Environment Issue

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(b) Indoor and field meetings on forestry topics
(c) Production of two issues annually of Society's journal "Irish Forestry"

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IRISH FORESTRY

Special Issue
Forestry and the Environment

Guest Editor: E. P. Farrell

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1942-1992

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Editorial

It's nothing new to say we must take care of the environment. We know about the dependence of living organisms on their physical surroundings and on each other. We know too, about conservation and the demands of modern society to preserve for posterity something of the "old", the "beautiful" and the "natural", however these may be defined. As foresters too, we understood the principals of sustainable development, although we called it something else, long before the current term came into vogue. The vital importance of conserving the productive capacity of the site has been recognised for as long as there have been professional forest managers.

In this country, our predecessors were faced with an enormous challenge, the task of restoring a lost forest resource. For most of this century, foresters have been preoccupied with the establishment of productive forest plantations. They have approached this task with single-minded dedication and they have been very successful.

The ecosystems created as a result of their efforts are very obvious on the landscape. At first, they were regarded as marks of progress. Today however, their presence is viewed by many with a mixture of distaste and concern. Coniferous monoculture is seen as ugly, it transfers atmospheric pollution to the soil and to freshwater bodies, afforestation results in the destruction of precious remnants of our ecological history. Foresters are left confused, uncertain how to proceed. While we understand, for the most part, the management of forests for timber production, we lack knowledge of the environmental consequences of those management decisions.

In this Special Issue of Irish Forestry, we bring together papers on the interaction of forestry and the wider environment. These are the results of research into issues of importance for forestry in Ireland today. However, the coverage is not comprehensive, the results are often tentative and incomplete. These papers represent but one step on the path to improving our knowledge of ecosystem processes in our forests. Much more work is needed.

Investment in research in forestry in this country has been woefully inadequate and despite the major increase in afforestation, it has in recent years, actually declined. The establishment of COFORD is a welcome development, but without adequate financial support, it can achieve nothing. To be effective, forestry research today requires well-organised interdisciplinary teams, working on specific, clearly defined projects with adequate funding and with the certainty of sustained support for the duration of the project. Substantial funds must be committed to research if a truly sustainable forestry enterprise is to be established in this country.

EC support has been helpful in recent years, but funding awarded through competitive research programmes, on the basis of priorities established in Brussels for the whole Community, are no substitute for a national research programme, tailored to the specific, current needs of forestry in this country. This is the kind of support that is needed if the work reported here is to be extended and developed to provide the scientific basis upon which our forest managers can build a sustainable forest resource compatible with the economic, environmental and aesthetic demands of society.

E .P. Farrell

Classification of Landscape Sensitivity for Visual Impact Assessment of Forestry

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Summary

The landscape issue of greatest overall significance in Ireland at present is forestry. Large scale forestry development is increasing due to recent reduction in the viability of conventional agriculture. With growing emphasis upon leisure pursuits as well as on environmental quality, forestry is no longer regarded as a purely commercial enterprise, but also as an amenity, both inherently and visually in the landscape.

Relatively little serious research is being carried out on the visual impact of forestry upon the landscape, yet this impact is increasingly being recognised as critical, particularly as forestry is often located in visually sensitive mountain regions. With growing public sensitivity to the integrity of the rural landscape and tightening of control of development by county planning authorities, a systematic and thorough procedure must be developed for the assessment of this impact. As the scope of forestry expands to include amenity development, such assessment will become more critical. The positive development of forestry, especially in visually sensitive areas, will require long term planning and will likely have to conform to an overall land use and landscape policy which indicates the extent and type of forestry acceptable.

In order to determine which landscapes require strict control with respect to visual impact, it is necessary to first establish the visual sensitivity of the landscape. Visual sensitivity levels determine whether or not forestry development in a particular landscape is acceptable and are established by examining the following: landscape susceptibility, key viewpoint distance, landscape quality, aesthetic experience. Assuming that forestry is acceptable, a forest design is next produced, followed by the production of visual simulation. Visual impact assessment (VIA) is finally carried out on the site from key viewpoints based upon the visual simulation facilitating systematic assessment of the aesthetic relationship of forestry to the landscape.

Introduction

The landscape issue of greatest overall significance in Ireland at present is forestry. Timber volumes from coniferous plantations are increasing rapidly and will reach 4.4 million cubic metres by the year 2010, which is seven times more than what it was 30 years ago (Carbonnier, 1990). In addition, support for agriculture is declining due to the CAP reform, and forestry development, by removing land from primary food production, is seen as particularly relevant to the EC's problem of surplus of agricultural products (Conway, 1990). Due to the imminence of transition from small mixed farming activity to forestry, there is growing concern about the environmental consequences (Farrell, 1990). Research is currently being carried out at University College Dublin (UCD) in conjunction with other bodies in the EC on edaphic and ecological impacts of forestry as well as socio-economic impacts. One of the most critical impacts, but receiving relatively little attention in terms of serious research, is that of the visual impact of forestry, whether in isolation or integrated with amenity. The visual transformation of landscape character by forestry from planting through thinning to harvesting can be enormous and is one of the first impacts to be immediately and directly experienced, especially by the public.

Changing Attitudes Towards Forestry

The objective to maximise timber yields has resulted in forestry being carried out primarily on pragmatic grounds. Plantation design has conventionally been determined by practical considerations such as soils, drainage, elevation, aspect, access and gradient. Until recently forestry has been practised with little or no cognisance being taken of the ultimate visual impact on the surrounding landscape. While a plantation can be regarded simply as another crop in the landscape, clearly it is distinguished by both the duration of its existence and its three dimensional character, and thus has considerable visual implications in the long term. If, therefore, the forest designer is asked to step back and view the site in the context of the surrounding landscape, taking into serious consideration the visual implications of, for example, existing landform, vegetation, structures and amenities, the original design is likely to be affected.

Gradually forestry is no longer being regarded purely as a commercial crop but also as a visual and recreational amenity. This shift in attitude can be attributed to factors including increasing public sensitivity to the integrity of the rural landscape as a whole and tightening of control of developments in the landscape by county planning authorities, including the likely future emergence of a national landuse policy with incentives for the conservation of rural landscape, as are provided in Britain.

Public Concern

The public often perceives commercial coniferous plantations, particularly in scenically attractive mountainous regions, as a monotonous and visually dominating land cover or as an accumulation of scattered postage stamp plots disrupting the flow and destroying the traditional character of the landscape. Such public perception is all too often validly founded upon the prevalence of banal coniferous plantations comprising homogenous colour and texture and where overall plantation form is geometric and in visual conflict with the natural contour. The perception of forestry as an amenity, both visual and recreational, arises due to the increasing consciousness among an expanding urban population of the quality and integrity of the rural environment and also increased leisure time and demands for accessible rustic amenity. The outcry against commercial plantations does not come only from the urban population concerned about the conservation of the rural landscape and its preservation for visual and physical amenity, but also from the farming community which can regard forestry as a land grabbing" activity. The emotive response that forestry illicits from people, whether latent or explicit, positive or negative, cannot be ignored when planning plantations.

Planning Guidelines and Legislation

Planning authorities in Ireland are attempting to constructively control development in order to safeguard the integrity of the rural landscape. This is being helped by the recent regulations incorporating the environmental impact assessment (EIA) process as outlined in EC Directive 85/337 which have been incorporated into the Irish planning code. Procedural regulations are contained in S.I. No. 25 of 1990 and the 200ha. threshold under which primary afforestation requires EIA is set by S.I. No. 349 of 1989. The majority of afforestation proposals are, however, small enough not to require an EIA. Nevertheless, the positive development of forestry on a broad scale throughout the landscape, especially in visually sensitive areas, will in the future likely require long term planning of land use and include an overall land use and landscape aesthetics policy.

A national landuse policy, an objective of which should be to ensure that specific developments are appropriate, would incorporate aesthetic controls based upon visual sensitivity levels and would indicate the extent and nature of development suitable for each area. Visual sensitivity levels can be determined by examining landscape susceptibility, key viewpoint distance, landscape quality and aesthetic experience. Sensitivity levels can establish the degree of visual sensitivity, indicating whether forestry is acceptable, and if so, whether the site is located in a sufficiently sensitive landscape as to require a visual impact assessment (VIA) as part of a submission for approval to granting bodies such as the Forest Service or to the Planning Authorities.

Assuming that the assessment of a particular landscape for visual sensitivity indicates that forestry is acceptable in a visually sensitive area, a design is then produced. The design should be informed by the understanding previously gained of the site and context during the process of analysis for the establishment of sensitivity level. The design should then be visually simulated in order to undergo a systematic VIA. Such assessment forms a vital part of any EIA and would be particularly important for forestry in the landscape. The VIA process is most useful as a means of identifying weaknesses in the design and for further refinement. Large scale forestry in any scenically sensitive area would particularly benefit from a detailed VIA.

Research on VIA and Design of Forestry

While criteria for the design of forests and the aesthetic judgement of existing forests abounds, relatively little has been published which provides detailed methodologies for the VIA of forests. Publicly available literature, such as in the *Forestry and the Landscape Guidelines* booklet by the Irish Forest Service (For. Serv. 1992), *Forest Landscape Design Guidelines* booklet by the Forestry Commission (For. Com. 1989) and *The Design of Forest Landscapes* written by O. W. R. Lucas (Lucas, 1991), focus upon design criteria rather than the visual sensitivity of landscape with regard to forestry and VIA of forestry proposals. One of the earliest publications to explore forest landscape visual analysis was *Forest Landscape and Inventories – A basis for Land Planning and Design* by R. B. Litton (Litton 1968). Much of this work, such as visibility of landscape with regard to distance and angle of view, continues to be used as a reference in more recent literature. *The Forest Landscape Handbook* by the Recreational Management Board of the Ministry of Forestry, British Columbia (Min. For., 1981) does formulate a guideline for the establishment of visual sensitivity levels. The procedure followed in the guideline is similar to that followed in an earlier case study on the forests of Victoria, Australia (Williamson and Calder, 1979). Both pursue a procedure comparable to that used for VIA in general (Yeomens, 1986). The procedure outlined below incorporates the findings of this research and is intended to serve as an indication of the kind of considerations necessary in VIA.

Visual Sensitivity Levels

While the need for embracing factors other than the purely pragmatic in the planning of forestry is by now clear, the question must be asked whether all landscapes require the same level of control and attention to aesthetic design. Not all sites would necessitate detailed assessment, but those in visually sensitive areas may while yet others in very sensitive areas, perhaps, should not be planted at all. Three possible categories of landscape are listed below, including a suggestion of the official documentary requirements for a proposal presented for approval:

- In areas of very high visual sensitivity afforestation would not be acceptable. It is envisaged that this category would obtain for relatively few sites.
- In areas of high visual sensitivity afforestation would be acceptable subject to submission of a VIA to the planning authorities and Forest Service. It is envisaged that this would pertain to the majority of

scenically attractive sites, especially in upland or mountain regions in high demand for amenity. The VIA should include a systematic analysis of, for example, layout, ride lines, roads, fire breaks, felling coups and replanting patterns on a phased basis, covering the forthcoming 150 years where relevant. All of this should be presented in plan and also visually simulated as a three dimensional representation.

- In areas of moderate and low visual sensitivity afforestation would be acceptable subject to submission of detailed proposals to the planning authorities and Forest Service. These proposals would include, for example, layout, ride lines, roads, fire breaks, felling coups and replanting patterns on a phased basis covering the forthcoming 150 years, where relevant. This would pertain to flat landscape of relatively low population and with low demand for amenity.

In order to determine to which of the above categories a site might belong, it is necessary to first establish the visual sensitivity level of the landscape in question. Some landscapes are in scenically attractive areas with high user numbers and close to urban areas or heavily used roads, others are also scenically attractive but remote and relatively inaccessible, while yet others are not visually sensitive. Four variables in the establishment of visual sensitivity levels are identified, namely landscape susceptibility, key viewpoint distance, landscape quality and aesthetic experience (Williamson and Calder, 1979). The results of the analysis under each of these variables are combined in a matrix to establish the visual sensitivity level.

In analysing the landscape for visual sensitivity a thorough understanding of the visual integrity of the site and its context is obtained which will prove useful in both producing the forest design and also assessing that design. For example, appropriate response to such features as rocky crags, water bodies or adjacent hedgerows will likely become clear while examining the landscape under the four variables listed.

Landscape Susceptibility

Each area of landscape is subject to particular demands by the public, reflecting its function, location and character. Depending, for example, upon the intensity of use of an area and public interest in, or attitude towards, the landscape, the site for proposed forestry development may be classified in one of three susceptibility levels, high, moderate or low (Alonso, Aguilo and Ramos, 1986). A site such as Glendalough, for example, would experience both high intensity of use and high public interest, resulting from it's proximity to Dublin as well as it's cultural significance. Clonmacnoise, however, a site of comparable cultural significance, experiences a relatively low intensity of use due to the remote location of the site from any large centres of population or major travel routes. For the purpose of analysis of intensity and nature of use much data is provided by O.S. and road maps, but the analysis should be substantiated by ground investigation.

Key Viewpoint Distance

Specific points in the landscape where the public gathers or moves should be identified from the analysis of user intensity levels. For example, a site may be viewed from places of amenity such as golf courses, centres of population, such as towns or villages, or busy thoroughfares, such as commuter roads or waterways used for amenity. Such points are called key viewpoints and the closer they are to the landscape under analysis the higher the sensitivity level. The distance of each key viewpoint to this landscape is measured and assigned to one of three categories, namely foreground, middleground or background.

Landscape Quality

The aesthetic quality of the landscape is determined by examining the physical components, comprising landform (including water), vegetation and structures. The aesthetic quality of each of these physical components must be systematically assessed and quantitatively rated. The criteria identified for high physical landscape quality includes (Williamson and Calder, 1979; Steinitz, 1990):

- prevalence of semi-wild land such as moors and heaths, along with agricultural land with minimum evidence of population or structures;
- presence of water;
- vistas providing opportunity to view distant landscapes;
- high relief and rugged landscapes, such as hills and mountains;
- diverse and well maintained vegetation distribution in the foreground and middleground.

Following this assessment carried out from each key viewpoint, the landscape can be assigned to one of three landscape quality categories, high, moderate or low.

Aesthetic Experience

Research identifies not only the physical or bio-physical landscape as being central in landscape assessment, but also the aesthetic experience of the user, including how he/she is affected emotionally and psychologically by the landscape and the cultural meaning which is embodied in the site and its context. (Bourassa, 1988; Schauman, 1988; Lamb and Purcell, 1990; Lange, 1990). Assessment of aesthetic experience provides a significant basis in understanding aesthetic value which any landscape has for the user, and thus indicates the degree of sensitivity. While the aesthetic experience of the site is derived from the physical landscape, the assessment of this experience is less tangible than the assessment of that landscape. In order to determine the emotional and cultural components of aesthetic experience such factors as intrigue, fascination, delight, enchantment, awe and symbolic content must be systematically assessed and quantitatively rated. These various factors are encapsulated by the 'spirit of place' or *genius loci.* The cumulative score for these factors can then be allocated to one of three categories of aesthetic experience, high, medium or low.

Forest Design

Assuming that the visual sensitivity levels for a given landscape establishes forestry development as acceptable, the next step is to produce a design for the forest. While it is not the main intention of this article to produce detailed design guidelines, some fundamental considerations will be discussed briefly.

Forest design should be carried out with the aim to create aesthetic harmony and balance and ensure not only a positive relationship to, and effect upon, the immediate landscape, but also a visual enhancement of the surrounding environment. Well designed forestry becomes a visual amenity, a particularly critical necessity in visually sensitive areas.

In designing for a particular landscape, advantage should be taken of the insight provided during the analysis for the establishment of visual sensitivity. While the design should be informed by these specific details, some general objectives are listed below:

- Production of a design which responds appropriately to topography.
- Creation of forestry so shaped as to appear harmoniously integrated with adjacent woodlands, hedgerows and field patterns.
- Designing appropriately in relation to adjacent structures, such as farm buildings and roads.
- Holding an ecologically credible yet economically practical balance between disposition and configuration of coniferous stands and indigenous deciduous species and hedgerows.
- Amelioration of the visual impact of straight lines and geometric patterns, such as roads, tracks, and boundaries, by breaking continuity or screening.
- Working within the limits of existing forest compartments (ownership boundaries) in order to modify existing rectilinear plantations through re-structuring at thinning stage. An existing plantation can be modified to improve integration with its surrounds, achieve the appearance of natural harmony, improve amenity value and increase ecological diversity.

Design of forest landscapes can be executed using three scales of aesthetic relationship of internal aesthetics, aesthetics of local relationships and aesthetics of broadscale relationships outlined below. The proposal, in principle, is judged in terms of the visual integrity of the landscape and whether the development enhances or detracts from it.

- Internal aesthetics covers the visual integrity and spatial interrelationships of not only the forest but also possible associated amenity development, eg. clearings, blocks, roads and vistas.
- Aesthetics of local relationship is concerned with the relationship between the forest development and its immediate surrounds, eg. edge conditions and access points.
- Aesthetics of broadscale relationships is concerned with the effects the proposed development has on the surrounding landscape as a whole, eg. the mass of forestry in the landscape as viewed from a distance.

