reinforcement in the tensile zone of the member section, can induce a more favourable ductile failure in the compression zone as opposed to brittle failure in the tension zone in unreinforced glulams. This has the advantage of increasing the reliability of the structural member. It is believed that technology developed from the project could also be utilised to reinforce in flexure timber of even lower structural grade, such as C14, to potentially qualify the timber as a higher-grade timber. The FRP reinforcement could alternatively be utilised to manufacture beams of a reduced mass and section size to facilitate situations where building heights or headroom are critical factors. This will also result in lower transportation and installation costs. It is hoped that the research will assist in the replacement of conventional engineering materials by new-engineered wood products and that an improved understanding of the behaviour of new-engineered wood products will be gained. The project will also succeed in augmenting the knowledge base for a new EU standard regarding the use of FRP reinforced timber materials.

Table 5: Stress block analysis: Elastic assumption, full size beam.

Reinforcement Cross/Section			
Tension (%)	**Com-pression (%)**	**M_{ult} (kNm)**	**% $(M_{ult})_0$ (%)**
0	0	62.8	-
0.5	0	86.6	38
1	0	104.1	66
1.5	0	115.3	84
1	0.5	122.7	95
1.5	0.5	136.5	117
1.5	1	156.7	149
2	1	166.9	166

Table 6: Stress block analysis: Plastic assumption, short span beams.

Reinforcement Cross/Section			
Tension (%)	**Com-pression (%)**	**M_{ult} (kNm)**	**% $(M_{ult})_0$ (%)**
0	0	14.1	-
1	0	23.7	68
2	0	29.2	107
2.5	0	30.5	116
1	1	29.2	107
2	1	36.5	159
2.5	1	38.5	173
2	2	43.0	205

Table 7: Stress block analysis: Plastic assumption, full size beams.

Reinforcement Cross/Section			
Tension (%)	**Com-pression (%)**	**M_{ult} (kNm)**	**% $(M_{ult})_0$ (%)**
0	0	78.0	-
0.5	0	107.5	38
1	0	131.3	68
1.5	0	141.1	81
1	0.5	147.0	88
1.5	0.5	167.5	115
1.5	1	184.7	137
2	1	201.9	159

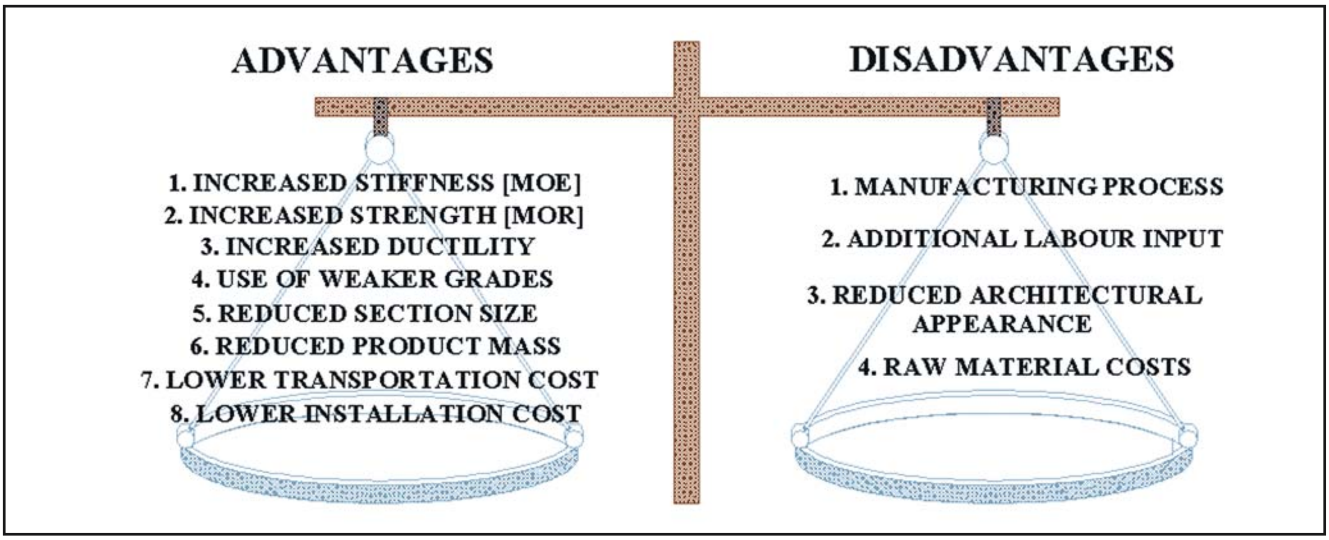

Figure 2: Economic balance of FRP reinforced glue-laminated beams.

The primary disadvantages of the FRP-reinforced glulam beams comprise the additional phases involved in the manufacturing process, the resulting additional labour involved and the cost of the materials. However, the significant advantages of the reinforced beams are expected to greatly outweigh these disadvantages. Figure 3 illustrates in flow chart form the additional phases that are involved in the production of FRP-glulam beams over the current procedure for the manufacture of glue-laminated beams.

It is envisaged that in singly reinforced beams, the FRP laminate can be easily incorporated in the bonding phase along with the remainder of the lamination assembly before cramping. Where routing is required in order to strategically place rod or flat bar reinforcement in the section, a separate phase will have to be introduced into the manufacturing procedure. These additional phases result in additional manpower costs. It is believed that prices of FRP pultruded material will reduce in the future because of its ever-increasing use in the construction industry. A detailed cost benefit analysis will be executed after the experimental programme is complete.

CONCLUSIONS

Details of a research programme which is investigating the use of fibre reinforced polymers to enhance the structural performance of Irish-grown Sitka spruce beams have been presented. Glass fibre reinforcement has been selected as the most cost effective reinforcement medium. Analytical studies of glass fibre reinforced beams have shown that increases in stiffness of up to 45% and increases in

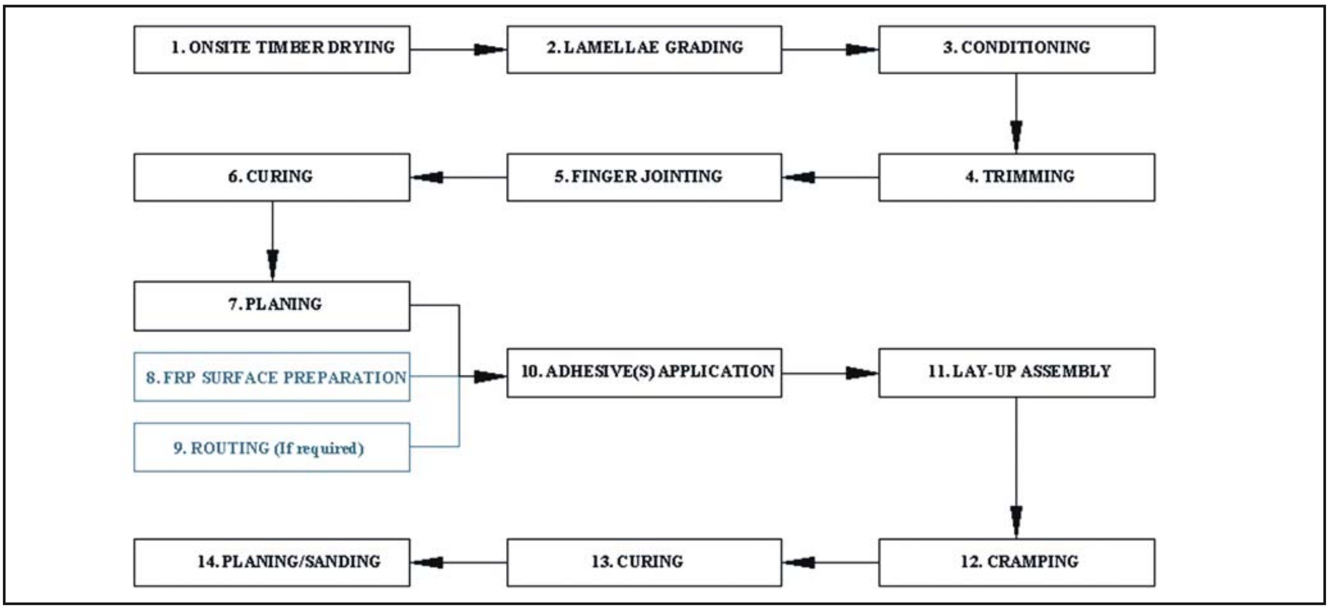

Figure 3: Glulam manufacturing process incorporating FRP reinforcement.

ultimate strength of in excess of 200% are theoretically achievable.

The experimental phases of the research have recently commenced. This experimental work will be used to assess the technical feasibility of the process and will be used to validate the theoretical studies. In addition, it will enable the commercial viability of the process to be accurately assessed.

ACKNOWLEDGEMENTS

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Chemical and Thermal Modification of Fast-grown Softwoods

C. Birkinshaw*, S. Dolan, F. Bonger, B. Tjeerdsma and M. Hale

INTRODUCTION

Wood modification can be taken to include any process which chemically or physically modifies the structural polymers of the wood. It does not include impregnation with preservatives, waxes or oils. Modification of wood by heat, or by chemical means, has a long history, heat treatment through charring to harden tools or weapons dating back to pre-historic times. Chemical modification is more recent, with important early publications on reaction with formaldehyde by Tarkow and Stamm (1953), and on acetylation of wood in lumber thickness by Goldstein *et al.* (1961). Over the past twenty years increasing concern about the use of heavy metal preservatives has resulted in a large increase in interest in these sorts of processes with many papers and patents emanating from the Netherlands, Belgium, Germany, France and the Scandinavian countries in Europe, and from the USA and Japan. Several of these countries now have large scale commercial operations underway. In Europe the Finnish Thermowood plants and in the Netherlands the Plato heat treatment plant are notable, whilst sizeable acetylation plants exist in Sweden and again in the Netherlands. The scale of these operations confirms heat treatment and acetylation as the leading processes for environmentally acceptable durability enhancement.

It is clear that modification through chemical intermediates or through heat is important and is having an increasing commercial impact on the timber industry. Its relevance and consequences for the Irish industry therefore have to be evaluated. The first points to be considered are the potential benefits of the processes. Although it is not intended to deal with process economics in this paper it is clear that modification processes are going to prove more costly than traditional preservation systems such as CCA impregnation. There are two claimed benefits of both heat treatment and chemical modification. They are reduced hygroscopicity and reduced susceptibility to fungal decay, thus giving the wood better dimensional stability in service and greater durability. The mechanisms by which these improvements are obtained differ between heat treatment and chemical modification but the outcomes are intended to be broadly similar, though differing in extent.

Acetylation and heat treatment pilot plants have both been established in the Netherlands and so joint projects were initiated, supported by COFORD, with the timber research establishment, SHR, in Wageningen. Via that establishment access was obtained to three facilities. First, those of Acetyleer Kennis BV, an industry consortium sponsored acetylation plant in Arnhem. Secondly, two heat treatment facilities, described in this work as Treatment A and Treatment B. The first of these involves heating under mechanical plate constraint whilst the second involves live steam treatment.

Species were chosen on the basis of long term availability and were Sitka spruce (*Picea sitchensis*), lodgepole pine (*Pinus contorta*) and Japanese larch (*Larix leptolepis*). After some initial laboratory work, boards taken from normal commercial sources, and in cross sections of 150 x 75 mm, 150 x 45 mm and 150 x 25 mm by 1.8 m lengths, were treated in those plants. The treated boards and untreated controls were then subject to standard mechanical and physical tests and durability assessment. A further important part of the assessment process was an analysis of dimensional change, or stability through the process.

This latter aspect illustrates why it was important to carry out these investigations. A great deal of experience has been gained in Europe using these types of processes, but in the main the work has involved slow growing northern softwoods of higher

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density and better grain structure than is obtained with timber grown in Ireland. The processes are stressful at both the micro and macro level, and the more irregular grain, higher knot frequency and lack of clear definition between heartwood and sapwood of fast grown Irish timbers are all factors likely to influence the practical outcomes of the treatments.

All work on the acetylated timbers is complete and a report of mechanical, physical and durability results published (Birkinshaw and Hale 2002). Dimensional stability results are available but have not yet been published. The heat treatment work is ongoing. Timbers have been treated and some of the physical and mechanical test results are now available.

THE PROCESSES

Chemical modification with acetic anhydride is the most studied of all the modification processes. Acetic anhydride is a highly reactive chemical which is capable of reacting with all of the structural polymers of the wood, that is with cellulose, lignin and hemicelluloses (Hill and Jones 1996). The reaction with cellulose is illustrated in Figure 1 and the important point is that the hydroxyl group, important in moisture uptake, is converted to an ester group which bulks the cell wall in a permanent way. Two benefits ensue, first moisture absorption is greatly reduced, and secondly resistance to wood rotting fungi is enhanced (Forster *et al.* 1997, Suttie *et al.* 1999, Martins and Banks 1991). Reactions with lignin are equally important but are more complex.

An important consequence of the reaction is the liberated acetic acid which must be removed from the wood. The overall reaction is strongly exothermic and to prevent waste of anhydride the wood must be relatively dry before treatment. Both the drying and the chemical reactions stress the wood and the consequences of this will be considered in the results.

The Acetyleer process, shown schematically in Figure 2, involves vacuum impregnation with anhydride followed by heating, cooling after reaction initiation, and then extraction of unreacted anhydride and acetic acid.

Heat treatment can take various forms but all involve heating the wood to temperatures around 200°C for a period of time (Militz 2002). It is thought that the main changes which occur involve a thermal plasticisation of the lignin in the cell wall and some

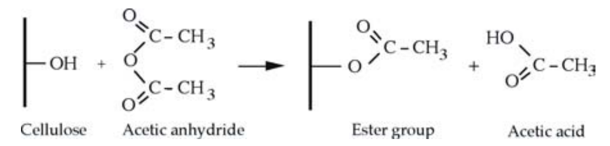

Figure 1: Reaction of a cellulose hydroxyl with acetic anhydride.

degradation of the hemicelluloses (Tjeerdsma *et al.* 2000). The overall result is a reduction in the wood's ability to bind water and a reduction in its ability to act as a fungal food source. It is accepted that this process is not as effective at improving durability as acetylation, but is much lower in cost.

The two heat treatment processes used in this work differed in approach and the operational sequences are shown schematically in Figures 3 and 4.

There is also an important difference in marketing approach between these two companies. Treater A starts by asking the customer what species they are interested in using and in what application and hazard class, and will then specify an appropriate heat treatment regime. Treater B seeks to provide various standard grades of heat treated timber which a customer can then select from for their application.

RESULTS AND DISCUSSION

The tests were carried out to the usual international standards where applicable. With acetylated materials the testing programme is complete but with the heat treated timbers at the time of writing (October 2004) only partial results are available. Fungal durability was assessed by weight loss of small blocks exposed to the brown rot fungi *Coniophera puteana* in the case of the acetylated timbers, and *Coniophera puteana*, *Poria placenta* and the white rot *Trametes versicolor* with the heat treated materials. The more extensive programme of testing was used with the heat treated timber because of greater uncertainty about potential durability improvement.

Figure 5 shows the equilibrium moisture content for acetylated spruce, pine and larch respectively, and as would be expected very significant reductions in equilibrium moisture content are apparent, and these relate closely to the weight percent gain. The trends shown here are very similar to those obtained with slower grown northern European softwoods.

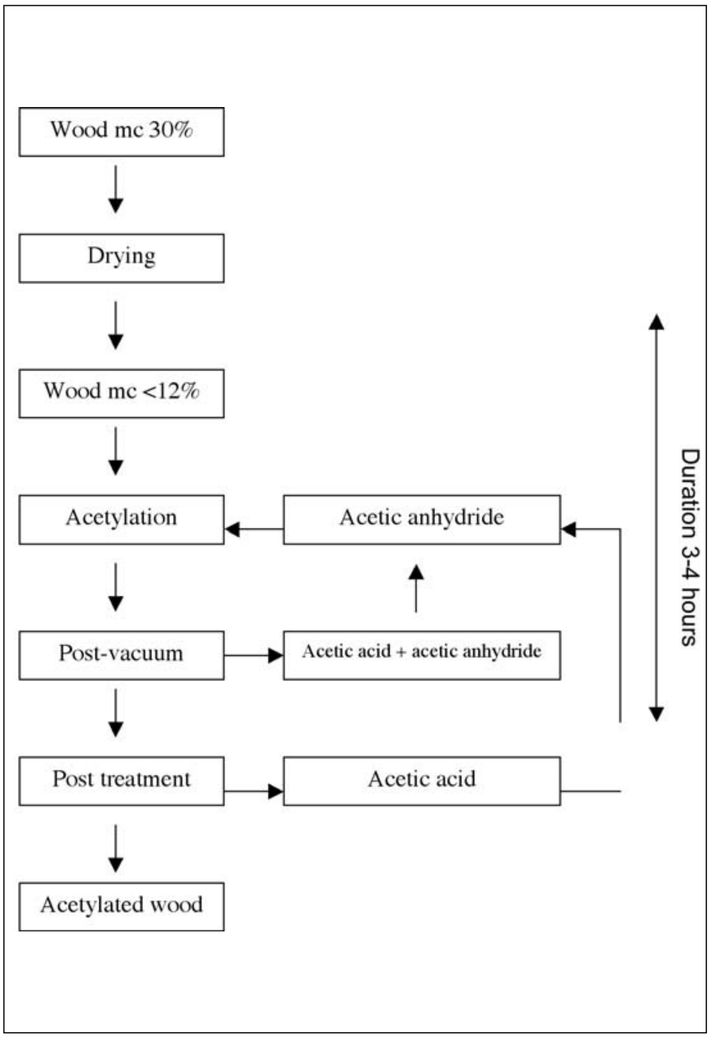

Figure 2: Acetylation process.

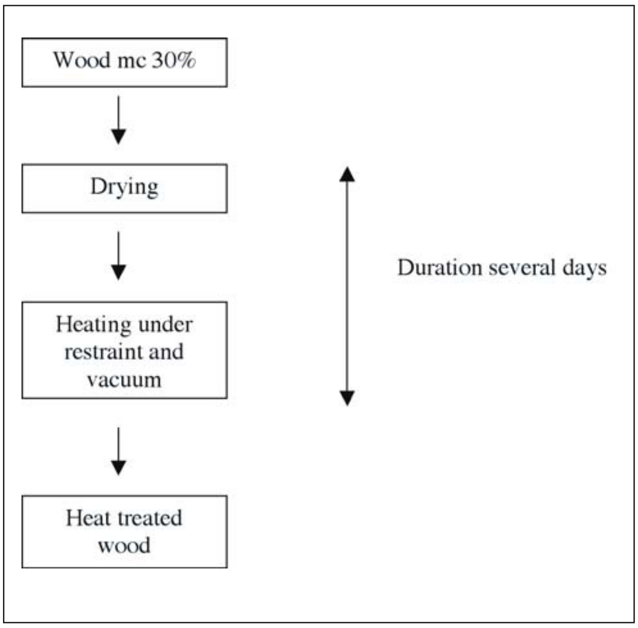

Figure 3: Treatment A process.

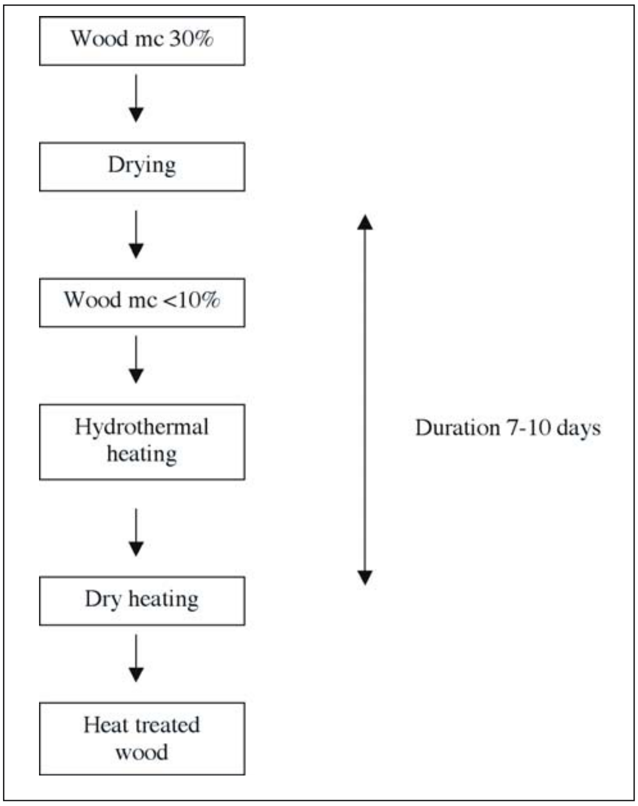

Figure 4: Treatment B process.

Mechanical properties for control and acetylated materials are compared in Table 1 and show no significant deterioration after treatment. Fungal durability comparisons are given in Figure 6 and it is apparent that the acetylated materials have a high resistance to decay by the aggressive brown rot fungus, *Coniophera puteana.* Again these results are consistent with those of other workers using slower grown materials (Beckers *et al.* 1994, 1995).

Measurement of distortion during the process was particularly important and modes and classes were defined according to NEN 5461. Figure 7 shows the behaviour of the materials as they pass through the acetylation process and it is clear that that significant irregular shape changes occurred. The sequence of change shown in the figure demonstrate that these arise from the drying stresses and associated dimensional change as the timber is dehydrated and then re-bulked by the acetylation, and not simply from the acetylation part of the process.

Considering heat treatment, Figure 8 shows the equilibrium moisture curves for the treated materials and controls and significant reductions are apparent with both processes. Some limited fungal durability data is presented in Figure 9 and although these results are from early in the total test programme, they indicate small improvement in durability with some of the timbers and treatments.

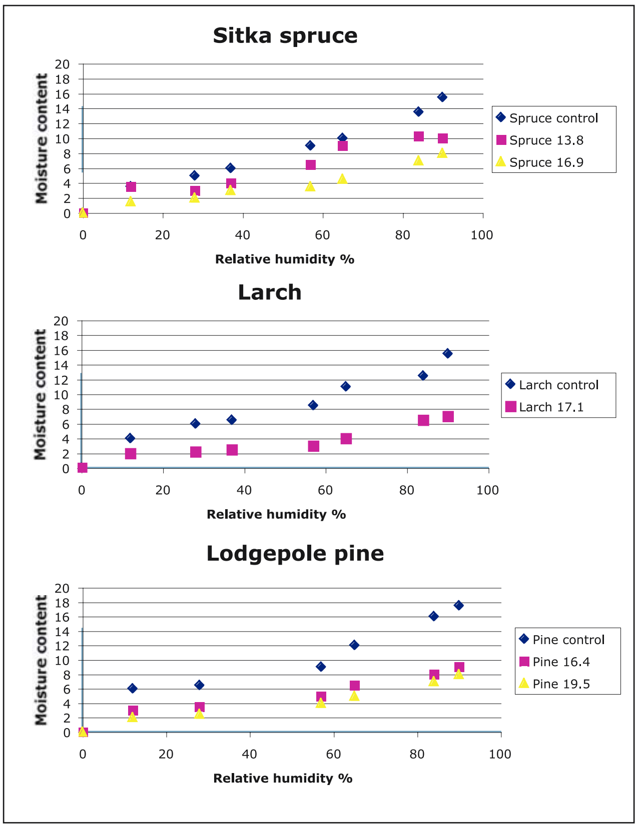

Figure 5: Equilibrium moisture content of timbers acetylated to various wpg.

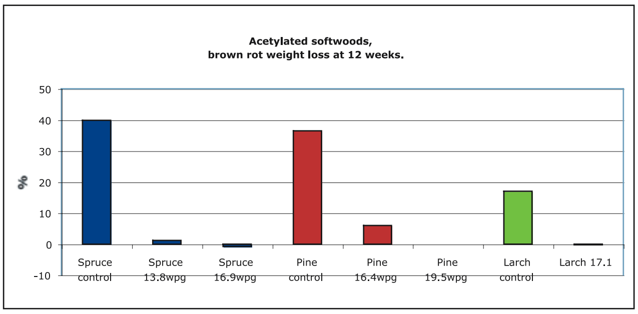

Figure 6: Weight loss of acetylated timbers exposed to the fungus *Coniophera puteana*.

CONCLUSIONS

It is clear that acetylation of fast grown softwoods gives very significant reduction in equilibrium moisture content and improvement in fungal durability, however in respect of the boards used in the testing this gain is obtained at the expense of unacceptable levels of distortion. This distortion arises from the drying stresses inherent in the process and if any use is to be made of this technology it will be through selection of appropriate boards.

With the heat treated timbers work to be completed includes conclusion of the fungal durability measurement, analysis of the dimensional change and distortion through the process and mechanical testing. This will be reported in detail later, but some provisional comment is possible. Some of the early decay results suggest that application of this process may be limited to out of ground contact applications. In considering these heat treatment results it is important to stress that processes were not optimised for the fast grown timbers and this may explain why results obtained to date are less good than those quoted for slower grown timbers.

Table 1: Modulus of rupture (MOR) and modulus of elasticity (MOE) results for acetylated timbers. (Standard deviations given in brackets)

Material	MOR (MPa)	MOE (MPa)
Spruce		
unmodified	63.2 (3.4)	5.40 (1.28)
13.8 WPG	65.7 (4.4)	5.06 (1.31)
16.9 WPG	70.7 (13.5)	6.20 (1.16)
Pine		
unmodified	75.6 (9.0)	5.87 (0.66)
16.4 WPG	90.2 (8.8)	6.71 (0.77)
19.5 WPG	85.7 (13.5)	6.00 (0.64)
Larch		
unmodified	85.1 (14.0)	8.21 (1.98)
17.1 WPG	68.9 (20.7)	6.37 (2.20)

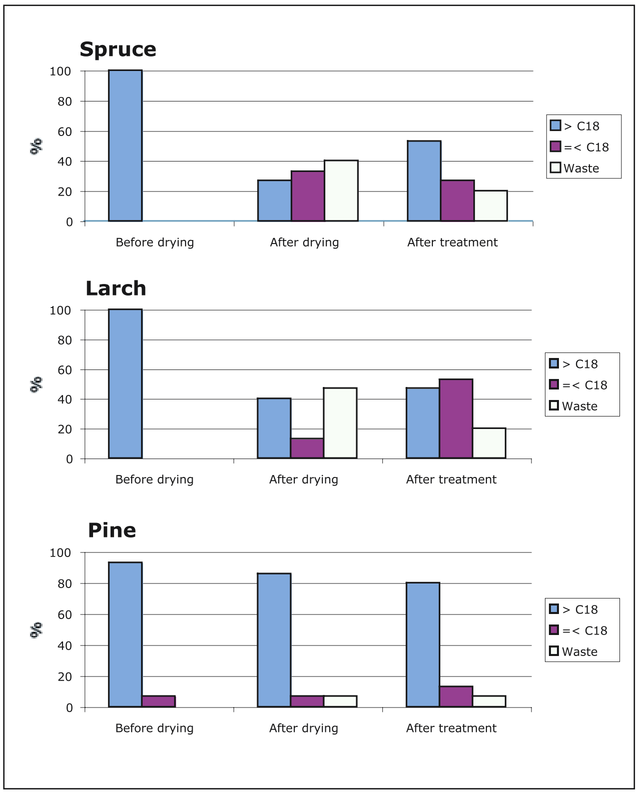

Figure 7: Distortion of timbers passing through the acetylation process.