Visual Simulation of Proposals

In the event that the establishment of visual sensitivity levels indicate that a VIA of the forestry proposals is required, once the design is created, the next step is to produce a visual simulation. Such simulations should depict the development in three-dimensions from each key viewpoint at various stages of the forest rotations. Visual simulations of forestry proposals succinctly annotated can prove to be of great value in regard to design, as they facilitate both planning and granting authorities in visualising the changes in the landscape resulting from a proposed development relative to existing conditions. Thus, the submission for approval to relevant authorities should include depiction of the site prior to planting and simulation of the site at such stages as planting, thinning, semi-mature, felling and replanting. Accurate simulation should be the objective, and this is especially critical where proposals are contentious and are being subjected to a tribunal.

Traditional techniques of visual simulation of proposals comprised the artist's impression, often using photographs of the existing site as a basis for comparison between existing conditions and proposed. Alternatively, such photographs have been used for the creation of a photomontage whereby layers of coloured drawings depicting the proposed development are physically stuck on to the photographs. Such manual techniques cannot be relied upon for accuracy and have thus been superseded by computer graphic simulation which can provide far greater accuracy. Ideally, visual simulation should satisfy two criteria of accuracy, namely visual accuracy and physical accuracy.

Visual Accuracy

Visual accuracy involves the photorealistic depiction of a development in context such that the simulated image is both credible and legible, especially to non-professionals. Details of, for example, vegetation, fencing and roadways, both existing and proposed, are depicted in colour with photograph-like definition. Photographs taken from key viewpoints depicting existing site conditions are scanned into a computer. Simulation is achieved by using computer "painting tools" in combination with the manipulation of elements of landscape from the same or other photographs scanned into the computer.

Physical Accuracy

Physical accuracy is concerned with measurement and the precise location of objects in three dimensional space. Such simulations can withstand scrutiny during tribunals. They can also provide a reliable basis for on site implementation of forest design, particularly where the forestry layout, rather than being determined by existing rectilinear field boundaries, is more fluid in response to landscape contour. The physical accuracy results from the use of OS maps with contours. These maps are digitised into a computer, including elevation data, in order to produce a vector or line drawing representing the landscape, otherwise know as a digital terrain model (DTM). The particular advantage in terms of accuracy of simulation is the ability to identify any point in space three dimensionally with respect to OS data and the National Grid.

Combining Image and Vector Based Data

Photorealistic images, while visually accurate, cannot be relied upon for physical accuracy as no method of measurement is inherent. DTM's are physically accurate but provide minimal information on detail such as ground cover and none on colour or texture. The combination, however, of both image and DTM is possible and overcomes their respective shortcomings, producing a visual simulation which is both visually and physically accurate.

Visual Impact Assessment

The assessment of the visual impact of the proposed forestry development comprises the examination of the aesthetic relationship of the forestry proposal to the landscape based upon the visual simulations produced. The proposed forestry development is systematically examined from each key viewpoint, the amount of detail visible being a function of viewing distance. Each of the following criteria are used to systematically determine if the proposed design is deemed to be acceptable or not acceptable:

- *Colour*
  Colour is concerned with the relationship of the forest to the surrounding landscape with respect to hue and value. Pure mono-culture coniferous plantations tend to be of uniform colour and can

often visually conflict with the indigenous colours of the landscape. Alternatively, combining different species, particularly broadleaf and deciduous, will help to increase colour variation.

- *Texture*
  Texture is concerned with superficial variation of the surface of the forest canopy. Pure monoculture coniferous plantations tend to be of uniform bland texture, while the combination of different species and/or age classes will help to increase textural variation.
- *Line*
  Line includes edge and internal ride lines, fire breaks, roads and internal felling coupes. A positive relationship to the surrounding landscape might be, for example, feathering the transition between broadleaf and conifer stands or creating non-rectilinear edge to stands at boundaries, roads and transmission lines.
- *Form*
  Form is concerned with the relationship of the shape of the plantation to the surrounding landscape, including response to changes in landform. Deciduous trees can help to blend a plantation with surrounding fields, hedgerows and woodland.
- *Silhouette*
  Where forestry breaks the skyline, appearing in silhouette, the natural flow of the landscape may be disrupted. This can be particularly severe where a mature stand covers a significant portion of a hill or mountain and terminates abruptly at a boundary near the crest.
- *Scale*
  Scale is concerned with the extent of cover of the forest relative to the overall visible landscape, and is measured with regard to other areas of vegetation and diversity.
- *Spatial Dominance*
  Spatial dominance is concerned with the spatial impact of the three dimensional mass of the forest relative to the space in which it is viewed.

The design process should incorporate the VIA, using it to highlight possible aesthetic weaknesses. In addition, it should reflect the understanding of the site and context obtained during the analysis of visual sensitivity. For example, while coniferous plantations are often criticised for creating a serrated profile in silhouette, depending upon the form of the landscape, they may create a certain "alpine" appearance which can be attractive in suitable locations.

The result of the examination of aesthetic relationships may facilitate mitigation of adverse visual impacts, where appropriate and feasible, allowing modification of the design prior to submission for approval to the relevant authorities. Visual improvement may not always be possible, however, due to silvicultural considerations or the existence of physical constraints, such as transmission line routes and existing public roads.

The VIA report should, finally, be submitted to the relevant authorities. This should comprise the following:

- Outline of the description and analysis procedure.
- Results of the aesthetic relationship assessment.
- Annotated simulations of the site before and after afforestation stages, including an indication where adverse visual impacts occur but, due to other considerations, cannot be ameliorated.

Conclusion

Visual sensitivity levels can be regarded as a local or small scale regional land use policy. Categories of visual sensitivity provide a basis for developing specific design objectives for any given site. When these objectives are incorporated in a design they can be visually simulated and tested and refined through the VIA process. Such a means can ensure higher design standards and overall enhancement of the environment. With the recent tendency to shift from purely commercial forestry towards more integrated developments involving amenity, the creation of visually well designed forests must inevitably be an objective.

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Forestry and the Cultural Landscape: Understanding the Past in the Present

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Summary

Afforestation will be the single most important agent of rural landscape change in Ireland in the 1990s. At the same time the value of another resource – the cultural heritage – is seen as the core of the drive to improve our tourist industry. This paper outlines the impact of afforestation policies on the cultural landscape, especially the archaeological heritage. It analyses the key issue of the nature and management of that heritage which is not as widely understood as it might be. Finally it suggests that a more sensitive approach would not only protect the archaeological heritage but lead to a better understanding of the role of woodland as an integral part of the historic rural environment.

Introduction

It is widely recognised that the 1990s and beyond will see major changes in the Irish rural landscape as the economic base of these areas diversifies away from traditional agriculture as a consequence of the reform of the EC Common Agricultural Policy. Two of the most important aspects of this diversification that have been recognised in the National Development Plan 1989-93 are afforestation and tourism. Both have the potential to create wealth and employment and to sustain people and communities on the land. The land and landscape are the space where these two vital Irish assets interact. The characteristics and quality of the Irish natural and cultural landscape are fundamental to the Irish tourism product (e.g. Anon., 1992). The driving force of the forestry programme is the expansion of the amount of public and privately-owned land under forestry with the aim of an annual planting figure of 30,000 hectares by 1993 (Anon., 1991a). Not only is this expansion of forestry creating a new cultural landscape but in turn it is taking place in a context of a record of human settlement in Ireland going back over 9,000 years. Any assessment of the impact of forestry on the environment must take account of this historic cultural landscape which needs to be maintained, managed and protected if it is to be utilised as a core aspect of rural tourism.

Recognising the Nature of the Archaeological Resource

What has been said above will not be unfamiliar to anyone following the discussion about the impact of increased afforestation on the Irish environment. The EC-supported Forestry Operational Programme, the Forest Service of the Department of Energy, the legislation under which Coillte Teoranta was established and the operational procedures of Coillte itself all emphasise the importance of protecting the quality of the environment, including the built or cultural environment, with specific regard to avoiding inadvertent environmental disturbance or degradation as a result of afforestation policies. The recent publication of guidelines to help non-archaeologists involved in forestry development identify archaeological sites and monuments and to protect them during the different active stages in the forest development process (Anon., 1991b) indicates a concern for the archaeological heritage. There is a monitoring procedure whereby applications for grants for private forest planting in areas where sites are marked on the Sites and Monuments Records, produced by the Office of Public Works, the state body with statutory responsibilty for archaeological sites and monuments, are referred to the Office of Public Works for comment and action where necessary.

But those guidelines and the monitoring procedure also illustrate very clearly that there is not a clear understanding of the nature of the archaeological heritage in the landscape or the extent to which it has been recorded. As pointed out above the basis of the monitoring procedure regarding the impact of afforestation on archaeology are the Sites and Monuments Records (SMRs). These are being produced on a county by county basis as the first of three stages in the compilation of a comprehensive survey and data base of archaeological sites in the state by the Archaeological Survey in the Office of Public Works. The second stage is the production of county Archaeological Inventories (e.g. Buckley 1986) and the final one is the compilation of full Archaeological Surveys (e.g. Buckley and Sweetman 1991) for each county. Where the three stages differ is in the accuracy and completeness of the records they contain. Sites and Monuments Records are based primarily on existing sources of information, such as the six-inch Ordnance Survey maps and estate maps, archaeological and historical journals and other documents, museum collections and archives and aerial photographs. The latter include both oblique photographs which tend to be of specific sites or areas and the vertical aerial photographs which have been taken for mapping or other purposes. The vertical aerial photography undertaken by the Institut Geographique National de France for the Geological Survey of Ireland covers the whole country and offers a valuable record of the landscape as it was in the mid-1970s. This can be compared with the landscapes recorded on the various editions of the six-inch Ordnance Survey maps going back to the 1840s and to more recent aerial photography taken in the 1980s particularly by the Ordnance Survey.

What the Sites and Monuments Records consist of then is a rapid office-based survey of known sites, they are *not* based on an active programme of fieldwork to identify the full extent of archaeological sites in a county, that is the role of archaeological inventory and full survey. By the end of 1992 SMRs were available for all twenty six counties in the Republic. Marked up sets of six-inch Ordnance Survey maps showing the location of sites, with accompanying check lists will have been circulated to county planning offices and development agencies, such as the Forest Service and Coillte. The purpose of the SMRs is primarily to monitor the impact of developments, including forestry, on the archaeological heritage of the country. It should be emphasised that, contrary to the impression that a reader might gain from the *Forestry and Archaeology Guidelines* (Anon., 1991b), they do not in any way represent a full archaeological survey but only the first step in the compilation of such a survey which *must* be based on fieldwork as well as an analysis of existing documentation.

Measuring the Impact of Afforestation – The Present Situation

The reason why the basis of the SMRs has been outlined in some detail is because they are so central to the process whereby the Forest Service measures the nature and extent of the impact of a proposed planting programme on the archaeological resource. It is the central thesis of this paper that the SMRs by themselves, without active field-based mitigation measures, are an inadequate baseline to utilise in quantifying the impact of specific afforestation projects on the archaeological resource. The procedure at present is that on the receipt of an application for a private afforestation development Forest Service Inspectors will check the proposed planting site against the relevant SMR maps and lists of sites specifically protected as National or Registered Monuments under the National Monuments Acts 1930 to 1987. It should be noted that National or Registered Monuments form a very small percentage, less than 2.5%, of the estimated national total figure of monuments in the Republic (Cooney 1992). The reality that other sites not previously recorded will be present in the field is implicitly recognised in the *Guidelines on Forestry and Archaeology* which includes the aspiration that Forest Service Inspectors will be trained to recognise such sites.

If an archaeological site is present then maps of the proposed afforestation are forwarded to the Office of Public Works for comment within one month. Assessment within the Office of Public Works is dealt with, on a part-time basis, by one administrator and one archaeologist who may be dealing with up to twenty applications a week. The assessment is largely office-based, again based on the SMRs. This is not surprising given the time constraint of a month and the totally inadequate resources within the Office of Public Works given to carrying out field monitoring. If a site is of archaeological importance then it will be registered, with no planting allowed with a 10-20 metre or occasionally larger zone around it, or planting will be permitted provided an excavation is undertaken by an archaeologist or where the site is only of possible interest pre-planting work may proceed provided particular care is taken. There is no requirement for field assessment by a trained archaeologist at any stage in this procedure. Where there are recognised sites of archaeological importance grant approvals will preclude planting of the sites, will include buffer zones and access routes and they will be protected at all stages of forest development such as road building and felling operations.

In relation to public afforestation Coillte send copies of land acquisition maps on a monthly basis to the Office of Public Works for comments and it has an education programme for staff to help them identify archaeological sites in the field. Otherwise the procedures operate as detailed above for private afforestation.

Identifying the Inadequacies of the Present Procedure

An analysis of this present set of procedures for identifying and mitigating the impact of afforestation on archaeology would firstly have to recognise that planting is concentrated in areas where the SMRs are least reliable. Uplands, areas of marginal mineral soils, blanket and cut-over raised bog are all zones where there has been very good survival of archaeological sites. The marginality of these areas for agriculture which makes many of them commercially attractive for forestry is the reason why they are such important zones of survival of archaeological sites of many different periods. Furthermore their physical remoteness and difficulty of access has meant that the archaeological sites have not been very well documented. In parts of counties such as Galway, Leitrim and Mayo as few as 5% of known archaeological sites were marked on the six-inch Ordnance Survey Maps. As Moore (1992, p. 226) has pointed out even when a field survey is carried out it tends to focus on areas where there are known monuments and so the bias against the documentation and survey of upland and marginal land will be carried on into fieldwork. So, on the one hand unimproved land is the last refuge of well-preserved archaeological landscapes, on the other hand many of these areas remain unsurveyed (Shepherd 1992, p. 162). In blanket bogs, raised bogs and areas of peaty mineral soils most of the archaeological sites may not appear on the surface but as sub-surface features. Ground preparation for afforestation by ploughing or ripping, tree-root growth and the process of tree harvesting and extraction will remove or substantially damage such features. Operations associated with forestry such as the construction of access roads and the drainage of areas to be planted can lead directly and indirectly to further damage to archaeological sites.

The corollary of the above is that many archaeological sites in these vitally important areas for our understanding of the evolution of settlement in the landscape will not have made it into the county SMRs which are office-based surveys. Recognition of sites on the ground in this kind of terrain is a specialised archaeological skill, developed out of a suitable professional qualification and long experience in the field. To suggest that Forest Service Inspectors or Coillte foresters will be able to adequately assess the presence and diversity of sites in these areas is to engage in an act of faith similar to believing that an archaeologist could be entrusted to not only identify different species of conifer but also to predict their growth rates in different conditions and to manage a forest. Field assessment by professional archaeologists is needed as part of the monitoring procedure, otherwise that procedure in many cases amounts to nothing more than a token gesture towards protection of the archaeological resource.

In Scotland the Woodland Grant Scheme of 1989 and its revision in 1991 stipulate that sites considered important by archaeologists, usually the Regional Archaeologist, will not be damaged. In 1989 The Royal Commission on the Ancient and Historical Monuments of Scotland set up a survey unit, the Afforestable Land Survey, to work in areas prior to afforestation and Historic Buildings and Monuments, Scotland (Historic Scotland) have also made funds available for rapid field assessments related to specific grant applications (see Halliday and Ritchie 1992; Shepherd 1992). Given the scale of on-going afforestation in Ireland, similar to that in Scotland, an active field-based policy of assessment needs to be put into operation here by the relevant authorities if we are serious about managing the archaeological resource in afforestable areas.

Of course it is not realistic to suggest or expect that all archaeological features in the landscape should be preserved. The aim as Macinnes (1990) has recently stated is to preserve as much as possible, where land-use and development is not in conflict with preservation or can be adjusted to avoid conflict. If sites have to be damaged or destroyed then as a minimum they should be surveyed and recorded and where deemed necessary excavated.

At the moment in Ireland the only grant-aided afforestation projects subject to a mandatory pre-planting field-based assessment are new forestry developments over 200 hectares. These require an Environmental Impact Assessment (EIA) to be carried out under EC Directive 85/337. Given that the average size of plot being afforested at the moment is 10 hectares (Anon., 1991a, 33) it is clear that a very small proportion of grant applications for private planting or planting projects by Coillte now or in the future will require an EIA.

A recent preliminary survey by the Irish Association of Professional Archaeologists demonstrated the reality that afforestation has had a direct detrimental impact on the archaeological heritage in many areas. While much of the damage to archaeological sites is done at the ploughing and planting stage it is worth repeating that the whole forestry process, from initial ploughing and planting through growth, thinning and felling has a potentially damaging impact. Afforestation can also affect archaeological sites indirectly, for example drainage of wetland areas may cause loss through desiccation of well-preserved deposits which may lie outside the area being planted. In the past as today the location of settlement and other types of sites was an important decision. Many different types of sites were located very specifically in relation to other sites or to overlook an area. This wider landscape setting of a site can often be lost as the result of insensitive planting.