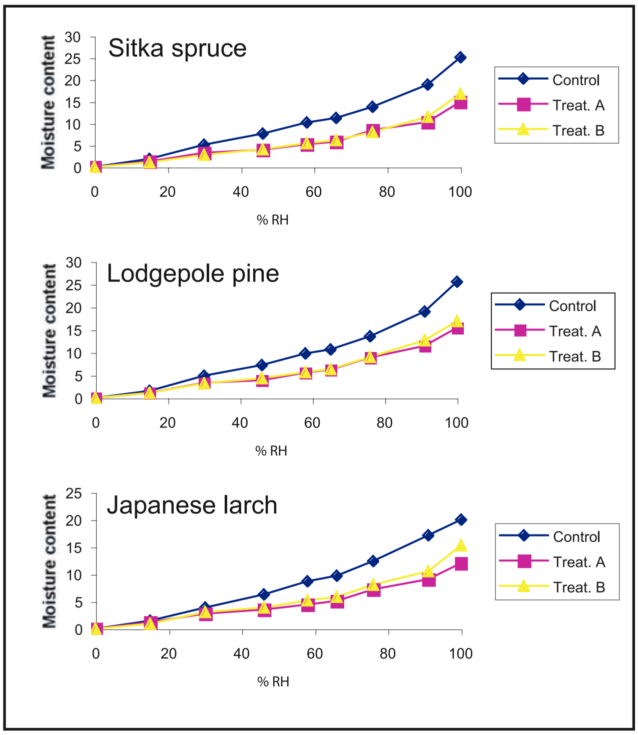

Figure 8: Equilibrium moisture content of heat treated timbers.

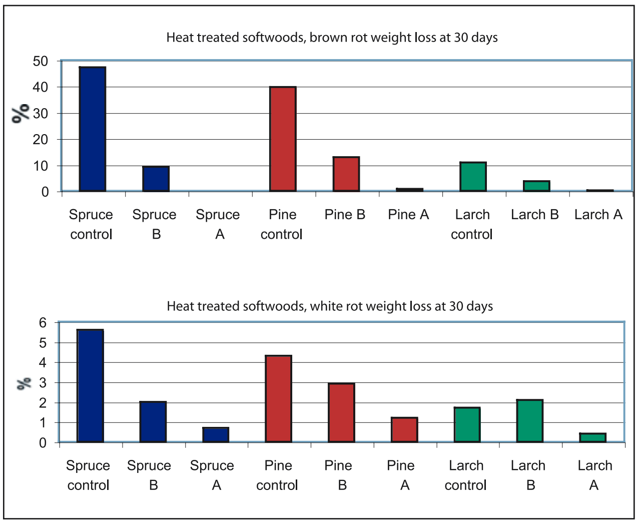

Figure 9: Weight loss of heat treated timbers exposed to *Coniophera puteana* and *Trametes versicolor*.

Possible future work should focus on optimisation of the various technologies through material selection and process condition adjustment to give the maximum technical gain for the fast grown timbers. The materials tested here were not specially selected and were representative of timbers going through the mills in the normal run of work. Also the process conditions used were those judged by the process operators as likely to yield the best results, but because of consideration of process time and cost, detailed refinement of processing conditions through iterative testing was not possible. Further work could usefully address these areas. It is likely that both technologies will become important in the European industry and it is desirable that processes be optimised for fast grown materials.

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WoodEnergy: COFORD Strategic Study on Maximising the Potential of Wood Use for Energy Generation in Ireland

K. Healion*

BACKGROUND

The overall aim of the study is to increase the competitiveness of the Irish forest industry by promoting the development of a new market in wood energy. At present wood supplies about 1% of the Total Primary Energy Requirement (TPER) of the Republic of Ireland, but there is potential to increase this contribution substantially, thus providing benefits in terms of employment, energy supply, rural development, environment and the national economy. Increasing the use of wood energy will help to achieve Ireland's targets to limit greenhouse gas emissions to 13% above 1990 levels over the period 2008-2012 and to provide 13.2% of our electricity consumption from renewable sources by 2010.

OUTLINE APPROACH

COFORD organised and sponsored a '*Wood for Energy Strategy Group*'. The Group met seven times from March 2002 to January 2003. The Group steered a team of consultants in the production of the '*Strategic Study: Maximising the Potential of Wood Use for Energy Generation in Ireland*'. The members of the Group were:

- Organiser and Sponsor: Joe O'Carroll, Operations Manager, COFORD;
- Chairperson: David Kidney, Managing Director, Balcas Kildare Ltd.;
- Patrick Lehane, National Chairman, Farm Forestry Section, The Irish Farmers' Association (with Barbara Maguire);
- George McCarthy, Director of Planning, Research and Environment, Coillte (with Richard Lowe, John Lyons and Pádraig Ó hUallacháin);
- James McNamara, Managing Director, Laois Sawmills Ltd., representing Irish Timber Council;
- Garret Mullooly, Director, Woodland Managers Limited;
- Donal Whelan, Technical Director, Irish Timber Growers' Association;
- Peter Wilson, General Manager, Glennon Bros Timber Ltd. succeeded by John Brady, Managing Director, Woodfab Timber Ltd., representing Irish Timber Council;
- Secretary: Kevin Healion, Tipperary Institute (secretariat to the Group provided on contract to COFORD);
- Consultant: Peter North, Electrowatt-Ekono (UK) Ltd.

The study was led by Electrowatt-Ekono (UK) Ltd. (part of the Jaakko Pöyry Group), with inputs from Electrowatt-Ekono Finland. Peter North was the project manager for the Study. Tipperary Institute was a subcontractor to Electrowatt-Ekono. Tipperary Institute in turn had a number of subcontractors: Joc Sanders, Consultant (graduate of the Tipperary Institute Certificate in Renewable Energy); Ecofys bv, the Netherlands (Dr Richard van den Broek); Dr Philip Blackstock, Woodland Consultant, Northern Ireland; and the Forestry Contracting Association, United Kingdom (Ben Hudson). Dr van den Broek has previously examined the Irish potential for wood energy (e.g. van den Broek *et al*. 2001). Dr Blackstock has completed research into the technical aspects and market potential of wood fuel in Ireland, including forest residues (e.g. Blackstock and Binggeli 2000). The Forestry Contracting Association in the United Kingdom has considerable experience on the topic of forest residues for wood fuel (e.g. Hudson 1997). Kevin Healion was project manager for the Tipperary Institute component of the Study, with assistance from Seamus Hoyne.

Specific inputs from Electrowatt-Ekono included review of energy technologies, the parameters for trading of wood fuels (based on Finnish experience), the costs of energy production from wood energy (drawing on Electrowatt-Ekono experience in plant

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construction), cost-benefit analysis of wood energy (for example, based on cost per kilowatt-hour (kWh) of electricity generated or cost per tonne of carbon dioxide abated), review of policy options (including examination of international experience), policy analysis, and recommendations.

Figure 1 shows a sample of the output from Electrowatt-Ekono. It shows the cost of electricity generated from wood fuel at wood prices from €0 per green tonne to €70 per green tonne (at 50% moisture content on a wet weight basis). The graph shows the costs for co-firing in peat and coal power stations, from new stand-alone power generation plant and from new Combined Heat and Power (CHP) plant. The horizontal lines show the prices for biomass under the government's recent Alternative Energy Requirement (AER) competitions. Also shown are the Best New Entrant (BNE) prices for 2002 and 2003 (representing the cost of electricity generation from combined cycle gas turbines). The BNE cost for the latter part of 2004 has since risen to 5.2 cent per kWh (CER 2004). Two points are of particular interest from this graph – the cost of electricity generation from wood is increasingly competitive with that of conventional energy (represented by the BNE cost); and the production of energy from wood can provide attractive prices to wood fuel suppliers. For example, an operator co-firing wood with peat or with coal, or generating electricity in a new 20 or 30 MegaWatt (MW) wood-fuelled power station could pay €20 per green tonne of wood fuel delivered while competing strongly with BNE costs.

It should be noted that while the cost of electricity generation from CHP is more expensive than that from co-firing or new power-only plant, the cost per tonne of carbon dioxide abated is cheaper for CHP than for the other options, due to the additional emissions abatement benefit of the heat used.

Relative competitiveness of different power generation options (15 year period, 10% Internal Rate of Return, value of heat from CHP of 1 cent/kWh)

Tipperary Institute provided information on the Ireland-specific components including: energy supply and demand (a detailed analysis by Joc Sanders of the Economic and Social Research Institute's energy demand model); Irish energy policy; wood supply and demand; wood energy delivered-in costs; and an overview of the technical options for using wood fuel in Ireland (by Ecofys bv – for example, co-firing sawdust and coal in Moneypoint power station). A startling fact from the energy supply analysis is that nearly 70% of electricity generation in Ireland could be from natural gas by 2010, with a resultant high dependence on international security of supply (in 2001, 93% of natural gas was imported). Example outputs from Tipperary Institute are shown in Figures 2 and 3. Figure 2 shows the total timber production on the island of Ireland in the year 2000 and the markets

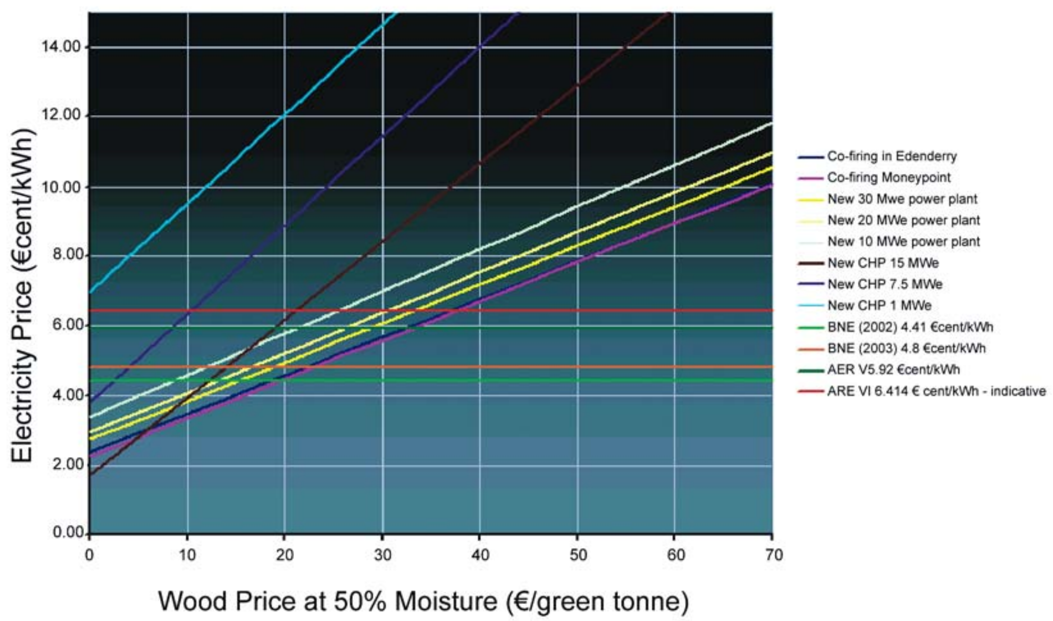

Figure 1: Example output from Electrowatt-Ekono showing relationship between electricity cost (for different power generation options) and delivered price of wood chip fuel (15 year period, 10% Internal Rate of Return, value of heat from CHP of 1 cent/kWh).

which it supplied (based on analysis of the Timber Industry Development Group report (2001). Figure 3 shows the delivered-in cost of wood fuel, in € per GigaJoule (GJ) of Net Calorific Value (NCV), for twelve different wood fuel supply options.

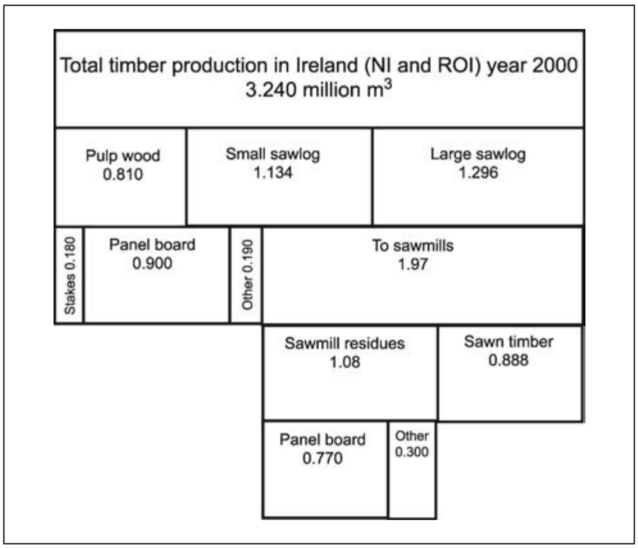

Figure 2: Timber balance for the island of Ireland (in million m^3), 2000.