Much of the forestry estate in Ireland today was planted between the 1930s and 1970s when there was much less sensitivity in the forest industry to environmental protection. This means that in many planted areas there are many known archaeological sites that are not protected in any way, with trees planted on or in the immediate vicinity of the site and sites at potential risk, particularly at the felling stage. There is no procedure at present to safeguard these sites. So it is not only at the stage of vetting planting applications but right through the forestry process and in already established forests that a more proactive approach needs to be taken to safeguard archaeological sites and monuments. As a State company managing an estate of over 485,000 hectares or approximately 6% of the national land area, making it the country's largest land-owner and a major custodian of archaeological sites, Coillte has a special responsibility in this area. The Forest Service vets grant applications for private afforestation projects. This mechanism could be used much more effectively to ensure field assessment in areas considered sensitive by the Office of Public Works. But it is only when there is a realisation of the wealth and importance of archaeological sites and landscapes in afforestable areas that a change in perspective will come.

The Wider Perspective

The importance of a more active policy of monitoring the impact of afforestation on the archaeological heritage lies not only in preserving and studying the historical dimension of the landscape but in presenting it as a major present-day resource. In the development objectives and strategy of the *Forestry Operational Programme 1989-93* one of the aims of the forestry programme being widely dispersed in rural areas is to underpin rural development, tourist development and recreation and preservation and improvement of wildlife and the environment. Understanding and presenting the development of the cultural landscape through archaeological monuments could be the key element of a strategy to develop rural tourism as a viable complementary enterprise to forestry and farming (e.g. Feehan 1992). Bord Failte research shows that in 1990/91 visits to archaeological and historical sites featured in the holidays of 1.3 million overseas tourists. For 150,000 people it was the main reason that brought them to Ireland. Over 40% of the European Regional Development Funding grant aid was allocated to the 'history and culture' product under the *Operational Programme for Tourism 1989-93*. Every parish in the country has the potential to present its physical and cultural heritage as something worth coming to see, stay and appreciate. In turn such a strategy would also lead to more community awareness and understanding of the importance of the past of people's own place. As stated above many of the best-preserved archaeological site complexes and landscapes are in areas potentially attractive for afforestation, already planted or under consideration for forestry. Given the importance of these areas it is a priority to ensure that some accommodation can be reached whereby they would be maintained as integral landscapes.

Studies of the development of the Irish landscape over the last 10,000 years make it clear that the first substantial human impact on what was a predominantly forested landscape only took place from about 4,000 BC with the beginnings of agriculture. The island had already been occupied by hunter-gatherers for over 3,000 years and long after farming was established substantial parts of the landscape were forest-covered (e.g. Mitchell 1987). Thus a woodland setting, even of non-native conifers, may be more appropriate as a landscape background to many prehistoric monuments in trying to interpret the way they were perceived and used by people. This kind of approach requires that the archaeological heritage and forestry are seen not as conflicting land uses but as complementary resources to be developed in tandem. One example could be the recently discovered complex of hillforts of later prehistoric date near Baltinglass, Co. Wicklow (Condit 1992). Here selective clearance of planted areas would enhance the integrity of these hilltop sites and also serve to highlight their presence in the landscape. An interesting note to end on is to speculate how the balance between these two resources; archaeology and forestry, would be viewed if even half of the level of grant aid afforded to forest planting in both the public and private sector was given to the protection, preservation and presentation of suitable archaeological sites, complexes and landscapes in rural areas of Ireland.

ACKNOWLEDGEMENTS

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Monitoring Forest Condition in Ireland (1988-91)

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Summary

A range of 878-995 trees were assessed for vitality status over the years 1988-1991, in two projects equally funded by the EC and the Forest Service, Department of Energy. Four species were studied in a total of 47 plots distributed around the country: Sitka spruce (*Picea sitchensis*), Norway spruce (*Picea abies*), lodgepole pine (*Pinus contorta*), and noble fir (*Abies nobilis*).

Forest damage levels, amongst the lowest in Europe, were very low in the spruces, and almost negligible in lodgepole pine and noble fir. Exposure and insects were the most common causes of damage, being influenced greatly by the position of the assessed tree (damage increasing as follows: internal > internal edge > external edge) and altitude, and less so by age, soil type, and nutrition.

Forest condition in the spruces improved from 1988 to 1991, the improvement being attributed largely to relief in climatic stresses, leading especially to reductions in insect populations (green spruce aphid, *Elatobium abietinum*) and water deficits. There was no evidence of long-term damage and, as such, the existence in Ireland of forest decline, as defined by continental Europeans, is questioned.

Introduction

In the late 1970s concern arose over the widespread decline observed in the general health or vitality of the forests in Central Europe. This condition became widely known as "forest decline". Concerns that forest decline may be occurring elsewhere led many countries to conduct surveys to monitor the condition of their forests.

Germany (formerly West Germany) was the first country to bring the so-called forest decline phenomenon to public notice, and it was also the first to institute surveys of forest decline. The methods they employed have largely been adopted by all countries participating in the co-ordinating action of the United Nations ECE, ICP Forests (International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests). Thus, European forests have been surveyed annually from the mid- to late 1980s, using a common methodology, which allows comparison of results between countries and detection of trends.

Three surveys of forest condition are ongoing in Ireland. They are being carried out by Coillte Teoranta (Irish Forestry Board), funding for which is provided by the European Commission and the Forest Service, Department of Energy.

These surveys are being conducted annually, under Council Regulation (EC) No. 3528/86, a Community programme for the protection of forests against atmospheric pollution, and comprise the following:

(1) EC Forest Health Inventory, initiated in 1987 (22 "Periodic" Plots)

(2) Study of the Cause-Effect Relationships Underlying Forest Decline, initiated in 1988 (25 "Permanent" Plots)

(3) Study of Ways to Improve Methods of Measuring Forest Health, initiated in 1990 (33 plots).

This paper reviews the forest damage results, from the first two of these surveys, over the four-year period, 1988-91. The third survey will be referred to for the early results from it showing the stong relationship between the location of a tree, with respect to its partners, and the amount of damage sustained. More detailed information on the results for the individual years (1988-1990) for each survey is available in the annual reports published[6,7,8,9,10,11]. Annual reports are also published with the forest damage results for the whole of Europe[3,4].

Assessment Methods

Estimates of needle or leaf loss (defoliation) and discolouration are assumed to reflect the condition or health status of a tree. Trees in all plots are assessed for defoliation and discolouration in July-September of each year. The assessment is carried out by a single surveyor, who has attended international training courses on assessing forest damage.

The number of trees assessed in each plot varies according to the availability of trees suitable for assessment, that is, tree crowns which are sufficiently visible to assess accurately. In most plots, only trees located on plot edges were suitable, since the crowns of trees located elsewhere in a stand were generally not sufficiently visible, unless the stand had been thinned considerably. Thus, the number of trees assessed was largely dependent on the availability of "edge" trees. The number of trees assessed in each plot ranged from 10 to 25.

Before the start of the original survey all selected sample trees were numbered, so that a record of changes in condition over time can be obtained for each individual tree.

Each sample tree is assessed for degree of defoliation and discolouration in 5 % classes as follows: a tree with 0-5 % defoliatiion is recorded as 5 %, 6-10 % is recorded as 10 %, and so on. However, the data are transposed to broader classes, as shown in Table 1, for ease of interpretation. Details on the criteria used in defining defoliation classes are also shown in Table 1. Discolouration criteria are similar, except that there is no Class 4.

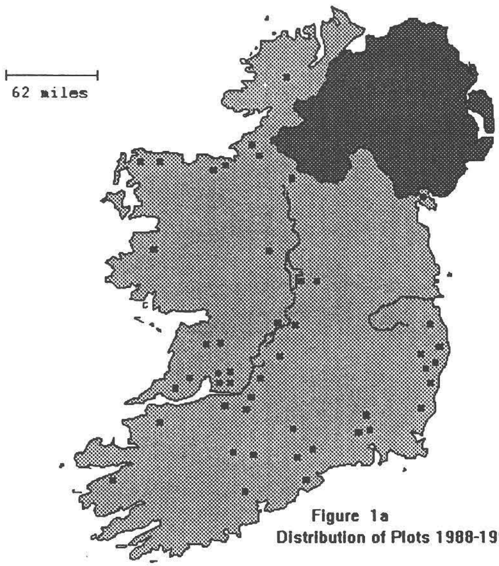

Figure 1a
Distribution of Plots 1988-1990

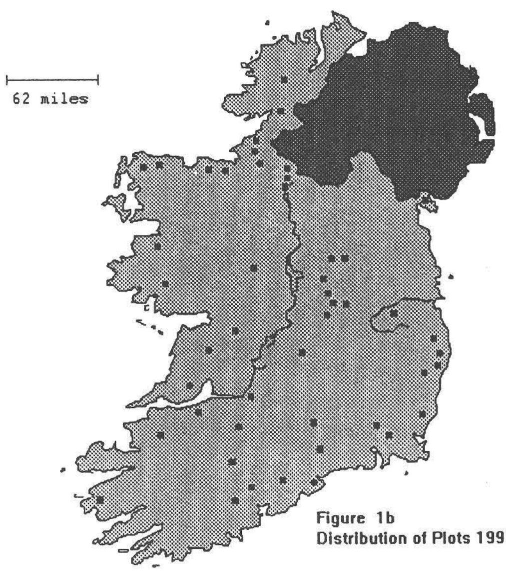

Figure 1b
Distribution of Plots 1991

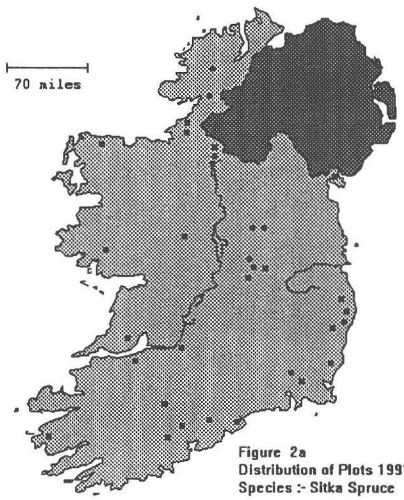

Figure 2a
Distribution of Plots 1991
Species :- Sitka Spruce

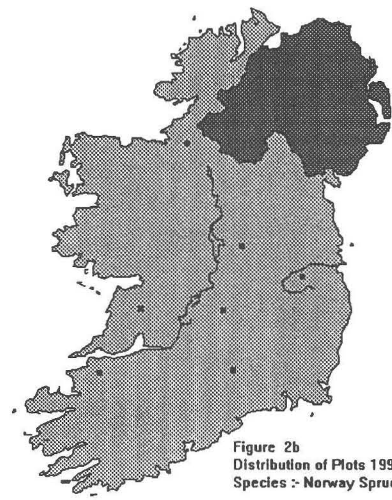

Figure 2b
Distribution of Plots 1991
Species :- Norway Spruce

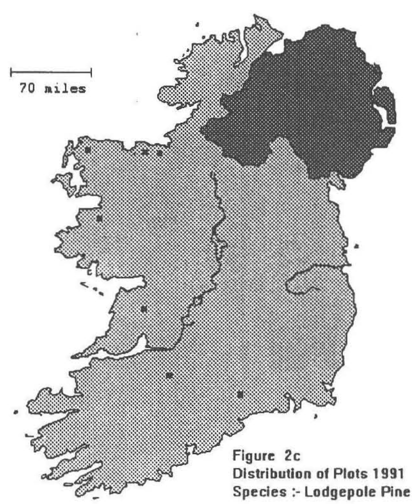

Figure 2c
Distribution of Plots 1991
Species :- Lodgepole Pine

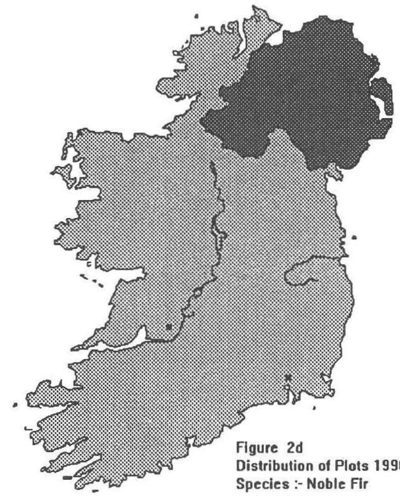

Figure 2d
Distribution of Plots 1990
Species :- Noble Fir

Table 1: Defoliation criteria.

CLASS	DEGREE OF DEFOLIATION	NEEDLE LOSS (%)
0	None or negligible	0-10
1	Slight	11-25
2	Moderate	26-60
3	Severe	> 60
4	Dead	

When possible the probable cause(s) of the forest damage was recorded for each tree. The surveys were confined to four of the more important coniferous species in this country, that is, Sitka spruce (SS), Norway spruce (NS), lodgepole pine (LP), and noble fir (NF).

Location of Plots

The distribution of plots was the same in 1988-1990. However, in 1991, in the "Study of Cause-Effect Relationships Underlying Forest Decline" project, 15 of the original plots were replaced to obtain a network with better representation of forest regions, age classes, and altitudes (Figure 1).

Figure 2 shows the distribution of plots by species in the "EC Forest Health Inventory" project. The 22 plots in this project have remained unchanged over the four years being reviewed (1988-1991).

The number of plots and trees for each species is shown in Table 2.

Table 2: Plot numbers by trees and species composition.

SPECIES	PLOTS		TREES	
	1988-90	1991	1988-90	1991
SS	26	33	447	676
NS	12	7	231	156
LP	7	7	164	163
NF	2	0	36	0
Total	47	47	878	995

Results

Results for defoliation and discolouration are presented for a combination of all the plots from both the "EC Forest Health Inventory" and "Study on Cause-Effect Relationships Underlying Forest Decline" projects. In this paper emphasis will be placed on the "0" and "1" classes of defoliation and discolouration, since it is generally accepted that trees assessed in those classes are undamaged[2,5]. Indeed, Becker[1] has produced evidence to show that foliage losses of up to 40 percent may occur in some species without affecting annual increment.

I. Defoliation

Sitka Spruce

The assessments of defoliation in Sitka spruce show that there was very little needle loss in any year of the surveys. This is illustrated in Figure 3a, where the percent of trees in the undamaged classes (0+1) never went below 73 percent, and reached as high as 90 percent in 1991. There was a clear improvement in the crown density from 1988/89 to 1990/91, which reflects a decrease in the occurrence of the green spruce aphid *(Elatobium abietinum)*, of which there were significant outbreaks in the early years of the surveys.

Norway Spruce

The defoliation results for Norway spruce are somewhat similar to those found in Sitka spruce, undamaged trees (classes 0+1) ranging from 65 to 83 percent of total trees assessed, the improvement in crown condition increasing in the course of the survey period (Figure 3a).

Lodgepole Pine

Defoliation in lodgepole pine was even less than in the spruces (Figure 3a). The crown density remained relatively constant over the four years, the proportion of trees in the undamaged classes being in the 85 to 93 percent range.

Noble Fir

There were only two plots of noble fir, and these were discontinued after the 1990 survey. For the three years (1988-90) that it was assessed, the crown density of noble fir was, like lodgepole pine, relatively unaffected, all trees being classed as undamaged except for 5 percent of trees in 1988 (Figure 3a).

II. Discolouration

Sitka Spruce

The pattern of the results for defoliation in Sitka spruce is found also with regard to discolouration. This applies not only to the high proportion of trees in undamaged classes, but also to the improvement in the results through the survey period (Figure 3b).

Norway Spruce

The discolouration assessments for Norway spruce were very similar to those found for Sitka spruce, with more than 80 percent of all trees assessed as being in the (0+1) classes (Figure 3b).