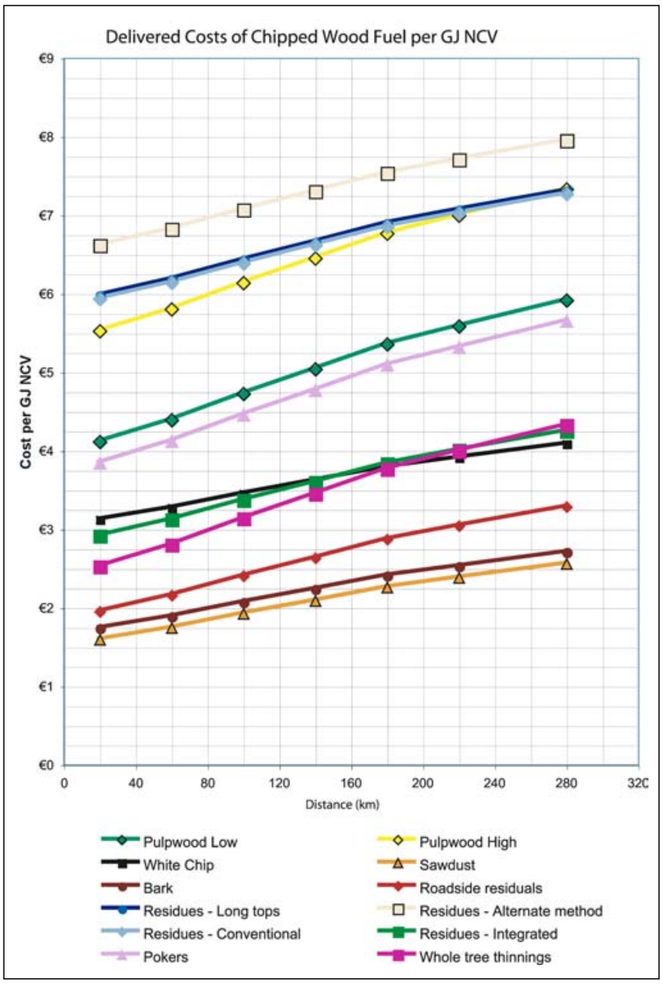

Figure 3: Delivered-in cost of wood chips.

RESULTS

The study calculated that over 400,000 green tonnes of wood fuel could be available in Ireland at present, from excess pulpwood (15% of total, principally thinnings), excess sawmill residues (30% of total, principally sawdust) and currently unharvested forest residues (50% of total, based on harvesting of spruce tops from environmentally-suitable sites). The quantity available could rise to over one million green tonnes by 2015. The term 'available' is used to indicate that these quantities could be used for energy production without diverting supply from existing markets (e.g. panel board production).

The energy content of all pulpwood, sawmill residues and harvestable forest residues produced in Ireland represents about 3% of the country's TPER (20 PetaJoules out of over 600 PetaJoules). The 'available' quantity represents about 4 PJ of energy, equivalent to about 1% of TPER. This proportion could be maintained to 2015, as wood fuel supply grows in line with Ireland's projected increase in energy demand. Other work funded by COFORD demonstrates that waste wood (from packaging, construction and demolition) could supply as much energy again as 'available' pulpwood, sawmill residues and harvestable forest residues.

While the potential contribution of available wood energy may seem small from the viewpoint of national energy supply, the quantities of wood used and energy produced are very significant from the perspectives of forestry, renewable energy and greenhouse gas abatement. Using the available wood fuel to replace fossil fuels could reduce carbon dioxide emissions by a third of a million tonnes now, rising to one million tonnes by 2015 (in the context of a projected overshoot of our Kyoto target by 13 million tonnes of carbon dioxide equivalent). If used for electricity generation, the wood fuel available could fuel 50 MW electrical now, rising to over 130 MWe by 2015, providing from 9% to 23% of our renewable electricity target. If used for heating, the wood fuel could replace about one third of the use of solid fossil fuels in the commercial, domestic and industrial sectors. As can be seen from Figure 4, the heat market is as important as the electricity market in terms of energy requirement.

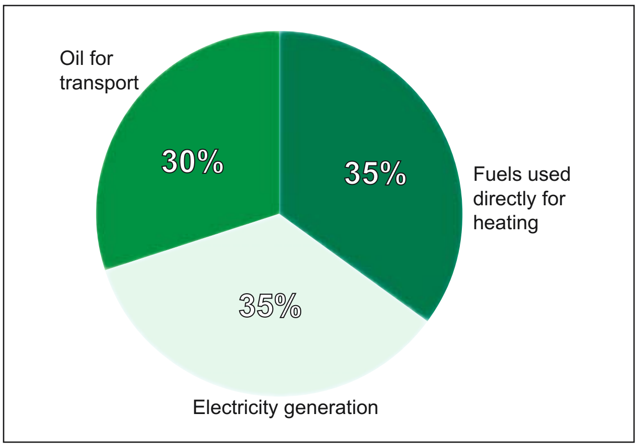

Figure 4: Breakdown of total primary energy requirement (TPER), 2001.
Source: Based on data from Department of Public Enterprise (no date). Representing 14,582 kTOE of TPER. Not including 170kTOE of "Own use/losses" of Oil and Natural Gas.

RECOMMENDATIONS

The study made a number of clear recommendations:

- the inclusion of bands for 'wood energy' (including co-firing) and 'wood energy with CHP' in the Alternative Energy Requirement. Wood has a high value in displacing peat for electricity generation, due to the abatement of carbon dioxide emissions;
- a Sustainable Energy Ireland capital grant scheme for domestic wood pellet heating systems (this market provides the best opportunity for the highest prices to wood suppliers);
- a demonstration scheme for wood heating systems in commercial, industrial and public buildings (the decentralisation of government provides an opportunity);
- exemption of wood energy from carbon energy taxation (should such taxation be introduced in the future);
- enhanced capital allowances for wood energy investments (to allow the cost to be written off in the period of investment);
- co-operation with government departments to remove barriers to wood energy and put in place suitable support mechanisms;
- wood energy harvesting and drying trials (for example on whole tree chipping, forest residue bundling, harvesting of 'poker tops');
- collation of data on wood fuels (for example, the percentage breakdown of sawmill residues into chips, sawdust and bark; moisture contents of wood fuels);
- co-operation on promotion (including COFORD, Sustainable Energy Ireland, Local Energy Agencies and the Irish Bioenergy Association);
- strategic environmental assessment (including assessment of the possible impacts of whole tree chipping and forest residue harvesting on the nutrient and carbon status of forest soils, soil structure and water quality). Such assessment would help link wood energy into sustainable forest management and certification;
- inventory work on private forests (to provide accurate information on the production of thinnings by geographical area to 2015, including suitability for whole tree chipping).

In all wood energy developments, from production through processing to end use, best practice should be adhered to, and international standards applied where available.

IMPLICATIONS AND DEVELOPMENTS

During the course of the study, the Wood for Energy Strategy Group made a number of submissions to Government, and held meetings with other organisations on matters relating to wood energy. A successful trial was conducted at the Edenderry Power peat-fired station to test sawmill residues as fuel. A new 'biomass CHP' band was included in AER 6 (unfortunately there was not a specific 'wood energy' band). Data from the study is being used by the Bioenergy Strategy Group, established by the Department of Communications, Marine and Natural Resources in December 2003 (the author is a member of the Group). The study will feed into the new wood energy website to be launched by COFORD.

A number of major developments have occurred recently which give reason for optimism for the wood energy sector. A wood-fired CHP plant, owned by Independent Biomass Systems, is operating in Enniskeane, Co Cork (a successful bidder under AER 6). A wood pellet plant started production at Balcas Ltd., Enniskillen, this year. The plant consists of a 15 MWth boiler raising steam for a 2.7 MWe turbine and providing heat for kilns and the manufacture of 50,000 tonnes of wood pellets per year. The total project cost is £8 million, including grant assistance of £2 million. Wood pellet boilers have been installed in Laois Sawmills, Portlaoise and the Coillte offices in Newtownmountkennedy, Co Wicklow. Wood chip heating systems have been installed at the offices of Natural Power Supply Ltd. in Co Waterford and at the Camphill Community Jerpoint, Co Kilkenny.

CONCLUSIONS

It can be concluded that significant potential exists for new wood energy developments in Ireland. There have been recent positive moves at both the policy and commercial levels. Most importantly, there are now exciting new wood energy projects to visit. These projects are greatly increasing awareness of, and interest in, the wood energy sector. The COFORD Strategic Study has contributed significantly to national understanding of the potential of the wood energy sector and the possible mechanisms for its development. The Strategic Study report is available on request from COFORD.

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POSTSCRIPT.

The proposed Best New Entrant Price for 2006 is 7.3 cent per kWh (CER 2005). This further improves the competitive position of wood energy in comparison to other fuels see Figure 1).

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The Markets for Non-Wood Forest Products

P. Collier[*]

INTRODUCTION

Successive governments, since the foundation of the state, have run grant-aid schemes for afforestation, with the overall objective of increasing forest cover. Up to 1980, the uptake of private forestry grants, with some notable exceptions, was very limited. This situation began to change in 1981 when the Programme for Western Development included significant tax-free incentives for afforestation. In 1987 improved incentives were offered to farmers in the rest of the country. Further improvements were made in the 1989-93 Forestry Operational Programme and again in the Operational Programme for Agriculture, Rural Development and Forestry 1994-99. These policy changes produced a sharp increase in private planting from 5,500 ha per annum in the first half of the 1980s to about 12,000 ha in the decade 1985-95. Since then performance has been less consistent. Afforestation dropped from 1996 to 1998, as a result of competition from other land uses.

The main drawback to forestry as an enterprise is the absence of returns for 15-20 years even under the fastest rotations. Indeed, first thinnings in the Irish context are likely to yield a very low return, so that it is only on the second and subsequent thinnings, carried out on a cycle every five years or so, up to final felling at around 40 years after establishment that market returns are received. The annual forestry premium, currently paid to farmers over a 20-year period, is designed to overcome this. Studies show that it is the most important quantifiable factor in the decision to afforest. Other factors include the attractiveness of alternative enterprises and, as a positive factor, the availability and rate of remuneration from off-farm employment. Returns from sales of thinnings and timber, being heavily discounted, have very little weight in the afforestation decision.

In these circumstances, it is highly desirable to explore the possibilities of generating revenues from non-wood forest products (NWFP) as well as services. This is in the context of changes in consumer preferences towards increasing demand for uncultivated food products (as paralleled by the demand for organic food) and alternative medicines for which forests are a potentially important source. Likewise, more discrimination in the tourism market is generating demand for special interest holidays of the sort which can be provided in and around forests. There is also an important market for forest foliage for decorative use.

Non-wood forest products can be grown or sourced below the forest canopy as well as on open spaces at the forest edge (including riparian buffer zones), and along or adjacent to service corridors (electricity, public roads, railway lines), running through the forest.

It is against this background of production possibilities and changing consumer demands that COFORD commissioned the study reported here with the following terms of reference:

- Review market for non-wood forest products and services;
- Establish market potential for each product and service;
- Assess feasibility of supplying the markets;
- Identify obstacles to the development of the markets and
- Identify gaps in knowledge of commercialisation of the products and recommend necessary research.

The study involved desk research covering web sites and hardcopy publications, accompanied by telephone and face-to-face interviews with suppliers and buyers.

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FOLIAGE

Foliage is used to add volume and appearance to flower bouquets. Cut foliage previously was used solely in flower bouquets but more recently it is being used on its own or in combination with candles, pottery and oils to give value added products. These uses are popular on the continent and are now being introduced to the Irish market. Foliage consists of both cultivated and wild plants.

Markets

The EU market for cut flowers and foliage has been stable (approximately €12 billion) annually over recent years. Germany is the biggest consumer followed by Italy, France and the UK in order of importance. Dyke and Primrose (2002) found that in the UK, on average 10% of revenue from 19 businesses in the florist and floristry products area was accounted for by non-floral products (inclusive of foliage). Bord Glas (2002) figures for the Irish market in 2001/2002 showed that foliage as a percentage of fresh flowers and foliage was 7.7%. Based on these figures the market for foliage in the UK and Ireland is estimated at €195 million.

Suppliers

The leading suppliers of foliage to the main EU markets in 1999 are shown in Table 1. The table shows that with the exception of France, developing countries have a significant share of the EU market for foliage. In addition to the different range of plants available in developing countries, these are likely to be very cost-competitive.

Table 1: Leading suppliers of foliage to main EU markets, 1999.

EU market	Source of foliage	DC* share of imports %
Netherlands	India (33%), Germany (14%), China (8%)	64
UK	India (28%), the Netherlands (22%), Colombia (12%)	53
Italy	India (29%), France (16%) and the Netherlands (12%)	52
Germany	Italy (18%), The Netherlands (17%), India (17%)	44
France	The Netherlands (48%), Italy (14%) and Spain (11%)	7

Source: Profound Ltd. and Lanning.

Notes: *DC = Developing country.

Distribution channels

There is a difference across EU countries in the market shares of the distribution channels. Table 2 shows the distribution channels for a selection of EU countries including the UK. Florists are the major distribution channels in most of the selected EU countries, except in the UK, where supermarkets account for a larger share of distribution than florists.

Products

A survey of seven UK buyers of cultivated and wild cut foliage in 2003 was conducted by Kelly and Whelton (2004) (Table 3). Three of the 25 products for which there is known big demand are rhododendron, eucalyptus and bear grass. Tesco alone has a demand for over 500,000 stems at Christmans time for each of these products, and

Table 2: Percentage of total sales at retail level in select EU countries 1999.

Country	Florists	Supermarket	Market/street vendors	Garden Centres	Others	Total
	%					
Germany	64	10	8	-	18	100
Italy	80	2	15	2	1	100
France	58	16	9	8	9	100
UK	35	41	9	4	11	100
Netherlands	48	18	26	3	5	100

Source: Estimates from different publications (Horticultural Commodity Board, UK)

Table 3: Cultivated and wild foliage products used by seven UK buyers, 2003/2004.

Products	Source	Volumes No. of stems	Comments
Abies	Ireland		
Arbutis			Good at Christmas (Waitrose)
Bear grass		700,000	Tesco demand only
Ceanothus			
Cotinus	Ireland		
Contorted willow			
Elaoagnus			
Eucalyptus	Ireland +	500,000	Tesco demand only Tome Browne and Co. demand 20,000
Golden conifer			
Hebe			> 60 cm length Waitrose
Hosta			
Inus	Ireland		
Ivies			Very important recently
Leatherleaf fern*			Constant demand
Ozothamnus	Ireland		
Peony rose		50,000/wk	Waitrose demand
Pinus			Good at Christmas (Waitrose)
Pittosporum	Israel		Gap in June/July (Waitrose)
Rhododendron		700,000	Tesco demand only
Rose hip	Ireland		
Ruscus	Israel		20,000 Tome Browne and Co.
Salix	Germany		Good at Christmas (Waitrose)
Skimmia			Good at Christmas (Waitrose)
Tree Fern			Constant demand
Viburnum	Ireland		

Marks and Spencer use up to 15 million foliage stems per year.

Three of the four buyers currently sourced material in Ireland: Marks and Spencer, Tesco and Waitrose. Waitrose was critical of Irish produce and rated it from poor to average on a number of criteria as shown in Table 4. Tesco rated it average to good whereas Marks and Spencer were much more positive and considered it very good.

The general demand seemed to be for stem lengths over 50 cm long. Both Tesco and Waitrose stated they were not interested in variegated foliage. Waitrose were interested in foliage with fragrance, strong colour, good shape, berries and sticky bud.

Table 4: Rating of Irish foliage by the three multiples, 2003.

Criterion	Marks and Spencer	Tesco	Waitrose
Perception of Irish produce	Very good	Good	na
Grading	na	na	Fall short
Quality Service and Reliability	Very good	Good	Average
Range of Materials	Very good	Average	Average
Added Value	Excellent	Poor to average	Poor
Pricing	Good		Fair

Notes: na = not available

For Marks and Spencer and three other florists interviewed, painted (gold lilac and silver) birch and willow twigs were important foliage products.

Some of the florists interviewed emphasised that the demand in springtime was for catkins and flowers, summertime herbs and scented geranium, and hips and berries in the autumn.

There seems to be potential for inclusion of natural products (mosses, bark, cones, etc.) in arrangements. All three multiples would insist that their suppliers would comply with MPS and Eurogap protocols in relation to protection of the environment.

Table 5 shows the results of market research from a select number of sizeable operators selling product into the key European markets. The results show that there is an interest in new products but these are not specified. Pittosporum, rhododendron and leatherleaf fern are identified as key stable products. Holly and ivy with berries, willow with catkins and cotoneaster are listed as growth areas. One of the buyers interviewed also stressed the importance of complying with MPS and Eurogap protocols.

The view of the primary researcher who conducted the market survey reported in Table 3 to 5 was sought in relation to the potential of cultivated and wild product available in Ireland. The results are shown in Table 6. Products including bog myrtle, corkscrew hazel, mistletoe and holly with berries were deemed to have good potential. Good quality forest mosses, larch, forsythia and Serbian spruce were considered to be of medium potential, whereas Douglas fir, birch and mountain pine have low potential. Lawson cypress, Norway spruce, Sitka spruce, western hemlock, Japanese cedar, common box, rowan, Weymouth pine that are also available in Ireland were not considered to have potential in the foliage market.

Kelly (2004) states that there was reluctance by those interviewed to reveal data about the state of the market now or in the future.

Conclusions

There is a very definite and sizeable European market for cultivated and wild foliage product currently available in Ireland. This market is strongly inter-connected with a market which is more than ten times the size of the foliage market.

Some of the leading UK multiples rate Irish foliage product very good whereas others rate it as at or below average.

Pittosporum, Rhododendron and leatherleaf fern are identified as key stable products for which there is strong demand for large quantities from the multiples. Holly and ivy with berries, willow with catkins and cotoneaster are listed as growth areas. Other products deemed to have good potential include bog myrtle, corkscrew hazel and mistletoe.

Research Programme

National strategy

The market information suggests that there are opportunities for the development of foliage as a sub-sector of forestry. To realise this a strategy needs to be put in place. In this strategy, technical research, market research and enterprise development need to be developed in a co-ordinated way. The following recommendations are some of the elements of this proposed strategy:

General principles

Research needs to be linked to commercial realities and focus on areas capable of significant growth. All businesses in the industry need to be given equal access to the findings from such research.

Product

- Prepare an inventory of locations and estimated volumes of selected species. Research into design and ways of adding value to the current product mix.

Linkages

- Investigate the implications for wood quality of managing foliage plants and cutting back trees and shrubs.

Husbandry

- Identify the changes in husbandry required to give a more blue-coloured foliage;
- Investigate the solution(s) to the problem of needle necrosis;
- Identify and specify the most suitable type of fertiliser programme (use of compounds, straights, etc.) for growing;

Table 5: Business and market profile of Dutch buyers and cultivated and wild foliage products purchased , 2003/2004.

	BLOOMINESS*	HORTIFLOWER**	HEIMBLUME***	METZ****
Established		>40 years	40 years	20 years
Turnover	€25m		€80m	€40m
Growth in T/O			+12%/yr over last 5 yrs	+20%
Employees	100			130
Main markets	Germany, Norway, Russia, Poland	Switzerland		Germany, Italy, England, France, Ireland
Sources	Austria, England, Italy, Ireland		Scotland	
Cost of foliage	€5m/annum	10 c per stem of Leather leaf fern and salal	7 to 9 c per stem	€2.8 m/annum
Products	Bouquets, other floral seasonal items	Bouquets		
Volume	30,000 bouquets/week	10,000/week to Switzerland	120,000/week from Scotland of rhododendron	
Interests	Foliage template with seasonal variation, new products	Natural and woodland products, rosemary and herbs in summer range extension	Pittosporum, rhododendron, leatherleaf fern, salal	New items, novel species, exotic foliage, herbs in summer
Growth areas	Wreath and pine rings		Cotoneaster, holly and ivy with berries, willow with catkins	Aspidistra
REQUIREMENTS				
Good quality	X	X		
Stable supply	X	X		
Bunches of known stem number	X			
Fair price	X			
30 cm	50%			
40 cm		80%		
50 cm			X	
55 cm	50%			
60 –65 cm			X	
Comply with MPS and Eurogap protocols		X (very important)		
Freshness		X		X
Reliable service		X		

** Packers/bouquet makers ** Packers/bouquet makers *** Wholesalers/importers/exporters **** Suppliers to florists*

- Identify the optimum spacing and timing of re spacing;
- Identify the performance of individual species in terms of shelf life, harvest period etc;
- Identify the optimum cutting regime and
- Investigate the various harvesting methods and of the most effective way to harvest as the crop grows bigger.

Markets

- Research the market to provide independent information, which keeps pace with the rapid rate of change in prices, demand and supplies;
- Investigate the possibility of producing in Ireland many of the plants currently being imported into Europe from South American and African countries and
- Identify of the potential for other species such as birch, hemlock etc.

Table 6: Expert assessment of cultivated and wild foliage available in Ireland, 2004.

FOLIAGE	COMMENTS	POTENTIAL
Bog myrtle	Competes well with other twig types. Its slight fragrance and plenty of side shoots make it attractive	Good
Mistletoe	Very popular, but needs a marketing boost to put it into the 'must have'.	Good
Corkscrew hazel	Its strong branches have a role in giant arrangements (e.g. reception areas, hotels, street fairy light displays, etc.).	Good
Holly	Berried selections are and will be important. Variegated ones hold a certain charm.	Good
Serbian spruce	The branches of younger trees are very attractive.	Medium
Forsythia	Is marketable in flower bud state. A good packing system is required to overcome a problem of disturbance in transport. It is certainly used in the market and there are currently many Dutch suppliers.	Medium
Larch	The larch seen were metre-long branches heavily coated with lichens. These were selling at Christmas. Early soft-green foliage is definitely sought. There may be shelf-life problems.	Medium
Forest mosses	The market is well supplied with product now, but the quality leaves a lot to be desired; there may be opportunity for good quality product.	Medium
Mountain pine	This might be of interest in small hand or table arrangements.	Low
Birch	There are vast quantities from central Europe, Britain and Ireland arriving in European markets now – mostly for painting. Consequently the market may soon become over-supplied.	Low
Douglas fir – Scots pine	May have innovative arrangement potential. Difficulty is that to make a significant break into this market, you have to dislodge some of the older habits in foliage usage and prove you have a better product.	Low

Source: Personal communication, Jim Kelly (Teagasc).

Logistics

- Research ways of increasing efficiencies of getting products to Europeans markets.

TOURISM

A recent survey of users of three Wicklow forests conducted by the Wicklow Uplands Council (2002) shows the reasons why people visit woodland sites (Table 7).

The most important reason for people using woodland sites is to walk and take some fresh air and exercise.

Data on the current use of forests for tourism and recreation at national level are not readily available. Bord Fáilte do not record statistics on the numbers of tourists in Ireland participating in hunting or the numbers visiting forests on whom a charge is levied.

Table 7: Reasons for visiting three woodland sites in Wicklow, March 2002.

REASON	NO. OF RESPON-DENTS	% RESPONSE
Walking (long distance)	110	67
Fresh air and exercise	77	47
View sculpture (Devil's Glen site only)	17	35
Woodland experience	42	25
Relax and picnic	24	15
Dog walking	24	15
Watch wildlife	16	10
Mountain biking	4	2
Cycling	2	1

Markets

On average 252,000 overseas visitors engaged in hill-walking or cross country walking each year between 1998 and 2002. The majority (71%) of these were holiday making.

The total spend in Ireland by visitors engaging in hiking/cross-country walking in 2002 was €161 million. This equates to €735 per visitor. Most of the expenditure (approximately 60%) was on food, drink and accommodation.

A research study conducted by DIT in 1999 investigated the profiles of users of three way-marked ways (Ballyhoura, Kerry and Wicklow) and the contribution made to the local economies by walkers. The data collected in 1997 and 1998 showed the contributions per walker (excluding day walkers) was €35.43 in Wicklow and €50.89 in Kerry. Approximately one third of walkers in Kerry and Wicklow spent no money within a 10 km range of the route - these were mainly day walkers. For the Kerry Way the contribution to the local economy was between €854,079 and €1,203,209 over the period March to September. Almost all (95%) income was from overseas visitors. The corresponding figure for Wicklow was €281,032. The lower Wicklow figure is partly due to a higher proportion of day walkers relative to Kerry, and the lack of data for the peak activity, summer months. The Wicklow Way is 132 km long, while the Kerry Way is 214 km. Only a very small percentage (2% - 3%) of visitors to forests pay a fee.

Products

Forest tourist centres

A number of tourists centres are located in forest within about 100 km of major population centres such as London, Manchester, Birmingham, and Lisbon. Those with some or all of the following facilities have the higher number of visitors:

- Swimming pool/tropical water complex;
- Restaurant/tea room;
- Tennis court;
- Conference/exhibition centre;
- Volleyball;
- Mini golf.

Activities

Visitors attending these centres engage in the following outdoor activities: bird watching tours; deer and boar hunting; range field archery; tackling woodland assault courses; trekking; fishing and sight seeing.

Environmental education products on offer include: spring bluebell walk; autumn fungus hunts; children’s activities - bug hunts, teddy bears’ picnics, barbeques and campfires, seasonal spotter sheets, wooden adventure playground; self-guided woodland trail with discovery sheets.

Other products include: wood and wood products; Christmas trees ‘dig your own’; conferences; mini train drive; tearoom; exhibition.

Pursuits centre

A recent feasibility study investigated the provision of a range of services in the form of an outdoor adventure centre based at a forest site and park in the mid west of Ireland. The site was an excellent location in close proximity to Limerick city and also in close proximity to a popular tourist route from Kerry to Connemara.

The project was found to feasible in all respects with the exception of its financial feasibility notwithstanding the fact that the proposed development costing €4 million was to open almost debt free.

Mountain biking

Since the mid 1990s there has been a major development by a wide variety of interests in the development of cycling tourism products in Wales.

No information exists to quantify the size of the UK mountain biking market on the size of the different market segments. Estimates have been made that cycle tourism is worth £18.25 million to Wales.