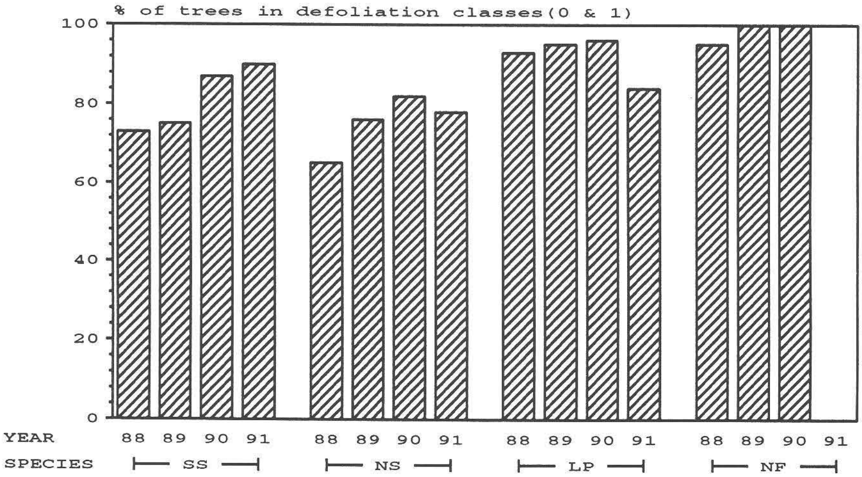

Figure 3a: Defoliation (1988-1991)

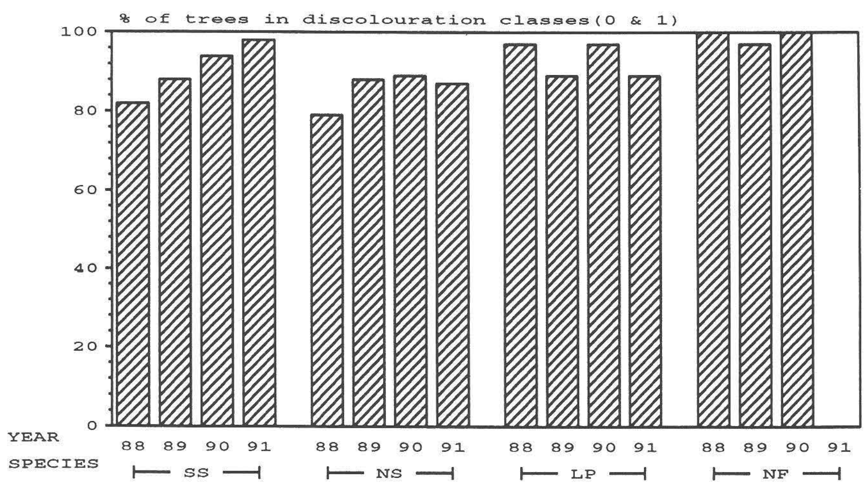

Figure 3b: Discolouration (1988-1991)

Lodgepole Pine
Discolouration levels for lodgepole pine were minimal for all years (Figure 3b). The levels fluctuated, with slight increases in 1989 and 1991.

Noble Fir
As with the defoliation assessments, the discolouration levels for noble fir were very stable over the three years that the species was monitored (Figure 3b), being the least affected of all the species surveyed.

III. Foliage Analysis
In the "Study of the Cause-Effect Relationships Underlying Forest Decline" project a representative number of trees in each plot (25 plots) were selected each year for analysis of the current year's foliage, in order to see if nutrient levels were limiting growth and/or causing damage, particularly in the context of discolouration. The nutrients analysed were: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg).

The average results for all plots, for each species, is shown in Table 3 for three of the four years of the survey, the results for 1991 not yet being available.

Table 3: Mean foliage analysis results for SS, NS, and NF in 1988-90 (percent of dry matter)

		SPECIES			
NUTRIENT	YEAR	SS	NS	NF	MEAN
N	1988	1.80	1.90	1.71	1.83
	1989	2.06	1.95	1.75	1.99
	1990	1.47	1.48	1.31	1.46
P	1988	0.18	0.19	0.17	0.18
	1989	0.19	0.17	0.17	0.18
	1990	0.15	0.16	0.14	0.15
K	1988	0.89	0.61	0.65	0.77
	1989	1.01	0.74	0.73	0.89
	1990	0.78	0.54	0.54	0.68
Ca	1988	0.45*	0.47	0.73**	0.49***
	1989	0.53	0.64	0.37	0.56
	1990	0.56	0.74	0.41	0.61
Mg	1988	0.11*	0.14*	0.06**	0.12***
	1989	0.10	0.17	0.13	0.13
	1990	0.09	0.11	0.10	0.09

Note:
* = analysis from only 4 plots (from a total of 14 SS and 9 NS plots)
** = analysis from only 1 plot (from a total of 2 NF)
*** = mean analysis from 9 plots (from a total of 25)

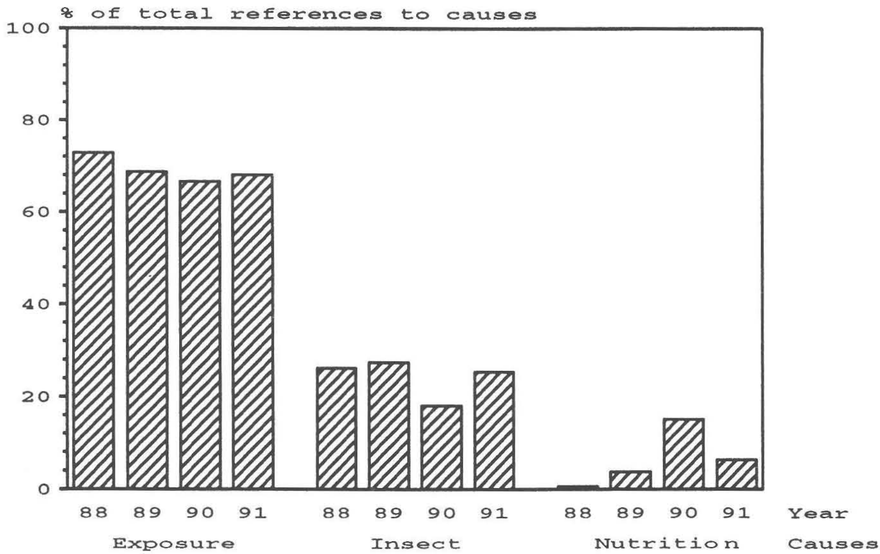

Figure 4: Causes of Defoliation
Class 2 Defoliation, SS(1988-1991)

The pattern of foliage analysis for all species was similar. There was an increase in N, K, and Mg from 1988 to 1989, followed by a decrease in 1990 to levels below those in 1988.

For P, there was little difference in concentrations between 1988 and 1989, but there was a decrease in 1990. Of the five nutrients analysed, Ca was the exception in that it alone increased from 1988 to 1990, in the spruces, but not in noble fir where the pattern was uneven.

IV. Easily Identifiable Causes of Damage

The most frequently enumerated causes of damage for all species, in order of importance, were : (1) exposure, (2) insects, and (3) nutrient deficiency. This is illustrated by the results which were obtained with Sitka spruce for the moderate defoliation class 2 (26-60 percent needle loss), which was typical for the other species also (Figure 4).

The data on "damage type" only records the presence of a cause, or causes, contributing to the damage, but does not indicate the scale of the effect attributed to the cause(s). The usefulness of the damage type records is limited to giving only general indications of the scale of the damage from different causes. This is because some trees can be subject to several types of damage, and thus will be represented more than once in the damage type records. In addition, a cause of damage to a tree is only recorded where there are identifiable symtoms of damage.

The influence of changes in soil moisture availability to the general improvement in forest condition can only be speculated upon. However, meteorological records show that soil moisture deficits, expressed as the number of 10-day periods with 50 mm or more in June-September, were less in 1990 than in 1989.

V. Effect of Altitude, Soil, Age and Position of Trees

Site (altitude and soil) and crop (age and position of tree) characteristics were recorded for each sample in the following categories:

(1) **Altitude** – in 50 m categories, up to 400 m.

(2) **Soil** – (i) Wet Mineral, (ii) Dry Mineral, (iii) Blanket Bog, (iv) Midland Bog, (v) Old Red Sandstone, (vi) Limestone.

(3) **Age of Tree** – in 20 year categories, up to 60 years.

(4) **Position of Tree** – (i) External Edge, (ii) Internal Edge, (iii) Internal (no edge).

A General Linear Models statistical procedure was used to estimate the significance to tree damage by the four factors above. The results for the relationship between defoliation (in Sitka spruce, Norway spruce, and lodgepole pine), as the dependent variable, and altitude, soil, age and position, as the independent variables, are shown in Table 4.

The R-Square values show that the combination of the four factors of altitude, soil, age and position of tree, account for 60, 68, and 49 percent respectively of the variation in defoliation damage in Sitka spruce, Norway spruce, and lodgepole pine, respectively. The highly significant F-values indicate the over-riding importance of position of sample tree, especially for Sitka spruce and lodgepole pine.

Three categories of trees were identified in terms of their position and susceptibility to forest damage:

(1) trees on forest boundaries (external edges) – most susceptible

(2) trees on forest edges within the forest (internal edges) – moderately susceptible

(3) trees within the forest, away from edges – least susceptible.

The small number of plots represented on each soil type makes it difficult to comment reliably on the effect of soil. Results indicate that damage has been worst on the gleys and least on the old red sandstone soils. It is hoped to determine if this is a real or a circumstantial effect.

Table 4: Statistics on relationships between defoliation and altitude, soil, age and position of tree.

		F Value	Prob > F
SITKA SPRUCE			
R-Square	0.60		
Source		F Value	Prob > F
Altitude		4.62	0.0002
Age		8.98	0.0003
Position		31.79	0.0001
Soil		3.86	0.0062
NORWAY SPRUCE			
R-square	0.68		
Source		F Value	Prob > F
Altitude		7.72	0.0002
Age		6.13	0.0059
Position		6.41	0.0048
Soil		2.47	0.0809
LODGEPOLE PINE			
R-Square	0.49		
Source		F Value	Prob > F
Altitude		2.79	0.0370
Age		0.88	0.3560
Position		9.92	0.0040
Soil		1.53	0.2266

Discussion

The results clearly show that forest damage levels recorded over the four years of the surveys were very low in Ireland. The overall forest damage is probably not as as bad as even these levels indicate. This is because most of the sample trees were located on stand or forest edges, and so would be more vulnerable than internal trees to environmental damage, especially exposure. Early results from a separate ongoing study, into the effect that the position of a tree has on the amount of damage received, shows that internal trees had 10-20 percent more in the undamaged defoliation categories than had edge trees[12].

In making comparisons with the rest of Europe a few important points must be appreciated. These relate to differences not only to pollution levels produced, but more especially to the characteristics of forests in Ireland. Irish forests tend to be young, conifers rarely exceeding 50 years, and they are planted at relatively low altitudes. European coniferous forests, by contrast, have a wider age structure, and they occur over a wider altitudinal range. The high levels of forest damage occurring in Central and Eastern Europe, and indeed elsewhere, are undoubtedly hugely influenced by the high proportion of their old and/or high altitude forests.

Comparison with the rest of Europe shows that Ireland experiences relatively little forest damage[3]. In the 1990 ECE forest damage survey, Spain and Ireland had the lowest damage levels recorded amongst the 34 participating countries and regions[3]. Ireland had less than 6 percent of the sampled coniferous trees in defoliation damage classes (2+3+4), which comprise those classes with at least a moderate degree of needle loss. This level of damage (5.4 percent) is in stark contrast to the high of 57 percent for Byelorussia, 50 percent for Czechoslovakia, and 45 percent for the United Kingdom.

It is not possible yet to be specific as to the reasons for the wide differences in forest damage sustained between countries. This is not surprising, since it is not always even clear within countries what factors are involved in influencing forest condition, not to mind what their relative importance is, or how they might interact.

Air pollution is considered by their respective governments to be the most important factor leading to forest decline in Austria, Czechoslovakia, Germany, and Liechtenstein[4]. In Ireland air pollution can be considered as no more than a possible predisposing factor. Ireland is one of four countries – the others being Hungary, Spain, and the United Kingdom – which considers factors other than air pollution to be more important in determining the condition of its forests. The 1988-91 surveys reviewed in this paper indicate that the most important of these “other factors” in Ireland are environmental in nature or reflect climatic stresses, especially exposure and insects.

Exposure is a difficult factor to quantify, since it embraces the involvement of other site factors, such as, elevation, aspect, topography, landform, distance from sea, and wind. The approach taken in these studies follows the practice used in most other studies of this nature (that is, general to semi-intensive), which is to employ the simple expedient of allocating a plot to a general exposure class based on an assessment of the factors contributing to exposure.

Of the four species monitored in the surveys, Sitka and Norway spruce varied more in forest condition than lodgepole pine and noble fir. This is attributable to outbreaks of the spruce pathogen, the green spruce aphid (*Elatobium abietinum*), in 1988 and 1989, and the absence of any notable pest/pathogen on the other species. The improvement in the condition of the spruces from 1988 to 1991 is largely due to the decline of the green spruce aphid over that period. It is heartening to note that spruces which were observed to have been considerably defoliated in the early years of the survey period appear to have recovered to a healthy state, which is in conflict with the commonly-held view that such trees suffer long-term damage.

Trees subjected to stress, such as, pollution, are predisposed to some pest attacks. For instance, outbreaks of bark beetle (*Dendroctonus micans*) are common on drought-stressed trees. Thus, it is perhaps tempting to speculate that trees subjected to pest attacks in the studies reviewed here were already pollution-stressed. However, there is no basis for this speculation, since the green spruce aphid – the predominant pest encountered here – is generally indiscriminate in its occurrence with regard to the condition of the trees it attacks. Outbreaks of green spruce aphid are largely dependent on winter temperature and the nature of the amino acids in the tree foliage.

In view of the importance of the green spruce aphid to the condition of the spruces, albeit a short-term effect, and since outbreaks of this insect are related to climatic factors, such as, the occurrence of mild winters, we can assume that the damage levels of those species will fluctuate accordingly.

It is a moot point as to whether there is forest decline in Ireland at all. The forest decline first noted by the Germans is a phenomenon which implies a continuing decrease in the forest condition. On the evidence of these surveys, admittedly for only four years, long-term damage does not appear to be happening in Ireland, since the condition of our forests generally rises and falls according to variations in such factors as climate and insect attacks. It is a consolation to Irish foresters, and the Irish forest industry, that the mean damage levels recorded in these surveys are so low, with the result that normal fluctuations are unlikely to have serious consequences.

Conclusions

The forest damage levels for all species assessed in 1988-91 were very low, being amongst the lowest in Europe. Lodgepole pine and noble fir were very stable, being relatively unaffected when compared to Sitka and Norway spruce.

There was an improvement in the condition of Sitka and Norway spruce over the four-year period. This improvement is largely attributed to changes in climate, which became less conducive for insect outbreaks and water stress. However, it must be borne in mind that the improvement was made from a base in 1988/89 when forest damage levels were already very low.

Exposure and insects were identified as the most common causes of damage. The position of a tree in a stand and altitude were undoubtedly very important factors in influencing the effects of exposure and insect attacks. The extent of the interactions have yet to be established. Soil type and age of trees were less important factors influencing forest damage.

Nutrient concentrations were generally above threshold levels, even in 1990 when concentrations tended to be lower than those in 1989. Studies are ongoing to determine if this is a temporary decrease, but even so, it is clear that it has not had a deleterious effect on forest condition so far.

The results show that there is no evidence of a long-term decline in forest condition in Ireland. The yearly variation in forest vitality reflects more the influence of non-pollution factors, in particular climate and the stresses that result from its extremes, such as, exposure, water deficits, and insect attacks.

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Forestry and the Ecology of Streams and Rivers: Lessons from Abroad?

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Summary

Forests are a natural part of our environment. However, with afforestation representing a major land-use of the upland regions, the possible interactions with waters flowing or draining from these areas merits examination. Several studies from various northern temperate regions have shown that afforestation on poorly buffered soils and in areas of high atmospheric pollution and marine salt influence, can result in profound changes to surface water quality and to the ecology of aquatic systems. The preparation of land for planting and subsequent development of a large canopy of trees can also result in significant changes in water budgets, stream hydrographs and water yields, in comparison to unafforested moorland. Attention has always been focused on the geologically sensitive areas that are negatively affected, but on well buffered soils less significant changes in stream chemistry, due to afforestation, may be expected. However, information from such areas is scarce. In Ireland little research has been carried out on the interactions between afforestation and aquatic systems, and forestry guidelines for protection of fisheries have been drawn up based on information mainly from the United Kingdom and elsewhere. This extrapolation from abroad may not be universally appropriate, as in many parts of Ireland, the soils and geology are generally well buffered, atmospheric pollution (by European standards) is low and the ecology of the systems is somewhat different from that in other countries. This review outlines the nature of changes to freshwater systems that have been found in geologically sensitive areas, but also stresses that extrapolation of results from such afforested areas to all areas under afforestation in general must be undertaken with care. Considerable further work is needed in Ireland and it is hoped this will lead to a better understanding of the interaction between forestry and water resources.

Introduction

Hynes (1975) in his famous essay 'The stream and its valley', recognised the critical link between streams and the surrounding landscape (the catchment), which through exchanges of water, matter and energy can strongly influence the biota of streams and rivers. Features of the catchment such as geology, soils and type of vegetation and land use can thus determine the physicochemistry and ecology of the streams and rivers which drain them. In this context, two major types of land use have been recognised as influencing surface water quality in recent years: agriculture and forestry. Because most afforestation has occurred in upland areas (Parry and Sinclair, 1985), and many major river systems either rise in forests, or receive drainage from planted areas, the interactions between forestry and stream

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ecosystems have received the most attention and are the subject of the present review.

Forests form a natural part of our environment. Certain tree species are native to Ireland, in particular oak, whilst other exotic species e.g. Sitka spruce and lodgepole pine have been introduced for commercial afforestation and timber production. For comparison on a geographical scale, afforestation covers an area of 7.3% in England, 11.6% in Wales and 12.6% in Scotland, with about 23% of U.K. uplands being planted with conifer forests (Avery and Leslie, 1990). In Nordic countries forestry represents 76% of the land area in Finland and 68% in Sweden. In Ireland however, only 7% of the land is afforested, though planting has increased in recent years and is projected to increase further in the future (Anon, 1991).

Much of the European research on the interactions between forestry and stream ecosystems have been carried out in the United Kingdom (U.K.A.W.R.G., 1988), in particular in Scotland and Wales, although many other studies have been carried out in northern temperate areas such as the USA (e.g. Likens, *et al.*, 1977), Scandinavia and Canada. In Ireland there has been little research on the interactions between forestry and aquatic systems, (see Allott *et al*, 1990) though a major joint research programme recently involved University College Cork, in Munster, Trinity College Dublin in the West, and University College Dublin in Wicklow, on the interactions between forestry and running water systems, (see Giller *et al.* 1993). Thus for the purpose of a review at this time, it is instructive to examine experiences elsewhere and to consider how these results may apply to Ireland.

One of the areas of research that has received most attention is the potential exacerbating effect of afforestation on stream water acidification. Water is a major natural resource and the possible consequences of afforestation on surface water quantity and quality, and on the aquatic ecology of rivers and streams, particularly fisheries, has been a cause for concern. In some areas, predictive models have been produced in an attempt to simulate the potential effects of afforestation under certain conditions; whether these models as they stand will be of use in helping us predict what interactions may occur in Ireland remains to be seen.

Ormerod *et al.* (1991a) identified a number of possible pathways of effect in which the influence of forestry operations on running waters could be summarised (Figure 1). These could be classified as physical, chemical and energetic effects. However in reviewing the interactions between forestry and running water systems it is necessary to state, in the first instance, that the major documented impacts of afforestation on water quality have only occurred under certain conditions. For example, planting of trees in certain geologically sensitive types of geology which have low buffering capacity (Table 1) and in areas receiving high atmospheric pollution and/or under

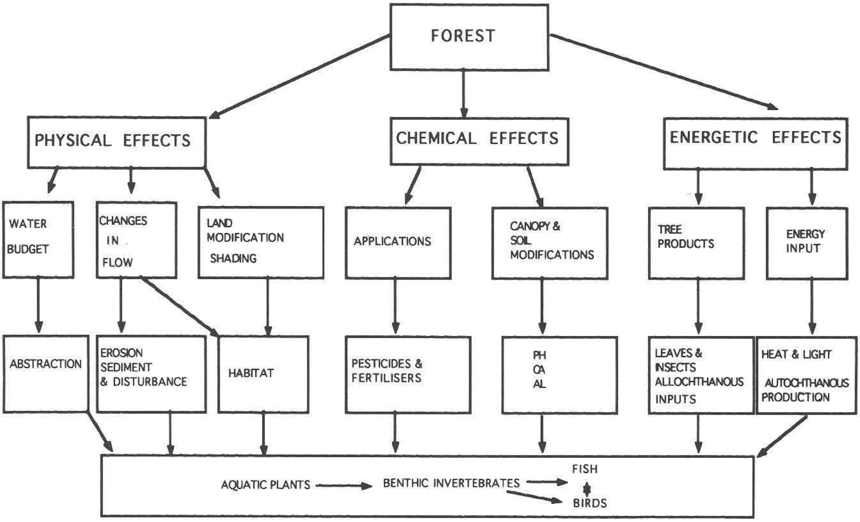

Figure 1: Selected pathways of influence by forest on aquatic fauna (modified from Ormerod *et al.*, 1991).

the influence of marine salt deposition, may have an effect on surface water quality.

In this present review we have concentrated attention on some of the most important effects. Not all the pathways have been fully elucidated yet

Table 1: Classification scheme for the sensitivity of areas of Newfoundland and Labrador based on regional geology. (Anon, 1986)

Class	Relative Sensitivity	Geology
1	Low	Extensive areas of limestone and dolomite
2	Low to moderate	Sedimentary rocks, containing widespread calcium and magnesium carbonates
3	Moderate	Volcanic terrains; major mafic igneous complexes
4	Moderate to High	Quartz-feldspar gnesses; sedimentary rocks poor in calcium and magnesium carbonates
5	High	Granites and related rocks

and this summary represents the major components of the interaction as described from other European and North American research and considers the appropriateness of applying these findings to the Irish situation.

Effects on Chemical Parameters and Surface Water Quality.

In certain geological areas of Wales and Scotland (i.e. those with poor buffering capacity (Table 1), and under the influence of atmospheric pollution), streams and rivers draining conifer afforested catchments have been found to be more acidic and/or contain higher aluminium concentrations than those in adjacent moorlands with similar soils and geology (Harriman and Morrison, 1982; Stoner *et al.* , 1984; Harriman and Wells, 1985; Stoner and Gee, 1985,). The factors and pathways of change in surface water quality due to afforestation have been reviewed by Gee and Stoner (1989) and are summarised in Figure 2.

Trees, both native and exotic, in upland regions scavenge atmospheric anthropogenic pollutants (sulphur dioxide and nitrous oxide), and, near coasts, sea salts from the air. Conifers however, are known to have a greater scavenging capacity than other types of trees (Gee and Stoner, 1989, see Table 2). Pollutants concentrate on the leaves and needles and change the concentration and composition of ions in rainfall and other forms of precipitation (bulk deposition) that reach the trees.

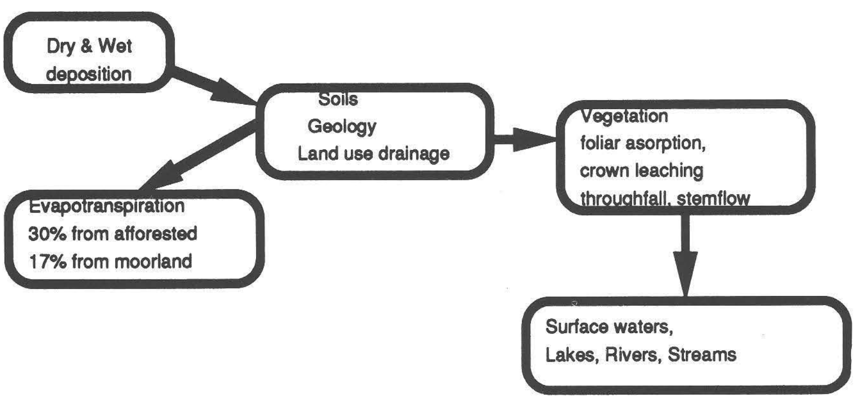

Figure 2: A simplified schematic representation of the factors affecting surface water quality (redrawn after Gee and Stoner, 1989)

Table 2: Comparison of mean values of three chemical parameters in throughfall of bulk deposition under spruce of two ages and oak. Annual range in parentheses (after Gee and Stoner, 1989).

	pH	SO_4 uequiv l^{-1}	Cl uequivl $^{-1}$
Bulk Deposition	4.6 (3.4-7.1)	54 (21-240)	145 (128-873)
Oak	4.7 (4.1-6.1)	115 (39-444)	242 (56-451)
12 year old spruce	4.27 (3.7-6.0)	144 (37-1181)	186 (85-958)
25 year old spruce	4.32 (3.6-5.9)	296 (51-1512)	268 (56-592)

This precipitation, when it reaches the soil by throughfall through the forest canopy, is often more acidic and where the buffering capacity of the area is poor and especially when the rainwater is acidic, this can in turn lead to an acidic runoff and acidification of stream water within an afforested catchment. This process can be illustrated clearly by studies in Llynn Brianne in Wales. The degree of effect, if any, of the introduced ions depends on the water chemistry of the surface waters which in turn relates to the underlying geology of the catchment. In areas of 'soft waters' ($<$15 mg/l Ca CO_3) the affects can be profound, whereas in areas where the water is 'hard' ($>$15 mg/l Ca CO_3) the effects are minimal (Jones, 1986). Acidification, (as dry deposition), may be constant over time in heavily polluted environments, but the changes in stream chemistry on poorly buffered soils generally follow a seasonal pattern and may be episodic due to changes in precipitation. For example Gee and Stoner (1989) describe a pH change from 6.2 in summer to 3.9 in winter in streams on poorly buffered soils draining forestry. Similarly calcium and aluminium (particularly labile monomeric) concentrations changed, with calcium levels dropping by three orders of magnitude and aluminium concentrations increasing by almost ten orders of magnitude. In the same way as seasonal episodes can cause changes in water chemistry, short episodes over a 24 hour period may also result in significant changes in surface water chemistry. In Welsh studies, pH changes from 6.0 to 4.0 and an increase of aluminium concentration of 1 mg/l, have been recorded within an eleven hour period after a snow melt (Gee and Stoner, 1989). Studies in the west of Ireland have shown similar dramatic drops in pH following heavy rain (Allott, *et al.*, 1990; Giller *et al.*, 1993).

Sea salt may also exacerbate the acidification process (Allott, *et al.*, 1990). This process of acidification occurs as a result of ion exchange in the soil, leading to an export of protons from the soil. The acidification process is due to sodium ions exchanging for hydrogen ions which leave the system accompanied by the chloride which is highly mobile and present in abundance in the soil. In this process too, aluminium ions may be leached, as they would under the influence of anthropogenically derived sulphate acidification.

A further source of chemical changes to aquatic systems is through the application of various chemicals used during afforestation and agricultural practices which can be biomagnified up the trophic system in streams. Ormerod and Tyler (1992) and O'Halloran *et al.*, (1993) have shown high levels of pesticides in the eggs of Dippers from upland areas, a species of bird that is exclusive to the riparian habitat and feeds on the stream invertebrates (see below). Herbicides which are often used during forestry management, may be washed into the stream systems and hence affect the water quality, its ecology and resource value. Clearly the use of herbicides and similar pest control measures should be notified to the statutory water bodies and the effects on non-target organisms should be monitored closely (Ormerod, *et al.*, 1987a).

Finally, dramatic chemical changes to stream waters can occur following deforestation/clear felling irrespective of whether the system is under the influence of atmospheric pollution or not and whether it is on sensitive or non-sensitive geologies. For example Likens *et al.* (1977) reported a significant increase in the concentration of a range of nutrients in streams in the Hubbard Brook U.S.A. following clear felling of hardwoods.

In summary, surface water quality from afforested catchments on poorly buffered soils in polluted environments can suffer from significant changes in ionic composition with an increase in acidity and an increase in some metal ions. Other forestry practices can also alter stream chemistry. The consequences for the ecology of aquatic systems can be profound when significant changes occur (see below). However, before discussing the ecology in detail it is necessary to review the physical effects of catchment afforestation on the streams and rivers.

The Influence of Afforestation on Physical Parameters

Different stages of forestry practice, such as ground preparation, road construction, drainage, clear felling and general forest management can influence the physical nature of the stream and hence its ecology. This can be via temperature and light attenuation changes, sediment yields, and changing stream hydrographs (Salo and Cundy, 1987). In the following section we consider some of these factors.

Temperature and light attenuation: As water flows downstream, its temperature will continue to change as a result of the influence of several factors that make up the heat balance of water. The net gain or loss of heat by a stream as it moves through a forest is the sum of the net radiation, evaporation, convection, advection and conduction (Brown, 1983). In afforested catchments, solar radiation is intercepted by the canopy of the stream side vegetation. The net solar radiation beneath a continuous canopy may be as low as 15% or less than that of an unshaded stream (Brown, 1983). This change in solar radiation will have serious consequences for the primary production and hence the biology of the streams (see below). However, it is important to point out that because of water's relatively high specific heat, seasonal and daily temperature changes of forested streams are relatively small and gradual (Beschta *et.al.*, 1987), thus in colder upland areas the canopy may buffer the effects of fluctuations.

Following clear felling, changes in the stream temperature and degree of solar radiation can be dramatic. Concern over the altered temperatures after logging stream side vegetation usually focuses on the inevitable increase in maximum temperatures observed during the summer (Beschta *et al.*, 1987). This focus in the U.S., in particular, is very much a result of a toxicological perspective on temperature changes that is prevalent in fisheries research. In the majority of cases however, stream temperatures in deforested watersheds, while invariably warmer than they were in the forested state, do not approach the tolerance limit of the resident fish species (Beschta *et al.*, 1987). The increased levels of solar radiation reaching the stream in a clear felled area will undoubtedly lead to an increase in the stream primary production and this contributes to some of the changes to the ecology that have been reported (see later).

Sediment: Nearly all forestry operations create some degree of soil disturbance (Everest *et al.*, 1987). During the preparation of land for afforestation, road construction and eventual harvesting, sediment from soils is released and washed into streams. Much research has been carried out in the U.S. on the yields of sediment from catchments under these different activities (for review see Ice 1979, Brown, 1983; Sidle *et al.*, 1985, Everest *et al.*, 1987). The sediment in these streams can be of two types, suspended sediment and bedload. These two types of sediment may effect the ecology through damage to fish gills, submersion following a sediment release or by changing habitat structure e.g. spawning and foraging grounds for fish (Everest *et al.*, 1987). At the early stage of planting, ground preparation and drainage will influence the rate of sediment release. Although most mass soil movements appear to be initiated by large rainfall or runoff events, road construction and the roads themselves can provide a major source of sediment in afforested catchments (Everest *et al.*, 1987). The relative importance of roads and clearcuts in accelerating sediment production can vary significantly from one area to another and through time in a single area. The large impact from a small road can equal or exceed the smaller impacts of clear cutting over a larger areas (Swanson and Dyrness 1975). Ice (1985) in his studies of 13 areas in the U.S. found that in 11, road construction contributed to more than half the sediment movement. From the above discussion it is clear that sediment production arises from a complex series of processes which will be influenced by stochastic events such as flooding and wildfire as well as by man's influence through catchment manipulation.

Water yields: Any type of afforestation (natural or exotic) can have a major influence on the catchment's hydrological characteristics and thus influence water yields significantly in comparison to unafforested catchments. In the early stages of afforestation there can be significant changes in stream flow, with increased run-off, sharper storm hydrographs (stream discharge levels over time) and the significant increase in sediment yields described earlier. Once the catchment is covered by closed canopy forestry, the effects of enhanced drainage become subordinate to the processes of soil drying and water loss to the catchment by evapotranspiration (Hornung and Newson, 1986, see below). Comparisons between adjacent catchments of upper River Severn in Wales (afforested) and upper River Wye catchment on Plynlimon, Wales (unafforested), shows a reduction in runoff of between 20-30% in the Severn catchment. Normal flood events tend to reach lower peak discharge levels and droughts may be prolonged due to the increased water storage capacity beneath the forest canopy and in the forest soil (Hornung and Newson, 1986). Two main processes are responsible for these changes in water yields: transpiration loss and evaporative loss of intercepted rain due to afforestation (Gash *et al.*, 1978).

The surfaces of leaves of most plants have numerous small openings called stomata, through which carbon dioxide is taken in for photosynthesis. These stomata also provide the means whereby water is lost from the plant to the atmosphere (transpiration), which results in the drawing of further water and nutrients from the soil. However, a proportion of the rain falling on a forest canopy, between 10-40 per cent, is intercepted by the canopy and evaporates before reaching the soil (Gash *et al.*, 1978), resulting in further losses (interception loss) of water to the catchment.

In summary, the loss of water due to afforestation in a catchment can be very significant for overall water yields in streams and rivers, Edwards and Brooker (1982) estimated that the cost of this water loss in the River Wye catchment in Wales was £0.3 million in 1980. Few other studies have been able to make any predictions along these lines.

In addition to the water yield loss, changes in stream hydrographs and flow changes due to afforestation can have significant influence on the ecology of systems (see Giller, 1990). The changes in water budgets may also lead to different sedimentation rates, flow regimes and erosion, resulting in changes to the stream morphology, ecology and physical properties of river systems. The management implications include potential increased costs due to loss in water yield for abstraction, electricity generation and repairing physical damage to river courses and riparian margins due to flooding.

The Influence of Afforestation on Aquatic Ecology.

In the discussion up to now, we have considered the influence of afforestation on the properties of water. However, water not only provides a resource for extraction, industry and recreation, but is also an important habitat in its own right, in particular in relation to the valuable ecology it supports. Fish, especially salmonids, form part of a complex food web in rivers and streams, and are very sensitive to changes in both the physical (sediment and stream hydrographs) and chemical characteristics of water. However, they are not only dependent on the river water, but also on the large biomass of invertebrate animals which forms the major components of their diet. Rivers are also important for angling and for providing water for fin-fish facilities in the aquaculture industry.

From the earlier sections we have seen that surface water quality can be significantly changed in streams running or draining from poorly buffered afforested catchments compared to unafforested moorland catchments. The ecology of streams and rivers is largely dependent on the energy flow into the system and the quality of the water. This section considers how afforestation, through changes in both surface water quality, and the nature, quality and quantity of detritus (allochthanous matter) inputs into running water systems from the surrounding catchments, can affect the aquatic ecology of streams, especially those running on poorly buffered geologies.

Before examining in detail the influence of afforestation, particularly through exacerbation of acidity in certain areas, it is important to emphasise that naturally acidic ecosystems exist and support their own unique communities that differ from other running water systems. Mean densities and numbers of species of insect larvae are generally higher in naturally alkaline streams compared with naturally acidic streams (northern hemisphere: Hildrew and Townsend, 1987; southern hemisphere: Collier and Winterbourn , 1990). In the same way, Pusey and Edward (1990) have reported low diversity of fish species assemblages in acidic peat ponds in south western Australia and salmonids are frequently absent from naturally acidic systems in the U.K., (U.K.A.W.R.G., 1988). In the systems we are reviewing here, the increased acidity is of anthropogenic origin and exacerbated by afforestation. In such cases the effects are evident at all levels of the ecosystems as outlined below and occur because the rate and degree of change is too rapid to allow community adaptation to the new conditions.