Mountain biking trail riding is where people use either purpose built mountain biking trails or follow mountain bike routes using forest tracks and rights of way network. There are two main segments to the mountain bike market. Those who are occasional users: these are predominantly males in their 20s and 30s who go riding once per month. They look for purpose-built, signed mountain bike trails. The second group are mountain biking enthusiasts. These are also predominantly male and are of an older age profile than the occasional mountain biker. They will plan their own routes and seek out trails using rights of ways.

The product requirements of the cccasional mountain bikers are:

- Purpose-built and signed mountain bike trails;
- Mountain bike hire;
- Car parking;
- Cyclist friendly accommodation (particularly camp sites and self-catering).

The product requirements of the mountain bike enthusiast are:

- Information on where to go mountain biking;
- Car parking;
- Cyclist friendly accommodation.

A car is the primary means of access by cycling tourists in Wales and hence the requirement for safe, off-road car parking.

No specific research has been done on the mapping requirements of cycle tourists to Wales. However, other research in the east of England has indicated that maps nned to be:
- OS based;
- Contain one route per map, possibly with short cuts;
- Fold to fit into map cases;
- Include simple route directions adjacent to the route map;
- Include brief details of places to visit;
- Include lists of refreshments stops with telephone numbers;
- Include essential information about the route such as length, riding surface, description of terrain, where to car park.

However, none of the route maps currently available meet this specification.

A key product requirement for cycling holiday visitors is cyclist friendly accommodation, providing safe overnight cycle storage and drying facilities. Other key product developments requirements include routes from centres, which provide facilities for cyclists, such as parking, cyclist friendly accommodation, cycle hire and cycle repair.

Destinations offering strong competition in the cycle tourism market include Scotland (Dumfries and Scottish borders), Switzerland (3,500 km of cycle routes), Netherlands (strong cycle culture), Germany (the Romantic Road and Three Castle Routes), Austria (the Donauradweg) and Loire in France.

Game

Wicklow conifer forests have the highest concentration of deer in Ireland. The deer-hunting season opens in September and runs until the start of January. In the 2000 – 2001 season over 4,300 Sika deer were culled in Co Wicklow.

The estimated expenditure on deer hunting in the Republic of Ireland by visitors and residents in 1995 was €1 million (Corbally *et al*. 1997) or €1.3 million in 2002 prices if inflated using the Consumer Price Index.

Conclusions

The overall picture is that forestry plays a very important role in tourism and particularly recreation in Ireland. Forests are part of the infrastructure that supports tourism and recreation. They provide the trails for walking, biking, horse riding etc. The set up of the trails, styles, signs, car parks is done by Coillte in Ireland and Forest Enterprise in Wales. However the overall potential to generate income directly from forest based tourism activities is low. Opportunities arise for those who provide food, drink and accommodation and especially for those who provide facilities catering for special needs of people engaged in outdoor pursuits. The Welsh experience shows that world class standards are needed to be competitive in attracting tourists. If Coillte on its own or in association with tourism interests were to provide facilities for mountain biking similar to Forest Enterprise in the UK then there would be potential for private entrepreneurs to generate income in the provision of related services.

There may be other niche opportunities within well-established tourist destinations and some sites might be attractive for holiday homes. Farmers afforesting lands should consider the option of tourist accommodation and related services in the context of their own situation and local market.

Research programme

The research and development needs of tourism related to forestry have been identified as follows:

Product development
- Investigate best practice in relation to development of forest parks overseas (UK, Netherlands etc.);
- Analyse the patterns and linkages between different types of uses and the implications for services such as refreshments, toilets, and environmental management;
- Monitor the changing needs of these users and customers and inform forest managers and
- Research and develop materials to maximise the potential for educational tourism in forestry by linking activities and subjects related to forestry and the natural environment to the curriculum at primary and second level curriculum.

Profile of users

- Compile information on people who use the forest for tourist and recreation purposes.

Benefits and impact

- Develop a model showing the likely benefits to the local area from the development of forest tourism infrastructure.

Inter-sector conflicts

- Investigate how forest managers can achieve the provision of services to people engaged in tourism and recreation and at the same time achieve sustainable forest management.

ALTERNATIVE HEALTHCARE

In the last ten years there has been a great increase in the popularity of alternative healthcare. Products, which were formerly sold in small specialist shops, often without licensing or control, have now become mainstream consumer products manufactured by large companies and sold through supermarket outlets. These products include health food as well as medicines.

Many medicines are derived from plants that have active ingredients. Where it is possible, the active ingredients in plants are synthesized such that the quantity and quality can be standardised. However in many plants it is not possible to synthesise the naturally found ingredients and the plant continues to be used.

Markets

Trade in herbal medicines is estimated at $9 billion annually. The EU market for licensed herbals is estimated at around $1.1 billion while estimated sales of herbal remedies, dietary supplements and functional foods combined exceed $7.5 billion (Commonwealth Secretariat 2001). Average annual growth rate for herbal medicines in the period 1985 to 1995 was 10%.

The European Union represents the largest single commercial market for medicinal plants and herb medicines in the world, with imports estimated at around 100,000 tonnes and valued at $250 million.

Germany is the most important EU importer with 38% of the EU market. France comes second (17%), followed by Italy (9%).

According to Key Note (2002), in 1999 36% of adults in the UK took health supplements and/ or herbal remedies; this was expected to increase to 50% by 2002.

An analysis of the alternative healthcare market in the UK by product category for the period 1996 to 2000 is shown in Table 8. The table shows a steady growth in each category each year over the period 1996 to 2000. Aromatherapy experienced the highest growth with an average annual of 14%, followed by herbal and homeopathic products.

The Key Note forecast for the period 2002 to 2005 is shown in Table 9.

Table 8: The UK alternative healthcare market by product category 1996 to 2000 (£ million).

PRODUCTS	1996	1997	1998	1999	2000	AVERAGE ANNUAL 1996–2000
	£ million					
Herbal	43.4	49.1	56.0	63.8	72.7	13.8
Aromatherapy	36.0	41.5	47.7	54.8	63.0	15.0
Homeopathic	8.1	8.9	9.8	11.0	12.4	11.2
Total	87.5	99.5	113.5	129.6	148.1	14.1

Source: Key Note (2002).

Table 9: Forecast growth in market for UK alternative remedies, 2002 to 2005 (£ million).

PRODUCTS	2002	2003	2004	2005	AVERAGE ANNUAL GROWTH RATE 2002–2005
	£ million				%
Alternative remedies	189	215	245	279	13.9

Source: Key Note (2002).

Suppliers

Medicinal and aromatic plants are cultivated on 63,000 ha in Europe as shown in Table 10.

Table 10: Area devoted to medicinal and aromatic plant production in Europe.

COUNTRY	ha
France	25,000
Spain	19,000
Germany	5,700
Austria	4,300[1]
Netherlands	2,500[2]
Italy	2,300
UK	2,000
Finland	1,900
Total	62,700

[1] excludes pumpkin seed; [2] fluctuates considerably.

Source: Commonwealth Secretariat (2001).

France and Spain are the two main producers, although the overall area under cultivation is small. Some producers of herbal medicine have their own plantations. The main species are lavender, opium poppy, caraway and fennel.

There are two distinct trends in European medicinal plant production. Large-scale production of relatively low value products such as evening primrose, thyme and milk thistle is generally on the decline and is being replaced by imports. For example, the area of medicinal plants under cultivation in Germany declined from 10,000 ha during the Second World War to 7,000 in 1990 and 5,000 in 1997. The costs of production in Eastern European countries is much lower than in Western Europe and consequently Bulgaria, Hungary and Albania are major suppliers of medicinal and aromatic plant materials.

On the other hand, production of more specialised plants in Europe is increasing especially using organic or biodynamic cultivation techniques. The largest buyers of medicinal herbs, particularly for teas or specialist uses, prefer to purchase their materials locally from farmers they know and trust (Commonwealth Secretariat 2001). Moreover, homeopathic medicines must use freshly harvested materials. Many companies find it difficult to get regular supplies of authenticated herbs from scattered overseas suppliers.

The most important sources of crude medicinal plants to the EU market are shown in Table 11.

Products

There are an estimated 2000 medicinal and aromatic plant species used in Europe for commercial purposes. The top selling plants, totalling $3.1 billion in sales, are shown in Table 12. The products mentioned in the Key Note report and expected to experience growth are shown in Table 13.

Currently the majority of herbs are imported into the UK from China, USA and mainland Europe.

Conclusions

There is a strong positive growth in the alternative healthcare markets.

Ten of the twelve top suppliers of crude medicinal plants are low- cost countries and they supply 90% of volume and 73% of the value of crude medicinal plants.

The climate in these ten countries is very hot relative to Ireland.

The production of low value medicinal and aromatic plant material has moved to low-cost Eastern European countries such as Bulgaria, Hungary and Albania.

Increasing regulation and the focus of pharmaceutical companies may result in the production of chemical analogues of active ingredients.

Table 11: Top 12 suppliers of crude medicinal plants to the European market.

COUNTRY	TONNES	$ MILLION
China	140,450	326
USA	11,650	120
Germany[1]	14,900	73
Singapore	14,400	63
India	35,650	53
Chile	11,700	26
Egypt	11,300	14
Albania	7,100	14
Bulgaria	7,350	12
Morocco	7,150	12
Mexico	8,250	9
Pakistan	8,500	5

[1] For re-export to other European countries.

Source: Commonwealth Secretariat (2001).

Table 12: Top selling medicinal plants in Europe[1].

PRODUCT	$ MILLION	PRODUCT	$ MILLION
Gingko	600	Butcher's broom	120
Valerian	300	Evening primrose	110
Horse chestnut	250	Pygeum	105
Saw palmetto	230	Melilot	100
Bitter orange extract	220	Grape seed	90
Garlic	200	Milk thistle	80
Hawthorn	140	Melissa	65
Ginseng	140	Nettle	60
Psyllium	125	Bilberry	60
Echinacea	120	Camomile	45
Total			$3.16 billion

[1] Other researchers include St. John's wort, black cohosh and vitex in the top ten list of herbs consumed in Europe. In 1999 sales of St. Johns wort exceeded $250m while vitex and black cohosh sales were each in excess of $100m.

Source: Commonwealth Secretariat (2001).

Table 13: Products expected to experience growth.

Black cohosh	Kola nut
Chaste tree berry	Korean ginseng
Devils claw	St. John's wort
Green tea	Tribulus
Hawthorn	

Source: Dyke and Primrose (2002).

OILS AND OLEORESINS

Essential oils are aromatic, or odorous, oily liquids (sometimes semi-liquid or solid) obtained from plant material, for example flowers, buds, seeds, leaves, twigs, bark, herbs, wood, fruits and roots. Oleoresins are liquid preparations, which are made by percolating a volatile solvent through a ground spice or herb.

Essential oils are used in the food industry as flavouring, the perfume industry for fragrances and the pharmaceutical industry for their functional properties. Oleoresins are also used in processed and canned food products.

Essential oils are the most highly flavoured part of many spices and herbs, and are probably the most important single category of flavouring substances currently available in the food industry.

Markets

Because essential oils and oleoresins are used in highly competitive industries such as cosmetics, food and pharmaceuticals, it is very difficult to get information on their overall demand.

Suppliers

No figures are available concerning production of essential oils and oleoresins in the European Union.

There are around 2,000 species from which essential oils are produced. Lavender and peppermint are among the most popular. Production is particularly successful in Mediterranean countries such as France, Italy, Spain and Turkey. Examples of the forest-derived plants that are used in the production of oils are given in Table 14, together with the country of origin. The main essential oils by source are also shown in Table 14.

Table 14: Source of main imported essential oils.

ESSENTIAL OIL	SOURCE
Orange	Brazil (68%), the Netherlands (10%), USA (6%)
Peppermint	USA (43%), India (13%), China (12%), Germany (12%)
Lemon	Italy (37%), Argentina (21%), USA (11%)
Lavender	France (65%), Austria (4%), Croatia (4%), Ukraine (4%), Italy (4%)
Lime	Mexico (37%), UK (15%, USA (12%), Germany (12%)
Bergamot	UK (42%), Italy (26%), France (10%)

Developing countries supplied 52% of total imports. Brazil is the dominant source and accounted for 40% of the total import of essential oils and oleoresins in 1997. The key product group is orange oil.

Conclusions

There is little or no potential for import substitution, as the main oils imported into Europe are orange, lemon, lime which are sourced from hot fruit growing countries. Furthermore, they come mainly from low-cost countries such as Brazil and Mexico.

WILD FOODS

Forests generate a number of wild edible products. Many organic consumers view ‘wild’ products as being the most organic products available. The close connection between products from an organic production system and ‘wild’ products suggests that a review of the organic food market will give an indication of the size of the wild foods market.

Markets

Organic food accounts for 2% of the European food market, and just over 1% in the US. In Austria and Denmark the market is estimated to be in the region of 10% of the total market.

Theorganic food market in Ireland in 1999 was in the region of €23 million. This represents about 0.4% of the retail value of total food consumption. Organic fruit and vegetables account for 40% of the market (Western Development Commission 2000). Key informants estimate that this market is growing at 25-30% per annum. In the UK demand for organic food is increasing at the rate of 40% annually whereas the actual supply is rising by 25%.

A strong feature of the EU market for organic food is the very high level (60–70%) of imports. Various forecasts predict that organic food will represent up to 7% of all food sales by 2006. Consequently, opportunities exist on the domestic and foreign market for organic produce.