Primary Production: The main reduction in primary production in afforested streams where trees grow close to the stream bank is via a reduction

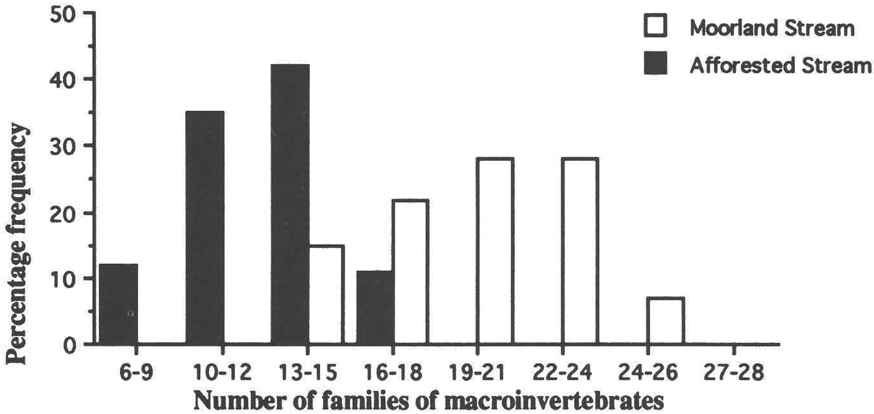

Figure 3: The percentage frequency distribution of macoinvertebrate animals at 25 sites in Wales (after Ormerod *et al.*, 1987b)

in solar radiation due to shading. In addition changes in stream chemistry can affect the plant species in the river system. Upland rivers are usually characterised as being of low productivity (oligotrophic) and afforested streams suffering from acidification generally have a lower diversity of autotrophs than unafforested streams (U.K.A.W.R.G., 1988; Welsh Water 1987). Streams with a closed canopy of forest are dominated by blue-green algae, whilst those draining acidic moorland or where the bank sides have been cleared are dominated by filamentous algae (Gee and Stoner, 1989). Little is known about the bacteria and micro-fauna in streams, but given the importance of these and algae for grazing macroinvertebrates it is likely that these micro-communities are important.

Macroinvertebrates: Field data from a wealth of studies on stream invertebrates, show a close relationship between the hydrochemistry of streams and their invertebrate faunas (e.g. Townsend *et al.*, 1983, Wright *et al.*, 1984, Hildrew and Townsend, 1987, Rutt *et al.*, 1989, Hildrew and Giller, 1994). As mentioned above, naturally acidic waters in general support a lower diversity of organisms than circumneutral and alkaline systems. In the same way, acidic streams draining afforested, poorly buffered catchments are no exception and whilst their invertebrate density may be higher than adjacent moorland (Ormerod *et al.*, 1987a) their diversity is usually reduced e.g. Stoner *et al.*, (1984) (Figure 3).

Some groups of invertebrates such as mayflies, molluscs and crustaceans and some caddis fly larvae are particularly restricted in waters at pH < 5.7 and > 0.1 mg Al/l and these taxa are often scarce in forest streams that lie on sensitive geologies (Raddum, *et al.* 1988).

There is still considerable debate as to whether sensitive taxa such as mayflies are influenced physiologically by pH, aluminium or a combination of both, or whether they are limited by reduced food quantity, quality and temporal availability in acidified streams (Ormerod, *et al.*, 1987a; Willoughby and Mappin, 1988). This food limitation may be either a reduction in leaf litter (allochtanous material) which forms the basic diet of many detritivorous stream invertebrates or by a reduction in primary production, in particular producer species, in the streams (autochtanous production). For example, limits in the production of food rich algae and bacteria (discussed above) may limit the distribution of grazing invertebrates (Ziemann, 1975; Winterbourn *et al.*, 1985). Nevertheless Ormerod *et al.* (1987a) have shown increased mortality of invertebrates independent of food levels in acidic streams in Wales. Physiological effects of low pH have been demonstrated on chironimids (Havas and Hutchinson,1983), mayflies (Willoughby and Mappin, 1988) and crustaceans (Sutcliffe and Carrick, 1973). In experimental studies carried out on five species of macroinvertebrates in the U.S. by Burton and Allan (1986), decreasing pH from 7.0 to 4.0 (no aluminium present) caused significant mortality for all species studied. However, the addition of 0.5 mg/l of aluminium caused additional mortality for only some species indicating that some species are more sensitive to a combination of aluminium and pH than pH alone. In poorly buffered systems the influence of afforestation on invertebrates may seem academic, but these animals provide the corner-stone to the functioning of aquatic ecosystems in both the afforested sections and downstream. In non-sensitive, well buffered geologies, these chemically induced changes in macroinvertebrates do not seem to be apparent, and acid sensitive species are usually found. However, physical changes occurring during various forestry practices can lead to changes in the stream communities. Clear felling for example, leads to alterations in the nature and quality of food available to macroinvertebrates in previously shaded streams (reduced allochthanous and increased autochtanous resources) with consequent changes in the invertebrate communities (Webtser *et al.*, 1983). Complete recovery cannot occur until the quantity and quality of all allochtanous inputs return to the pre-disturbance levels (Wallace *et al.*, 1988), which may take decades.

Fish: Fish are sensitive to changes in food availability (Frost and Browne, 1967; Twomey, 1988) and subtle changes in water chemistry, with many species having different tolerances to acidity and aluminium (Table 3). Stoner and Gee (1985) showed that in mid-Wales, trout were generally absent from conifer forested streams and lakes with hardness < 10 mg/l. More recent data collected by the Welsh Water Authority (1987) have shown that fish are absent from acidic afforested streams, but densities ranged from 0-0.9 m^{-2} in acidic moorlands with low invertebrate density. The question as to whether the acidity *per se* or the aluminium toxicity was limiting the distribution of fish in such afforested streams has received little attention. One study by Ormerod *et al.*, (1987b), using experimental manipulation of streams has shown that the mortality of salmon and trout was dramatically enhanced in the presence of aluminium (0.35 mg/l) at pH 5.0, but mortality was very low at pH 4.3 with no additional aluminium.

Table 3: pH levels at which populations of fish species decline, cease to reproduce, or disappear (various sources).

Species	pH Level(s)
Salmon and Trout	
Rainbow trout	5.5-6.0
Lake trout	5.2-5.5
Atlantic salmon	5.0-5.5
Arctic char	5.0
Brown trout	5.0
Brook trout	4.5-5.0
Others	
Lake whitefish	4.4
Northern pike	4.2-5.2

In Scotland, trout have also been found to be absent from streams draining long established forests and these streams are more acidic, and contain higher concentrations of aluminium than those of neighbouring non-afforested catchments (Harriman and Morrison, 1982). Declines in salmon fisheries have been related to the proportion of afforested sensitive catchments in Scotland by Egglishaw, *et al.*, (1986) and in Wales by Ormerod *et al.*, (1987b).

The effects of acidification and increased aluminium concentrations on the physiology of salmonids have been described by many workers, and are summarised by the U.K.A.W.R.G. (1988). Individual responses to low pH varies according to the dose level, duration of exposure and presence of other ions. Biological variables include species, development stage, size and genetic background. In addition to mortality, many sub-lethal effects have been described including: impaired ion regulation and acid base status, changes in reproductive physiology, developmental effects, de-mineralistion, metal accumulation, reduced growth and changes in behaviour (U.K.A.W.R.G., 1988). There have been a number of other physiological effects reported including a possible impairment of smoltification (Reite and Staurnes, 1987). Potts *et al.*, (1990) suggest that the deaths of adult salmon reported from the rivers Duddan and Esk in U.K. in 1983 were mainly due to inhibition of the sodium uptake system caused by a combination of low pH and high aluminium.

Other vertebrate animals: Other animals associated with rivers include amphibians, birds and mammals. Amphibians occupy a unique niche in temperate regions being dependent on fresh waters at the spawning and larval stages, but species rely on the terrestrial system for the remainder of their life history. Cummins (1986, 1988) has recently shown lethal and sub-lethal effects of low pH and high aluminium on frogs and newts. The European common frog (*Rana temporaria*) has been reported to show poor development at metamorphosis when exposed to pH 4.8 and aluminium concentration 0.8 mg/l (Cummins, 1986). Most research on vertebrates, however has been carried out on aquatic birds, in particular the dipper. Ormerod *et al.*, (1985) and O'Halloran, *et al.*, (1990) have shown that birds on acidic rivers and streams spend more energy searching for food due to the reduced number of invertebrates and that this may not leave sufficient body resources available for breeding. Ormerod *et al.*, (1991b) have shown that breeding of dippers is greatly impaired on acidic streams draining afforested catchments, the poor breeding and absence of the birds was related to both the scarcity of food and to the poor quality of food. When comparing pairs of birds along circum-neutral rivers (> pH 6.0) against those of low pH, dippers on acidic systems breed later, lay fewer eggs and rear smaller broods with slower growing young. Most other research on the influence of afforestation relates to the loss of moorland habitat for breeding wading birds and grouse, though clearly the provision of trees for other species such as hen harriers will prove beneficial (see Avery and Leslie, 1990 for review).

The role of physical effects, such as land preparation, shading, road construction and clear felling will also have an important role in the ecology of vertebrates in fresh water systems. The main effects will be via trophic interactions (such as food provisions) and through habitat provision for foraging and breeding.

Clearly the aquatic ecology of rivers, especially in sensitive geological areas, is very susceptible to changes. In the face of alterations in catchment use, loss of the ecosystem not only results in a major loss of the value of the resource in itself, but in the tourist and associated industry related to angling, aquaculture, conservation and to its intrinsic value.

The Use of Models in Predicting Effects.

Many studies (e.g. Ormerod, *et al.*, 1990), are now using models to predict water quality changes under different atmospheric sulphur emissions, geology and proportion of catchment afforested in attempt to predict the impact of afforestation on poorly buffered soils. One such model is a hydrochemical model called MAGIC (i.e. Model of Acidification of Groundwater In Catchments) which was developed to perform long term simulation of changes in soil and stream water chemistry in responses to changes in acidic deposition. Such models are of use to resource management teams to allow predictions, with a certain degree of confidence, as to the effects of various influences on stream water quality. However, it is important to note that all models are imperfect representations of the real world and often require cautious interpretation. Further research is clearly needed in this area.

Implications for Ireland

As mentioned in the introduction, very little is known about the influence of afforestation on water resources in Ireland, and any negative effects documented so far have been located in geologically sensitive areas and/or those receiving relatively high atmospheric pollution loads (Giller *et. al.*, 1993). In some cases, extrapolations have been made from studies carried out elsewhere. A conservative approach to the potential threat may be considered appropriate (i.e.'better safe than sorry') as in the production of forestry guidelines for the protection of fisheries, but over generalisations should be avoided and caution observed in translating lessons from abroad to the Irish situation, especially given the lack of objective data here. This cautionary approach is based on the environmental differences between Ireland and other countries where the majority of research has been carried out to date. Recent studies partly supported by the forest industry will help to elucidate these differences (see Giller *et al.*, 1993). The main differences are as follows, firstly the level of anthropogenic pollution in Ireland is probably very low, sporadic and with prevailing south-westerly winds the exacerbating effect of afforestation on acid rain is likely to be low. However, because of the maritime nature of the Irish landscape the influence of marine salts and their interaction with afforestation deserves investigation. All the pH problems associated with afforestation mentioned above have only been described for sensitive catchments with poor buffering capacity. However much of the underlying geology in Ireland is well buffered, though acid sensitive regions do exist in the west and in Co. Wicklow.

Other physical effects associated with forestry practice (e.g. establishment and clear felling operations, use of pesticides, shading, road building etc.) have been documented elsewhere and are likely to affect systems in Ireland in a similar way in both sensitive and nonsensitive areas alike. Examination of techniques to moderate adverse physical effects of such practices is required as a matter of some urgency.

Secondly, the species of macro-invertebrates and fish present in streams and rivers vary and are naturally less diverse in Ireland because of the island nature of the country (McCarthy, 1986); thus the ecology of the system is likely to be somewhat different. For these and many other reasons, current research is focusing on gathering information on the above problems. Some of the findings have indicated potential damage (e.g. Allott *et al.*, 1990), whilst other preliminary findings show little affect of afforestation (see elsewhere in this volume). One aspect of investigations which is currently not being fully investigated is the use of predictive models. These models may well help us not only to identify problems, but also direct us to potential solutions.

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Figure 1: Selected pathways of influence by forest on aquatic fauna (modified from Ormerod *et al.*, 1991).

Intensive Monitoring of Forest Ecosystems

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Summary

Pollution inputs and their impact on Irish forests are intensively monitored at four forest ecosystems. The sites, in Cork (Ballyhooly), Mayo (Brackloon), Galway (Cloosh) and Wicklow (Roundwood), supply stand and other environmental data to assist in interpretation of forest health surveys. They also contribute to research on the effects of plantations on freshwater stream ecosystems. The chemical composition of water, from the incoming rain, through the forest ecosystem and out through the soil is monitored. Results here are for three years for Ballyhooly and one year for the others.

There is significant pollution at Roundwood. At Ballyhooly, ammonium, apparently much of it from local dairy farms, has a potentially damaging long-term impact. Rain at the western sites is relatively clean, although there is evidence of a small but significant pollution influence in the region. The marine influence is strong at all sites, with very high inputs of the main marine ions, sodium and chloride, at Brackloon and Cloosh. The forest intercepts substances in the atmosphere and by this and other processes, deposition of ions on the forest floor (and consequently to forest soils and adjoining ecosystems) is generally greater than on open, non-forested land. This process is clearly seen at Roundwood where nitrogen inputs are augmented to the point where degradation of the ecosystem is likely to occur. Nitrogen inputs at the western sites are very low, but high salt inputs here may acidifiy adjoining freshwater ecosystems.

Long-term support for intensive monitoring is needed. There is a real risk of damage to forest ecosystems, and via forests to other ecosystems. Deposition and its impacts vary greatly with weather conditions, and, as with climatological monitoring, good evidence for effects which take many years must be based on several years' continuous monitoring.

Introduction

Leaching and acidification are the dominant processes in mineral soils of humid temperate climates. Leaching occurs since rainfall greatly exceeds evapotranspiration (Rohan, 1986). This removes basic cations released from minerals, which are replaced by the constant net acid inputs of rain (always acid, whether 'clean' or not) and acid excreta from plant nutrient uptake and microbial metabolism. Soil solution acidification is buffered under increasingly acidic conditions by carbonate minerals, weathering of silicate minerals and exchangeable base-generating cations; cycling of ions from deeper soil layers via plant uptake, and mixing by soil fauna also offset acidification effects. The natural acidification process can be accelerated by increased rainfall and increased or concentrated acid inputs in polluted rain.

Polluted rain has been responsible for accelerated soil acidification in continental Europe and has been implicated in a variety of growth disorders in forests. Forest decline, which has been a cause of concern in Europe since the late 1970s, takes many forms (Roberts *et al.*, 1989). Premature needle loss of conifers, premature leaf abscission of broadleaved species and yellowing arising from deficiencies of magnesium and potassium are commonly reported symptoms. Experts disagree on the underlying cause of these problems, but it is generally agreed that pollution is a factor.

The European Community Forest Health Survey was established by the Directorate-General for Agriculture in 1987 (Council Regulation (EEC) no. 3528/86). By 1990 a network had been established throughout the Community comprising 2,005 plots with a further 878 plots in non-EC European countries (Anon., 1991). The network of observation points used in the inventory is on a 16x16 km grid and covers the entire forest area of the Community. In Ireland, Coillte Teoranta is responsible for this network (McCarthy 1993).

Four intensive monitoring sites have been established in forest ecosystems by the Forest Ecosystem Research Group (FERG) in the Department of Environmental Resource Management, University College Dublin. They are designed to supply detailed information on stand, site and other environmental parameters in order to assist in the interpretation of forest health survey data. They also contribute to other studies, including research on the interaction of plantation forests and freshwater stream ecosystems (Giller *et al.*, 1993). Water, as it passes through the ecosystem is sampled continuously and analysed regularly, giving information on the effect of atmospheric deposition on the forest ecosystem, the potential impact of the forest on adjoining ecosystems, such as streams, and on elemental turnover within the ecosystem. Resources for the collection and analysis of samples are maximised through collaboration with a number of other agencies in Ireland, principally Coillte Teoranta, and in Germany (University of Munich). Joint research projects involve collaboration with several European research institutes.