Suppliers

Berries from Finland

Gathering wild forest food is extensively practised in Finland. Approximately 67% of the adult population in Finland pick wild berries, 45% pick mushrooms and 20% pick herbs.

Table 15 shows the estimates of the annual berry yields in Finland in poor and good crop years.

Lingonberry, crowberry and blueberry are the main species; the variation in yields between a poor and good year can be 100%.

It is estimated that the total production was 50 million kg of berries in 1997: 70% (35 million kg) of these were for own use, or domestic consumption, with the remainder (15 million kg) for commercial purposes (Table 16).

The harvesting season is relatively short, and runs from the middle of July for cloudberry and bilberry, to the end of September for cranberries.

Nearly 4 million kg wild berries are exported: the most important market for which is the jam industry. Another part of the market is the supply of berry juice concentrates to the juice industry; another outlet is consumer frozen and fresh berries supplied to wholesalers, retailers and market places.

Mushrooms harvesting in Finland

The two main wild mushrooms picked for commercial purposes in Finland are northern milk cap (*Lactarius rufus/trivialis*) and boletus (Table 17)

The collection of northern milk cap for commercial purposes was relatively stable in the period 1994 to 2000. In the period 1994-2000 the collection of boletus varied from a less than 100 tonnes at the beginning of the period, to very little in 1999 and then rose to 550 tonnes in 2000. Other mushrooms such as chanterelle are also picked but the volumes are relatively small at less than 20 tonnes per annum.

The value of wild mushrooms to the Finnish economy is estimated to be worth €100 million.

Mushroom harvesting in Scotland

Wild fungi are the most prominent woodland food in the UK. The main woodland species harvested in Scotland are chanterelle, cep, hedgehog mushroom,

Table 15: Estimates of berry growth in Finland in poor and good years.

BERRY	POOR YEAR	GOOD YEAR
	(MILLION KG)	
Lingonberry	200	500
Crowberry	150	250
Blueberry	150	200
Bog whortleberry	20	50
Rowanberry	10	50
Cloudberry	20	30
Cranberry	10	20
Raspberry	5	10
Juniper	0.1	0.2
Wild strawberry	0.1	0.3
Buckthorn	0.1	0.3
Arctic bramble	-	0.1
Black bearberry	-	0.1
Stone bramble	-	<0.1
Bearberry	-	<0.1
Total	565.3	1,111.2

Source: Salo (1994).

Table 16: Species and amounts of wild berries harvested in Finland.

	DOMESTIC	COMMERCIAL	TOTAL
	Millions kg per year		
Lingonberry	14 – 15	9 – 10	25
Bilberry	10 – 12	3 – 5	15
Cloudberry	5 – 7	1	6 – 8
Crowberry		1	1 – 2
Raspberries	2 – 4		2 – 4

Table 17: Wild mushrooms picked in Finland.

Mushroom	Tonnes/year
Northern milk cap	300
Boleteus	550

winter chanterelle, saffron milkcap and wood blewit. In addition to these wild fungi there are also mushrooms grown on a wood substrate. The main species cultivated is shiitake.

In some cases value is added to these mushrooms through drying, slicing and turning them into powder or preserving them in brine. These are sold direct to local restaurants and into markets in England and Europe. Distribution centres for the European market are based in Italy and France. The European market is also supplied from North America.

Hazelnuts from Turkey

Annual world hazelnut production is approximately 844,000 tonnes. Turkey is the largest producer accounting for approximately 75% of total production. It accounts for 80% of the world hazelnut trade and largely determines world export prices. Most (78%) of Turkish exports go to the EU. About 70% of exports comprise raw kernels with the remaining 30% being processed kernels, including roasted, sliced, chopped, paste, meal and flour.

Hazelnut production is one of the most important economic activities in the country, employing an estimated 385,000 growers. Most grow hazelnuts to supplement their income and own about 1 to 2.5 ha, using family labour at harvest time. Only a few large growers rely solely on hazelnut production as their primary income. There are approximately 536,000 ha in production.

Honey

World trade in natural honey is of the order of 300,000 tonnes, valued at US$ 300 million (FAO 1998). Russia, China, USA, Mexico and Turkey are the major producing countries. Germany, USA, UK and Japan are the major world markets.

Because of the predominance of conifer forests in Ireland there is, as yet, limited opportunity to develop a distinctive forest honey. However, leguminous species and others such as briars, holly, ivy and furze, often found near and in forested areas, are valuable sources of nectar and pollen. Increased open space in forests also offers opportunities for honey production.

Conclusions

There is limited potential for profitable production of berries because of lack of competitiveness with countries that have more favourable weather conditions and cheaper labour. Furthermore the opportunity is not attractive because of the low level of returns from harvesting wild berries.

There may be a niche opportunity for a small number of producers to harvest wild mushrooms and produce mushroom outdoors in a forest environment. The technology exists to produce exotic mushrooms that are to be found in the wild in countries like China, but the economics of doing so requires further research to establish if it would be cost competitive.

The dominance of Turkey of world hazelnut production combined with its aggressive marketing in light of overproduction suggests that it would be very unlikely for Ireland to develop a competitive industry for this product.

Ireland's erratic climate, preponderance of conifer forests and lack of labour cost competitiveness combine to constrain any potential for the production of honey from afforested areas.

Research Programme

There is need for ongoing market intelligence regarding trends in wild food products.

The research and development needs of edible NWFP have been identified as follows:

- Conduct a national survey of wild food (berries mushrooms and honey) producers in Ireland leading to the preparation of a database of all producers in Ireland;
- Prepare a wild food inventory indigenous to Ireland that identifies comparative advantages of particular areas of the country;
- Research related to the production techniques of growing wild mushrooms outdoors;
- Examine the feasibility of setting up a laboratory in Ireland to produce substrate for wild mushroom production;
- Investigate the trends in wild food products and
- Investigate the resilience of NWFP to harvesting pressures and on the full implications of the ecological roles played by these products.

Other recommendations

- Leaflets and point of sale material need to be developed to educate the consumers about wild food.
- There is need for ongoing education and training of pickers of wild berries in relation to market requirements and ways and means of improving quality.

FOREST GRAZING

Current policies do not allow for livestock grazing within a farm-forest plantation if the owner of the forest receives a forest premium payment. Livestock grazing within the forest could, in the past, be seen as double-funding, i.e. premium being paid to the owner for the afforestation and for the livestock. However, with the sinlge premium area-based system that has come into effect from 2005, forest grazing trails thoughout the world are worthy of note and show some potential.

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A Socio-Economic Assessment of the Contribution of the Irish Forestry Sector to the Irish and Regional Economies

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INTRODUCTION

The objectives of the study described in this paper were to evaluate the direct, indirect and induced economic contributions of the forest industry to the national and local economies. A further objective was to determine the social contribution of forestry to the local economies chosen. These local economies included Newmarket, Co Cork, Shillelagh, Co Wicklow, and Arigna, Co Roscommon. The paper presents the results of the economic analysis only.

HISTORY OF THE FORESTRY SECTOR

In the first half of the last century Government objectives for afforestation were to counter-act the depletion of the country's stock of softwood and to satisfy domestic timber requirements (Neeson 1991). In addition, the social function of forestry was emphasised, with forestry seen to play an important role in providing employment in remote rural areas in Ireland. The economics of forestry were not a major feature except in the 'narrow sense of ease of management from existing forest centres or the creation of the nucleus of new centres' (Durand 1969 p.251). With a change in government in 1958, emphasis was placed on economic issues and following this, the first review of the economics of Irish forestry was undertaken (Gray 1963).

A committee made up of representatives from the Department of Finance and the Forest Service examined the financial, economic and social implications of the afforestation programme in a cost-benefit analysis between 1972 and 1974. The economic analysis showed that the internal rate of return from growing wood ranged from 3.8% to 5.6% in real terms depending on assumptions as to future price trends. The study also assessed what the rate of return would be were social benefits included (i.e. job creation, secondary effects from the purchase of machinery etc) and concluded that the social rate of return arising from the afforestation programme ranged from 5.25% to 7.25%. In 1979, Convery (1979) undertook a comprehensive review of Irish forest policy, which included an economic analysis of forestry. One year later, the Forest and Wildlife Service carried out another review of the financial and social implications of a range of afforestation programmes and recommended a substantial afforestation programme. Estimates of the economic contribution of forestry have also been provided in a number of documents including '*Pathway to Progress: A programme for Forestry Research and Development*' where the gross forest output is given as £166 million (COFORD 1994). Similarly, the introduction to '*Growing for the Future, the Strategic Plan for the Development of the Forestry Sector in Ireland*', indicated that the value of total production of forestry in Ireland to be in the order of £90 million and added value was estimated to be £170 million (DAFF 1996). Clinch (1999) undertook a cost-benefit analysis of Irish forestry, which included a comprehensive analysis of the value of the non-timber benefits and costs of forestry. A cost-benefit analysis was also undertaken by Bacon and Associates (2003) to calculate the impact of the cutbacks to funding for forestry in 2003. In the aforementioned study both timber and non-timber values were considered, however, cost-benefit analysis does not allow the benefit or indeed costs of forestry to rural areas to be calculated. In addition, externalities were essentially considered in the report via the potential profit of trading CO_2 credits.

One technique that has been used to quantify the impact of one sector on national, regional and local economies is input-output analysis. Input-output analysis is a quantitative technique for studying the

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interdependence of production sectors in the economy (Ní Dhubháin *et al*. 1994). For example, Hurley *et al.* (1994) used input-output analysis to determine the economic impact of European Union grants for tourism in the Republic of Ireland. Similarly, Deane and Henry (1993) quantified the contribution of tourism to the economy of Ireland in 1990 and 1995 using input-output analysis. A more recent application of this technique was the development of an input-output model for the agri-food sector, which was used to analyse the economy-wide effects of changes in agricultural policy (Matthews and O'Toole 2000; O'Connor and Matthews 2001). Various studies have used input-output analysis in an attempt to evaluate the economic impact of forestry and forest-based industries on a national and a regional basis. For example, Ferguson (1972) estimated income and employment multipliers for the forest products industry in Australia. Alavalapati and Adamowicz (1999) used input-output analysis to determine the economic importance of forestry-related sectors in the provincial and north-western regional economy of Alberta, Canada. McGregor and McNicoll (1992) determined the impact of forestry on output in the UK and its member countries using input-output analysis. More recently, Munday and Roberts (2000) used similar analysis techniques to assess the economic contribution of the forest industry to the Welsh economy. In Ireland, input-output analysis was used to determine the economic impact of forestry on the economy of the west of Ireland (Ní Dhubháin *et al*. 1994). Crowley *et al*. (2001) also used input-output techniques in the investigation of the economic impacts of forestry at sub-regional level. Most recently, Moloney (2002) studied the impact of proposed cutbacks in forestry funding in Ireland. He used input-output analysis and the multipliers he generated were used in the Bacon and Associates report.

It is clear that a number of studies of the economic impact of forestry on the Irish economy have already been conducted. However, given the variety of methodological approaches that have been used, it has been difficult to make meaningful and ongoing comparisons over time. Regular estimates of this impact are required as the forest estate in Ireland is still at a relatively juvenile stage with over 50% of forest stands only half way through their first rotation. The economic impact will change as this estate develops. Furthermore, given that the forestry sector has many linkages with other industries, it is important that the full socio-economic contribution of the sector is quantified. This requires a methodological approach, which is transparent, replicable and sufficiently comprehensive in scope to allow for regular and consistent evaluation of the sector's performance. This methodological approach should be capable of assessing both direct, indirect and induced economic impacts. The input-output techniques that are to be used in this study are highly suitable in this regard.

While much work on quantifying the economic impacts of forestry has been undertaken in Ireland, this has not been the case for social impacts. The bulk of the work on social impacts has concerned the social implications of forestry with regards to farming and on farmers' attitudes to forestry (e.g. Collier *et al*. 2003; Kearney 1999, 2002; Ní Dhubháin *et al*. 1994). Kearney (2001) gives a summary of those studies. However, until recently few studies on the social impacts of forestry expanded beyond the farming sector in order to encompass the views of local communities. Those that have been conducted have relied on public surveys to evaluate the public perception of forestry at regional/local level. For example, Kearney and O'Connor (1993) examined the impacts of forestry on two local communities. Those communities expressed very dissimilar views of forestry with their views correlated with the level of employment in forestry in the community. Recently O'Leary *et al*. (2002) looked at the perception of two strongly contrasting populations (i.e. in Wicklow and Leitrim) with regards to afforestation in Ireland. The survey showed opposing views between the two populations with the population living in the area where forests have been a traditional feature of the landscape expressing more positive views. More recently an EU funded study, MULTIFOR RD, (Elands and Wiersum 2003) examined the potential role of forestry in rural areas in nine countries in Europe, including Ireland. The methodology involved in-depth interviews with a range of respondents representative of the rural communities. Despite regional variations, the study revealed that people were generally positively inclined towards forestry but that they perceive it as a natural and recreational feature rather than as an economic sector. These studies indicate the importance of socio-economic aspects of the forest sector in Ireland. However, more often than not social impacts are overlooked and are limited to the use of economic and employment indicators in order to evaluate community benefits. As long as forestry is essentially a mono-functional system with timber as the main output conventional economic methods are the most relevant. However, forestry has increasingly become a part of the landscape and a source of recreation instead of just a source of roundwood for industrial use (Hyttinen *et al*. 2002). Also it should be borne in mind that afforestation programmes are mainly aimed at reducing surplus agricultural production within the CAP reform and enhancing the economic quality of life in rural areas. In this context there is a greater need to investigate benefits not only in terms of economic values but also to consider how local communities interpret the meaning of rural quality, how they conceive the desired future of their area and how they perceive forestry as part of their social and physical environment (Elands and Wiersum 2001).

METHODOLOGY

This section outlines the objectives of the project and methodologies used in the research. The first section outlines the methodologies used in the economic analysis and the second section places emphasis on the sociological impacts.

The objectives of this research project are:

- To evaluate the direct economic contribution of forestry to the Irish economy;
- To evaluate the indirect economic contribution of forestry to the Irish economy;
- To analyse the opportunity costs for the forestry sector with regard to alternative land-uses;
- To review the social implications and the implications for sustainable development of the findings from the points above;
- To evaluate the economic contribution of forestry to the rural economy and sustainable development in Ireland;
- To evaluate the social contribution of forestry to the rural economy and sustainable development in Ireland;
- To investigate the factors that influence the economic and social contribution of forestry to rural development;
- To develop social indicators of sustainable forest management.

Economic Analysis

Contribution of forestry to the national economy

The method used to quantify the economic contribution of forestry to the national economy is input-output analysis. This method is similar to that used by Munday and Roberts (2000) in their investigation of the economic contribution of forestry to the Welsh economy. Input-output analysis is a widely applied quantitative technique developed in the first half of the 20th century. The input-output technique is based on the work of the Nobel Prize winning economist Wassily Leontief. Since the 1950's it has been used in many countries both as a way of analysing different sectors of an economy and as a technique in policy formulation.

Input-output tables have been available and in use in Ireland since 1960. The Central Statistics Office (CSO) has published six tables since 1964. These tables have all been constructed for Ireland as a whole. A seventh table based on the year 1998 is currently being prepared and is due to be published soon.

As stated above, the most recent CSO published input-output table for Ireland is for the year 1993. Given that a more up-to-date year to 1993 is required an input-output table for 1998 was constructed. This required a large amount of data collection and manipulation. The construction of the table involved using sectoral national account data and labour force data supplied by the CSO and other preliminary data for 1998. The CSO provided detailed advice on the work carried out. It is expected that when the 1998 CSO table (publication expected in Autumn 2004) is published only minor adjustments will be required. The input-output table for 1998 has 56 sectors based on the NACE-CLIO Classification (European Union 1990, A60:289). The construction and balancing of the tables and the calculation of the various multipliers was carried out using PyIO input-output software (Nazara *et al*. 2003). A full description of the software is published as a REAL Discussion Paper 03-T-23.

The linkages between the forestry sector and other sectors in the economy are investigated using the 1998 input-output table constructed for the project. The following economic impacts are being evaluated:

(i) The Direct Contribution of Forestry:

The direct contributions to a region or country represent the impact of the spending by the

Forestry Sector on goods and services produced in Ireland.

(ii) The Indirect Contribution of Forestry:

Indirect contributions are those that occur when local suppliers to businesses in receipt of expenditure in turn purchase goods and services to meet demand.

(iii) The Induced Contribution of Forestry:

Induced contributions refer to the additional consumer expenditure that takes place when the income generated from the direct and indirect contributions is in turn spent.

The sum of the direct, indirect and induced contributions, described above, represents the overall contribution of forestry. These contributions are expressed in terms of multipliers for expenditure (i.e. purchases of inputs) and employment. The total contribution of the Forestry Sector can thus be expressed in terms of money and jobs. Once the absolute contributions are estimated the direct, indirect and induced multipliers are obtained. From these multipliers two other multipliers are calculated: Type 1 multipliers reflecting the direct and indirect impact and Type 2 multipliers which represent the induced impact in addition to the direct and indirect impacts. The Type 2 multiplier indicates the overall impact of expenditure on the region or country.

The work described above was carried out on national data and from this analysis the contribution of forestry to the national economy was derived. Alongside this work, a survey of those involved in the forest industry in Ireland including Coillte, forest nursery owners, forestry contractors, management companies and sawmill owners was conducted. In this survey, data on employment in the firms surveyed, purchases by the firms as well as output from the firms was gathered. These data will be used to subdivide the forestry sector into the following subsectors: establishment; maintenance and harvesting. This will not only allow multipliers for the subsectors to be generated but will also allow the nature and magnitude of forward linkages to processing to be quantified.

Contribution of forestry to local economies

One of the key objectives of the project was to quantify the impact of forestry in a number of local economies. Each local economy or case study area was defined as the area within a 20 mile radius of the centre of the case study (i.e. 1,256 square miles/3,254 km^2). The areas chosen for study were as follows:

a) Shillelagh, Co Wicklow - an area comprising a normal forest producing a sustainable yield and with an extensive forest infrastructure (i.e. nurseries, sawmills, etc.).

b) Arigna, Co Roscommon - an area with a middle-aged forest cover, which has the potential to sustain infrastructure in time. This area has experienced very strong opposition to forestry in the past and resistance is still present.

c) Newmarket, Co Cork - an area with a young forest cover in which the area of forest is likely to increase. Local community groups have opposed recent afforestation development.

To quantify the economic impact of forestry in these case study areas, regional input-output models were generated. The national 1998 input-output table referred to above was disaggregated to produce three regional tables for the South West, West and South East according to the methods outlined by Moloney and O'Sullivan (2003). These were used to represent the three case study areas as this is the lowest economic unit for which viable input-output tables could be constructed. Multipliers were calculated for the region in which the case study area was situated. Those involved in the forest industry in the three case study areas were also surveyed to obtain data on employment, inputs and outputs which will be used to improve the regional models.

Sociological Analysis

A key element of the project was to determine the social impacts of forestry in the three case study areas and to use the data collected to derive social indicators of sustainable forest management. The three case study areas were chosen to illustrate the variation in forest area, forest industry and anticipated public perception of forestry across the country. Within each of the areas both quantitative and qualitative data were collected.

Socio-demographic and forest profile

Information on demography, employment and forest resources for each case study area was collected from CSO reports. Forest data were obtained from the Forest Service and Coillte. Other sources of information available locally were also consulted (i.e. local libraries, county publications, etc.). Table 1 gives a detailed account of the data gathered for each case study.

The data compiled provided a socio-demographic profile for each case study area. Additional information on the history and culture of the area was also added.

Qualitative data were collected using semi-structured interviews with stakeholders. In order to reflect the variety of opinions and concerns stakeholders were divided into three categories:

1. Producers are defined as people deriving their incomes from the land (i.e. farmers and foresters);
2. Consumers are defined as local community members (i.e. those not deriving their income from land use) and visitors ;
3. Decision makers are actors involved in public policy, lobbying, community groups, etc.

In total between 30 and 40 persons were interviewed in each case study area with about one third in each stakeholder category. The identification of individuals for each category was initially done by using key informants (i.e. Teagasc, County Board and Councils and locally based rural development organisations). This initial group of respondents then guided the interviewer to further contacts – a process known as the 'snowball effect'. An *aide-mémoire* was used to conduct the interview but the discourse was essentially a co-construction between the interviewer and the interviewee. The interview guide aimed at covering the objectives of the research and aimed to cover the following issues:

- What is the perception of the person vis-à-vis the rural environment she/he lives in?
- What role(s) forestry plays in the rural environment ?
- How can this role be optimised and reinforced?

Interviews were analysed using a framework known as 'grounded theory'. Grounded theory has been defined as a theory that is derived from data systematically gathered and analysed through the research process. In this method data collection, analysis and eventually theory are closely related to one another (Strauss and Cobin 1998). The key process in grounded theory is to break down the data into categories that are given a name or label. These categories form an index that records the recurrent subjects and themes in each interview. As further interviews are analysed the index is re-used and enriched with each new theme the reader comes across. Ultimately the main themes and issues identified during the process will be used to derive indicators.

Table 1: Data collected at case study level.

Socio-economic and forest variables
Population figures for the period 1946 to 2002
Population density (persons/km^2)
Share of employment in primary and secondary production and services
Evolution of employment over the period 1980-2002
Proportion of total area farmed
Proportion of total area under forest
Evolution of the public forest estate for period 1920-2002
Evolution of the private forest estate for period 1982-2002
Data on the public estate relating to age-class, species, elevation and soil types
Direct employment figures related to the forest and timber industry

CONTRIBUTION OF FORESTRY TO THE IRISH ECONOMY

This section presents output and employment multipliers for the forestry sector. The base year for the analysis is 1998. The direct, indirect and induced impacts of forestry are reported. The multipliers are applied to data for the year 2003.

Economic Contribution

Based on the values shown in the input-output table for 1998 constructed for this study, Table 2 reproduces the expenditure patterns of the forestry sector of the Irish economy for 1998. The sector has strong linkages to the domestic economy. Intermediate purchases account for 36.7% of all expenditure and imports account for only 25.7% of total expenditure. Wages and salaries make up 27.2%

of expenditure. This latter value may be understated as this sector subcontracts much of its harvesting to small operators.

Estimates of the direct, indirect and induced impacts of forestry on the Irish economy are reported in Table 3. Estimates of the national impact of forestry in terms of expenditure and employment are provided. In 1998, €96.76mn was the total direct output in the forestry sector. When the other impacts are taken into account, the overall value of forestry to the Irish economy was €196.42mn. In 2003 total expenditure was estimated to be €165.00mn. When the overall multiplier impacts are taken into account the contribution of the forestry sector is €334.95mn for that year. While there is increasing output in the sector, employment has remained broadly unchanged. This reflects the increasing labour productivity in the sector.

The employment figures are based on the Quarterly Household Survey results supplied by the CSO for the Forestry sector as they define it. This description is narrow and the final report will include estimates of other direct employment in forestry not included in the current definition. Thus the employment figures reported here should be viewed as minimum levels but the employment multipliers calculated are likely to be of similar magnitudes in the final report.

Table 4 reports results for each of the three regions targeted for study in this paper. The results are in line with the results at national level. As expected the multipliers are of lower magnitudes reflecting greater leakages at a regional level. It can be seen clearly that there are sizeable indirect and induced impacts at both national and regional levels. These results do not include up stream impacts such as sawmills, board mills, etc. If these areas are added in, the overall impact of the sector is much greater. These further impacts will be estimated at a later stage.

CONCLUSIONS

The study has calculated the economic contributions of the forestry industry to the national and selected regional economies. A description of the economic structure of the industry is provided. Various multipliers are calculated and analysed. Using these multipliers the total contribution of the sector to the economy are presented for the year 2003.

Table 2: Direct Expenditure (€ millions –1998) and Employment (Units) by Sector.

	Expenditure	% of Total Spend
Total Intermediate Inputs	35.51	36.7
Wages and Salaries	26.34	27.2
Profits	17.36	17.9
Net Other Domestic Inputs	-7.34	-7.3
Total Domestic Inputs	71.87	74.2
Imports	24.89	25.7
Total Supply	96.76	100.0
Employment	2300	-----

Table 3: Expenditure and Employment Impacts of Forestry for the Year 1998.

OUTPUT					
	Direct	Indirect	Induced	Type 1	Type 2
€ millions	96.76	36.77	62.89	133.53	196.42
Multi-pliers	1.00	0.38	0.65	1.38	2.03
EMPLOYMENT					
	Direct	Indirect	Induced	Type 1	Type 2
FTEs units	2300	575	920	2875	3795
Multi-pliers	1.00	0.35	0.56	1.35	1.91

Overall, the results in this paper should be viewed as preliminary. Further research is necessary to enhance our understanding of the forestry sector. To do this the industry will be subdivided into a number of subsectors including establishment, maintenance and harvesting. The nature and magnitude of forward linkages to processing will be quantified. The current estimates of the economic contribution of the Forestry sector should be viewed as minimum values.

When the analysis of sociological data is complete these will be used to supplement the economic results so as to provide a realistic picture of the socio-economic impacts of forestry in the selected areas.

Table 4: Expenditure and Employment Impacts of Forestry for the Year 1998 by Region.

South West					
Expenditure					
	Direct	**Indirect**	**Induced**	**Type 1**	**Type 2**
€ millions	12.62	2.52	4.04	15.14	19.18
Multipliers	1.00	0.20	0.32	1.20	1.52
Employment					
	Direct	**Indirect**	**Induced**	**Type 1**	**Type 2**
FTEs units	300	54	66	354	420
Multipliers	1.00	0.18	0.22	1.18	1.40
West					
Expenditure					
	Direct	**Indirect**	**Induced**	**Type 1**	**Type 2**
€ millions	21.03	3.58	5.68	24.61	30.29
Multipliers	1.00	0.17	0.27	1.17	1.44
Employment					
	Direct	**Indirect**	**Induced**	**Type 1**	**Type 2**
FTEs units	500	80	90	580	670
Multipliers	1.00	0.16	0.18	1.16	1.34
South East					
Expenditure					
	Direct	**Indirect**	**Induced**	**Type 1**	**Type 2**
€ millions	16.83	3.54	5.89	20.37	26.26
Multipliers	1.00	0.21	0.35	1.21	1.56
Employment					
	Direct	**Indirect**	**Induced**	**Type 1**	**Type 2**
FTEs units	400	80	92	480	572
Multipliers	1.00	0.20	0.23	1.20	1.43

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