Elemental turnover studies have been used extensively to advance the understanding of ion translocation, nutrient conservation and soil acidification processes within forest ecosystems (Miller *et al.*, 1979; Evans, 1984; Horn *et al.*, 1989; Heij *et al.*, 1991). They are also valuable in assessing the impact of pollutants on forests, thus contributing to the study of forest decline and understanding its causes (Ulrich, 1984). The ionic composition of precipitation is obviously relevant in this regard, but more important to the question of pollutant loads is deposition beneath the forest canopy. Although a significant proportion of the incoming precipitation is intercepted by the forest canopy, deposition of ions is often greater than on an open, non-forested site. Ionic deposition occurs, not only with rain (wet deposition), but also as aerosol and dust particles (dry deposition) and associated with fog or mist (referred to as *occult deposition*, but often included, loosely, with dry deposition). Forests, particularly coniferous forests, intercept dust and aerosol particles from the atmosphere, the so-called *scavenging effect*. Aerosols and particles, whether sea salts or pollutants, once trapped in forest canopies are washed down in subsequent rain events. In consequence, throughfall, rain which has passed through the forest canopy, usually has both higher concentrations and larger loads of most ions than the rain itself. The product of the concentration of an ion in throughfall and the volume of the throughfall gives an estimate of the deposition or load on the forest floor. The difference between throughfall and precipitation loads, therefore, is the net result of processes which include absorption through the foliage and bark (Eilers *et al.*, 1992; Klemn *et al.*, 1989), enrichment by dry and occult deposition, and leaching from the foliage.

Elemental turnover studies are important not only in the context of forest decline, but also in relation to the human influence on the landscape. The landscape of Ireland has, over the past three hundred years, been seriously disturbed by human activity. The native broadleaved forests were exploited almost to the point of extinction (Neeson, 1991) with consequences for soil fertility which are difficult, in retrospect, to quantify. Deforestation has led to the slow degradation of our soil resource and possibly to an extension of peatland development in upland regions. By 1900 little more than 1% of the land surface was under forest. As a consequence of the policy of afforestation followed throughout this century, the proportion of the land under forest is now close to 7%. Natural and semi-natural ecosystems have been disrupted by this afforestation. This has resulted in the interruption of nutrient cycles and the alteration of the ecology of ecosystems. Peatland forestry, in particular, has been the subject of debate and controversy (Hickie, 1990; Farrell, 1990a; Farrell, 1991; Farrell and Boyle, 1990). The interaction of these peatland plantations with the environment and in particular, with freshwater stream ecosystems is of importance to the economic development of regions where tourism and salmonid fisheries are major industries. Under polluted conditions in the United Kingdom, for instance, plantation forests have had a negative impact on stream water quality and on macroinvertebrate and fish populations (Gee and Stoner, 1989; Stoner and Gee, 1985; Harriman and Morrison, 1982; Hornung and Newson, 1986). Studies in sensitive fishery regions in Ireland have shown negative effects of forests on water quality (Allott *et al.*, 1990; Giller *et al.*, 1993). In this paper, the intensive monitoring of forest ecosystems in Ireland is described and preliminary results are reported.

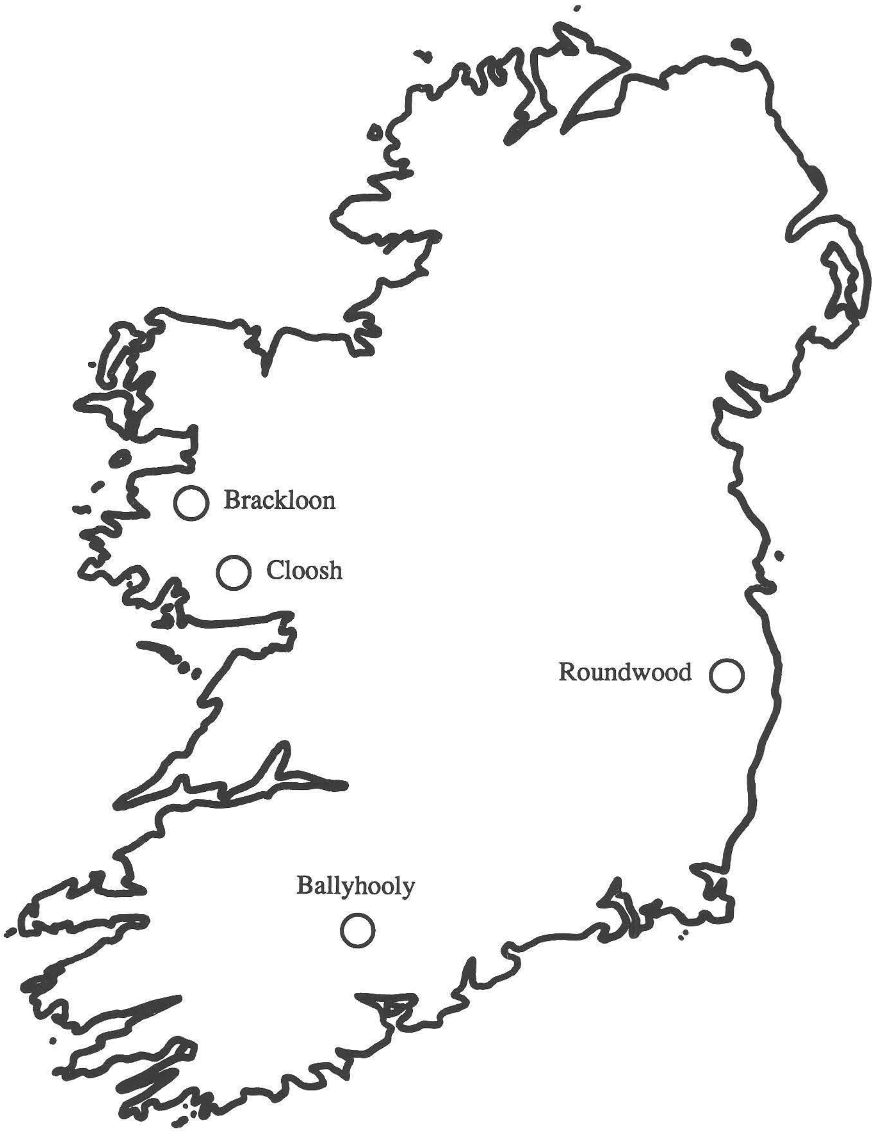

Figure 1: Location of monitoring sites.

Monitoring Sites

Details of the four monitoring sites operated by FERG in UCD are presented in Table 1 and their locations are shown in Figure 1. Each site was selected subjectively as representative of an important forest ecosystem. The first plot was established at Ballyhooly in Co. Cork in late 1988. The tree crop is a mature stand of Norway spruce (*Picea abies* (L.) Karst.) and the soil is acid and free-draining.

The other sites were established in 1991. Two are Sitka spruce (*Picea sitchensis* (Bong.) Carr.) plantations, at Cloosh in Co. Galway, on blanket peat and at Roundwood Co. Wicklow, on an acid mineral soil. The third, at Brackloon near Westport, Co. Mayo is a semi-natural oak-wood (*Quercus petraea* (Matt.) Lieb.). The soils at both Roundwood and Brackloon have podzol characteristics.

Sample Collection and Measurement

The details of sample collectors below apply to the Ballyhooly site unless otherwise stated. Installations at the other sites are broadly similar in design and distribution on site. In general, samples from individual collectors are bulked to give a single sample of each ecosystem component for each sampling event. At intervals of a few months, samples from each collector are analysed individually in order to give a measure of variance.

Precipitation: On an open site, approximately 300 m from the plot, there are three bulk precipitation collectors, each consisting of a permanently

Table 1: Details of intensive monitoring sites.

Site	Location	Stand / planting year or age	Soil / Geology	Monitoring start
Ballyhooly, Co. Cork	W 724 981 52°8'N 8°25'W	Norway spruce, 1939	Podzol / Old red sandstone colluvium	January 1989
Brackloon, Co. Mayo	L 973 799 53°46'N 9°33'W	Semi-natural oak, over 150 years old	Peaty podzol / Schist	January 1991
Cloosh, Co. Galway	M 104 346 53°21'N 9°20'W	Sitka spruce, 1958	Blanket peat / Granite	January 1991
Roundwood, Co. Wicklow	O 180 073 53°6'N 6°14'W	Sitka spruce, 1955	Peaty podzol / Schist	January 1991

open collector of radius 5 cm (collection area is 0.0079 m^2), connected via a coarse filter to a polyethylene bottle. Bulk precipitation (so called because, as the collectors are permanently open, the sample includes, in addition to wet deposition, some dry deposition) is collected weekly (or twice weekly in periods of heavy rainfall) and dispatched to the laboratory. Volumes are recorded and the samples bulked and analysed for pH, NH_4^+, P, Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, NO_3^-, HPO_4^{2-} and SO_4^{2-}. pH is measured on arrival at the laboratory, by low-conductivity combination electrode. $NH4^+$-N and P are measured colorimetrically using a visible-ultra-violet spectrophotometer. Cations (Na^+, K^+, Mg^{2+}, Ca^{2+}) are measured by inductively coupled plasma spectrophotometry (ICP). Anions ($C1^-$, NO_3^-, HPO_4^{2-}, SO_4^{2-}) are measured by ion chromatography (IC) using an anion exchange column and conductivity detection.

Throughfall: Throughfall is collected weekly in nine collectors, of a similar design to the bulk precipitation collector, located below the tree canopy but above the herb layer. The samples are bulked and throughfall water is analysed in a similar manner to the bulk precipitation. Throughfall collectors are systematically located at equidistant intervals on a plot diagonal at Ballyhooly. At the other sites they are more numerous and are randomly distributed throughout the plot.

Stemflow: Stemflow collection equipment consists of helical silicon rubber gutters, with the water diverted into 80 l PVC containers. The samples are bulked and analysed as for bulk precipitation with, additionally, dissolved organic carbon (DOC) being measured.

Soil water: Soil water is collected weekly at the forest floor-soil interface, and is extracted under suction, fortnightly, from two depths, 25 and 75 cm approximately, in the soil. There are four soil water measuring stations within the plot. Installed at each, are one zero-tension humus lysimeter, located at the forest floor-mineral soil junction and four P/80 ceramic-cup soil water samplers (two at 25 cm and two at 75 cm). In addition, a further three humus lysimeters are randomly located around the plot. Soil water is extracted using a suction of 600 hPa, which is applied four days prior to sample collection. The eight samples from each of the two depths are pooled for analysis. The analysis is similar to that for the bulk precipitation and throughfall, except that in addition, Al^{3+} is measured either by graphite furnace atomic absorption spectrometry (GFAA) or by ICP-OES. Ten tensiometers, installed at each of the two depths (25 cm and 75 cm) are read on a weekly basis.

Litter: Plant litter is collected monthly in ten collectors. Nitrogen is determined by Kjeldahl digestion and distillation. Sulphur is determined by x-ray fluorescence spectrometry (XRF). All other elements (P, K, Ca, Mg, Na and Mn) are analysed by ICP on a nitric-perchloric digest.

Table 2: Ionic fluxes (mol_c ha^{-1} $year^{-1}$) at Roundwood, 1991. Percipitation and throughfall fluxes are calculated from the product of sample concentration and water flux; humus and soil water fluxes are estimated from sample concentration, with chloride concentration used as an indicator of water flux. Chloride flux is assumed constant from throughfall to deep soil water, and on the open site, from precipitation to shallow soil water.

	H_2O	pH	H^+	NH_4^+	NO_3^-	Ca^{2+}	Mg^{2+}	K^+	Na^+	Cl^-	SO_4^{2-}
	mm		mol_c ha^{-1} $year^{-1}$								
Precipitation	1204	4.36	522	414	337	151	238	32	1511	1618	632
Throughfall	789	3.91	946	784	883	455	719	382	2945	3430	1633
Humus water	605	3.62	1449	1585	1295	853	879	423	2872	3430	1937
Soil water shallow	471	3.77	806	12	556	82	400	38	2584	3430	970
Soil water deep	681	4.04	618	48	1534	133	624	63	3120	3430	1514
Soil water shallow, open site	784	3.45	2750	6	116	145	311	69	1638	1618	881

Table 3: Ionic fluxes (mol_c ha^{-1} $year^{-1}$) at Cloosh, 1991. Calculations as in Table 2.

	H_2O	pH	H^+	NH_4^+	NO_3^-	Ca^{2+}	Mg^{2+}	K^+	Na^+	Cl^-	SO_4^{2-}
	mm		mol_c ha^{-1} $year^{-1}$								
Precipitation	1463	4.88	195	126	133	300	1072	109	5653	6134	890
Throughfall	790	4.60	199	67	110	746	1728	463	8172	9475	1428
Humus water	1092	3.67	2337	216	129	574	1733	307	8369	9475	1749
Soil water shallow	368	3.57	988	388	0	298	1903	16	6360	9475	1226
Soil water deep	513	3.99	528	1062	1	238	2021	38	6547	9475	1033

Table 4: Ionic fluxes (mol_c ha^{-1} $year^{-1}$) Brackloon, 1991. Calculations as in Table 2.

	H_2O	pH	H^+	NH_4^+	NO_3^-	Ca^{2+}	Mg^{2+}	K^+	Na^+	Cl^-	SO_4^{2-}
	mm		mol_c ha^{-1} $year^{-1}$								
Precipitation	1302	4.84	187	158	107	314	953	103	6803	6759	954
Throughfall	1143	5.17	78	90	79	907	2070	710	11236	14732	1885
Humus water	1317	4.04	1189	229	63	1458	2925	1547	14350	14732	1970
Soil water shallow	908	3.84	1300	28	0	879	2456	818	11446	14732	2004
Soil water deep	701	4.39	283	9	0	334	2537	256	9024	14732	1618

Table 5: Ionic fluxes (mol_c ha^{-1} $year^{-1}$) at Ballyhooly, 1989-'91. Calculations as in Table 2.

	H_2O	pH	H^+	NH_4^+	NO_3^-	Ca^{2+}	Mg^{2+}	K^+	Na^+	Cl^-	SO_4^{2-}	Al^{3+}
	mm		mol_c ha^{-1} year									
Precipitation	1027	5.18	67	311	126	188	352	60	2405	2232	443	
Throughfall	578	5.23	34	582	222	404	738	552	3353	4179	886	
Humus water	490	3.79	791	994	484	599	915	541	3449	4179	929	
Soil water shallow	417	4.09	332	32	413	271	584	59	3234	4179	730	610
Soil water deep	457	4.43	157	47	490	340	747	108	3508	4179	666	506

Atmospheric gases: Atmospheric gases are collected with a High Efficiency Annular Denuder (HEAD), located on an open site, and run occasionally for periods of about one week. Quantitative collection of gases, and their separation from particulate matter is achieved with appropriate sorbents as denuder coatings. These are leached off and the leachate analysed by IC (DIONEX).

Results and Discussion

Data presented are, for Ballyhooly, the mean of the three years 1989-91 and for the other three sites, for one year only (1991). Experience has shown that due to variability in weather conditions from year to year, data for a single year should be treated with caution. For precipitation and throughfall, ionic concentrations, measured in the laboratory are presented as fluxes, which are the product of concentration and the volume of water in precipitation or throughfall. Quantitative collection of humus and soil water is not possible, however. In these cases, ionic concentrations are converted to fluxes by reference to changes in chloride concentration from throughfall to the stratum in question. This assumes conservation of chloride, ie. that uptake or sorption of chloride is negligible, and that soil water movement is vertical. The second assumption is not entirely valid at all sites, thus flux data must be considered to be preliminary in nature, pending application of a more sophisticated soil-water-flux model to these sites.

There is a significant pollution influence at one of the four monitoring sites, Roundwood (Table 2; Figure 2). This forest stand has an easterly aspect within sight of the Irish Sea. It receives a cocktail of pollutants on easterly airstreams. These mostly occur under fairly dry conditions. This dry deposition is held in the canopy and appears in the throughfall following rain sometime later. As a result, deposition of sulphate, ammonium and nitrate is relatively high and throughfall pH at 3.92, is extremely low (volume-weighted mean). By comparison, the other three sites are relatively unpolluted. Deposition of the major pollutant ions at the two western sites, Cloosh and Brackloon is very low (Tables 3, 4; Figures 3, 4). In the latter two sites, the throughfall fluxes of ammonium and nitrate are both lower than the precipitation fluxes (in contrast to most ions). Ballyhooly is in an intermediate position, but even here, only ammonium deposition approaches significant levels (Table 5; Figure 5).

About 90% of ammonia emissions to the atmosphere, which give rise to ammonium in rain, are attributable to human activity, of which 90% is directly or indirectly due to livestock production (Isermann, 1991). The main source of nitrogen oxides, NOx, on the other hand, which gives rise to nitrate, has been considered to be high-temperature combustion of fossil fuels by motor traffic. However, recent evidence suggests that other terrestrial sources for nitrogen gases particularly nitrous oxide

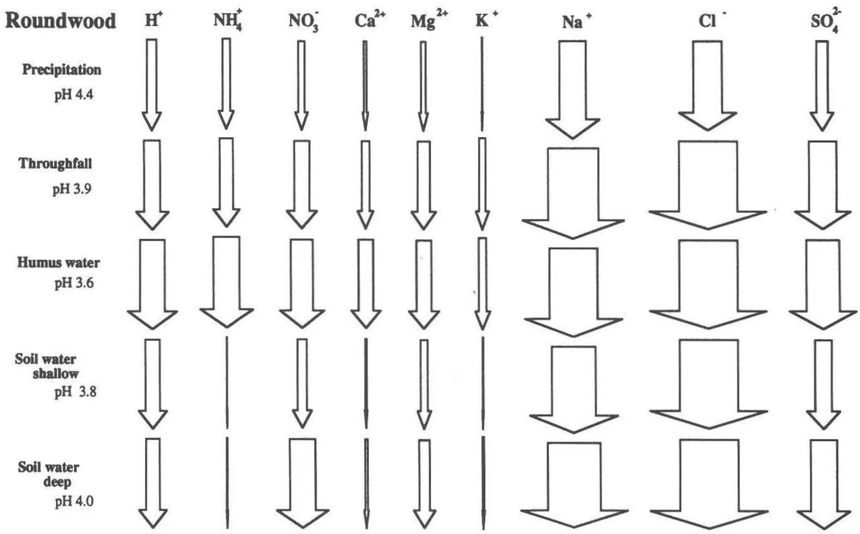

Figure 2: Ionic fluxes, Roundwood (mol_c ha^{-1} $year^{-1}$). Values are as in Table 2.

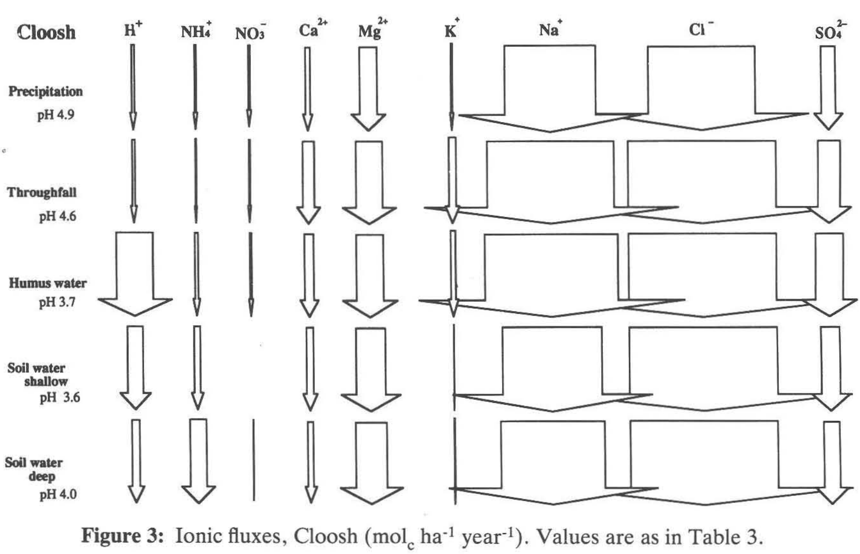

Figure 3: Ionic fluxes, Cloosh (mol_c ha^{-1} $year^{-1}$). Values are as in Table 3.

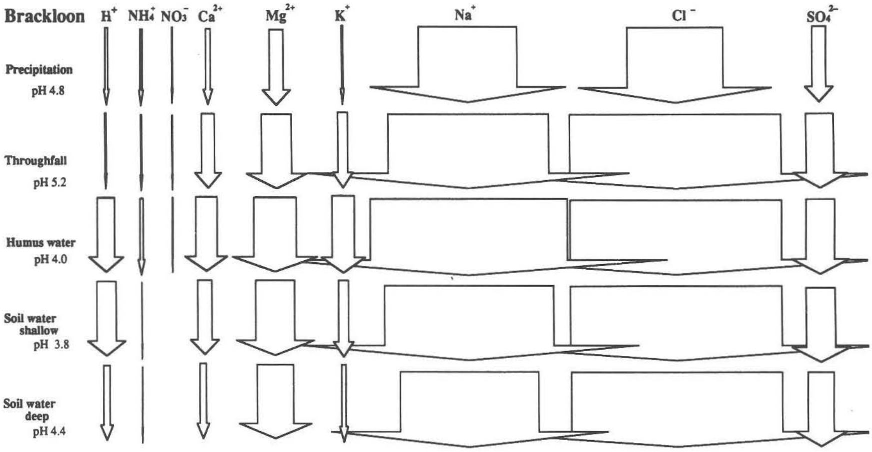

Figure 4: Ionic fluxes, Brackloon (mol_c ha^{-1} $year^{-1}$). Values are as in Table 4.

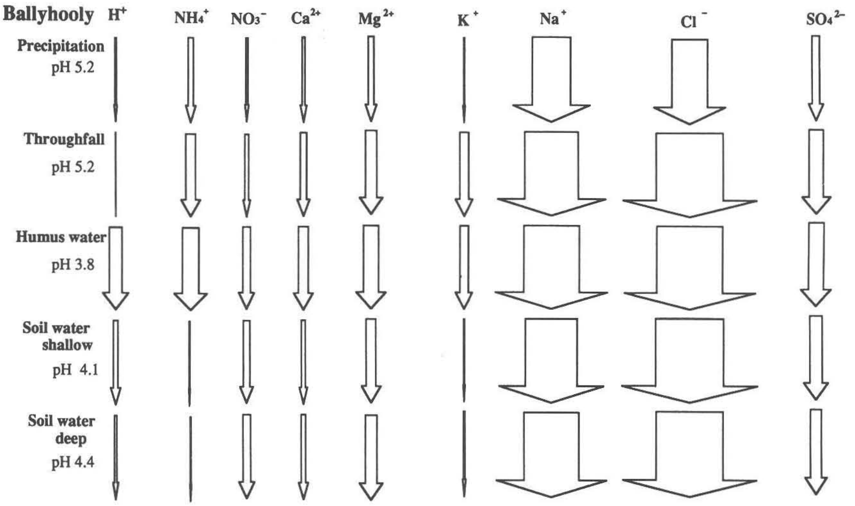

Figure 5: Ionic fluxes, Ballyhooly (mol_c ha^{-1} $year^{-1}$). Values are as in Table 5.

(N_2O)) may be significant (H. Papen, personal communication, 1993). The behaviour of nitrogen in ecosystems is very complex. The principal ionic species, ammonium (NH_4^+) and nitrate (NO_3^-) can both be taken up by plants. Ammonia gas (NH_3) is evolved from animal manure and slurry on the farms in the vicinity of Ballyhooly. Very high concentrations of both gaseous ammonia and of ammonium in throughfall have been detected on occasion. Ammonia neutralises acidity both in precipitation and throughfall, forming ammonium. However, this neutralisation is a short-lived benefit because the added ammonium reaching the soil increases soil acidification, either through plant uptake of ammonium, or through the microbial transformation of ammonium to nitrate (nitrification).

The significant contribution of nitrate to total nitrogen deposition at Roundwood, low throughfall pH, and the absence of intensive agriculture in the vicinity, all support the suggestion of a long-range pollution influence (Farrell, 1992). When levels of ammonium and nitrate in throughfall at all four sites are compared (Figure 6), it can be seen that total nitrogen deposition is greatest at Roundwood. Ammonium and nitrate levels are almost equal here, suggesting a mixing of pollutants from different sources during long-range transport. The correlation between ammonium and nitrate in precipitation (0.997, $p < 0.001$; Kramadisastra, 1993) supports this contention. Concentrations of ammonia in the atmosphere are lower at Roundwood than at Ballyhooly (Farrell *et al.*, in preparation). Consequently, the neutralising effect of ammonia is reduced and pH values are very low, particularly in throughfall.

In recent years, pollutant loads have been described in terms of critical load, *a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects to specified elements of the environment do not occur . . .* (Hettelingh *et al.,* 1991). Critical loads for coniferous forest

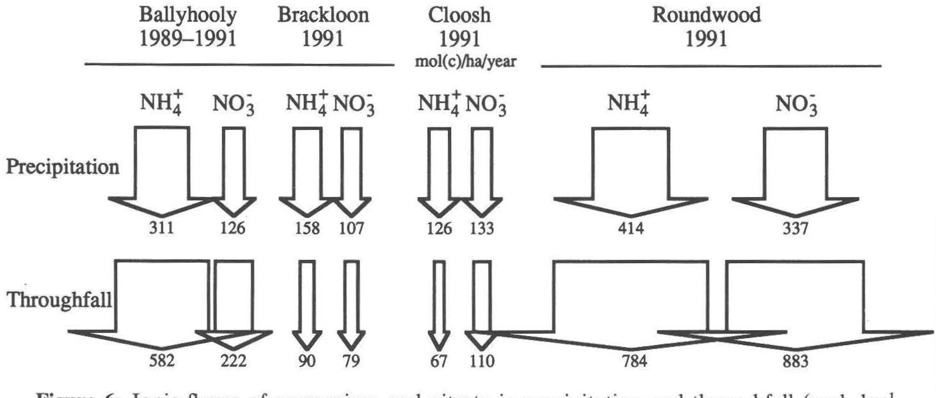

Figure 6: Ionic fluxes of ammonium and nitrate in precipitation and throughfall ($mol_c\ ha^{-1}\ year^{-1}$) at the four monitoring sites. Values are as in Tables 2-5.

ecosystems in the Nordic countries are of the order of 3-11 kg N ha^{-1} $year^{-1}$ (Sverdrup *et al.*, 1992). Total nitrogen deposition at Roundwood in 1991 was about 24 kg N ha^{-1}, significantly higher than the admittedly crude estimates of critical load which are available to date.

High salt concentrations have been reported for rainfall and throughfall in western Ireland (Farrell, 1990b). Results from the monitoring sites at Cloosh and Brackloon confirm this finding (Tables 3, 4; Figures 3, 4). The principal marine ions are sodium and magnesium amongst the cations and the anions chloride and sulphate. By comparison with continental European sites (Rasmussen, 1990; Rasmussen *et al.*, 1992), salt concentrations are high even at Ballyhooly. This establishes clearly that the marine influence is strong throughout Ireland.

The uptake of both sodium and chloride by plants is negligible in comparison with inputs, in an oceanic region. Chloride, as stated earlier, is a very mobile ion, not involved in sorption processes in the soil to any significant extent. Sodium, however, as with all cations, can be adsorbed onto the exchange complex of soils. There, it is held in a form in which it may be easily exchanged for other cations. It is possible that following a major storm event, when inputs of sodium and chloride are particularly high, that a significant proportion of the sodium is held on the exchange complex, displacing other cations including hydrogen. This could lead to the export of acidity from the forest, resulting in a temporary acidification of streamwater. This phenomenon has been reported for maritime regions in Scotland (Langan, 1987). Evidence for its occurrence in Connemara has been put forward by Allot *et al.* (1990). Annual mean deposition quantities for the Cloosh and Brackloon sites (Tables 3, 4; Figures 3, 4) would seem to support this. They show a pronounced change in the Na^{+}:Cl^{-} ratio as the water moves from throughfall to the deeper soil. This imbalance, however, would seem to suggest a long-term storage of sodium in the soil. No other evidence is available to support this.

Sulphate has two major sources, combustion of fossil fuels and the sea. By correcting for marine contributions, according to the ratio of an ion such as chloride, to sulphate in sea water, it is possible to estimate the proportion of sulphate deposition arising from pollution. There is a significant marine contribution at all four sites but the proportion of non-marine (also called "excess") sulphate varies from about 25% of the total in the western sites to 50% at Ballyhooly and 75% in Roundwood. In some respects 25% excess sulphate at the western sites could be considered surprisingly high. In fact, it goes to confirm that there is a small but significant pollution influence in the region. Indeed, in Cloosh, precipitation pH was above the conventionally accepted 5.6 threshold for acid rain during only two weeks in 1991.

Calculation of ionic fluxes in the soil provides a useful indication of the export of pollutants to surface waters, adjoining streams or lakes, and groundwater. Potential pollution at these sites can come from acidity, from aluminium which is toxic to living organisms, and nitrate which can be toxic and also contributes to eutrophication. It is therefore interesting to look both at the concentration of ions such as hydrogen (measured as pH) and aluminium and nitrate in the deepest soil water samples and also the flux of nitrate and aluminium. Roots are rare or absent at this depth (75 cm) and the sample is considered to represent water exported from the site. The Cloosh site is different, in that there is significant surface runoff laterally through the forest floor.

Soil water is very acid at all sites. At Cloosh and Brackloon it is more acid in the forest than at the open site. At Cloosh, annual mean soil water pH at 25 cm is 3.6, compared to pH 4.2 in the surface water of the open bog (Farrell *et al.*, in preparation). At Roundwood, however, the open site soil water is more acid than in the forest (Table 2). Determination of the influence of the forest canopy on soil water is complicated by the difficulty in finding a comparable, non-forested site. At Roundwood and Ballyhooly, the open sites available were clearfells. In Brackloon, old forest land cleared for agriculture is used, and in Cloosh, an area of undrainable bog. Despite this difficulty in interpretation, the capacity for the forest to develop higher atmospheric deposition loads than occur on open land is clear. The interceptive capacity of the canopy is reflected in higher fluxes of most ions in the throughfall and soil water.

Conclusions

Over most of Europe, environmental concern is focused on the problem of forest decline. In Ireland, however, attention has been concentrated not on the influence of the environment on the forest, but on the impact of plantation forests on the environment.

The ability of trees to intercept pollutants from the atmosphere is well known. The establishment of a forest plantation results in a drastic alteration of the original ecosystem. In the case of natural and semi-natural ecosystems, this disruption carries an inevitable risk of environmental damage.

The evidence from four intensive monitoring plots in Ireland suggests that one, Roundwood, experiences significant pollutant deposition. It is at this site that forest damage is most likely to occur and it is here also that a negative impact on surface waters might be anticipated. At Cloosh, there is little evidence of pollution deposition, although soil water is more acid under the forest then in the open. Acid events may occur here as a result of occasional instances of acid deposition or due to the displacement of protons from the soil exchange complex by sodium ions. However, the data reported here should be treated with caution. While they do indicate evidence of long-term ecosystem degradation, particularly at Roundwood, this is based on only a single year's data. Changes in forest ecosystems generally occur slowly. Long-term monitoring is required to provide the level of understanding needed before management strategies to reverse or mitigate damaging effects can be developed.

The modern forest manager would do well to consider him or herself not as a manager of a timber crop but as a manager of a plantation forest ecosystem, the primary objective of which is to produce timber. This simple adjustment in attitude alters the ground rules considerably. It brings a recognition that forest management results in ecosystem disturbance and that precautions are necessary to ensure that this disturbance is controlled and its detrimental consequences minimised.

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An Integrated Study of Forested Catchments in Ireland

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Summary

Forestry is an important component of the Irish landscape and many of our river systems rise in or pass through forested catchments. Because of the scarcity of objective and broad scale data from Ireland, a national research group AQUAFOR, has been established to investigate, in a multidisciplinary way, the interactions between forestry and aquatic ecosystems. There are three study areas in the west (Connemara), east (Wicklow), and south (Munster) of the country. Preliminary results of these studies are presented in this paper.

Marine ions, sodium, chloride, magnesium and sulphate dominate the atmospheric input to all catchments, particularly in the West. Dry deposition of these ions can also be high, giving the western sites extreme concentrations on occasions. Concentrations of these ions are increased by the passage of rainfall through the canopy of forests, thus increasing the concentrations of most in the soil waters. Stream water studies in a number of forested catchments have shown that acid episodes, with pH values frequently less than 4.0, can occur in the east and west on granite and other soft water catchments. Concomitant with these changes in pH, values of labile monomeric aluminium increased dramatically during low pH events and often exceeded 0.2mg/l, the concentration thought to be toxic to salmonids. In contrast, pH values in the better buffered catchments in southern Ireland did not drop below pH 5.0, irrespective of the land use and similarly aluminium levels were generally low (less than $0.1mgl^{-1}$ total aluminium). From these preliminary results therefore, only a proportion of the country as a whole may be expected to be vulnerable to acidity problems associated with plantation forestry.

Biological data supports the general conclusions from the chemical studies. Macroinvertebrate communities varied with chemistry across all sites in all three regions. Diversity tended to be lower in afforested sites on sensitive geologies in the east and west whereas in the south, macroinvertebrate abundance reflected stream water chemistry *per se* rather than the type of land-use, with most sites having the acid-sensitive mayflies. Fish distributions in Wicklow were found to be associated with changes in altitude and the amount of afforestation in the catchment with nine sites of the nineteen fished being fishless. Similarly only two of the eleven suitable sites in the West had no fish. In the South, fish densities tended to be higher than elsewhere and in the few sites where fish were absent, physical features (waterfalls) rather than hydrochemistry and catchment land-use were more likely to be the cause. Fish densities here did show a decreasing trend with amount of catchment afforestation although fish condition appeared to be unaffected by land-use.

Preliminary results from hydrological studies in the South indicate that the traditional methods (i.e. catchment characteristics/unit hydrograph) of stream flow computation are unreliable. This may be due to the forest land-use not being accommodated in the traditional methods.

1. Introduction

Ireland is part of the temperate deciduous forest biome. Deciduous woodlands of oak (*Quercus*), elm (*Ulmus*) and ash (*Fraxinus*) once covered extensive areas of lowlands. These forests were gradually cleared for agriculture and industry, such that 100 years ago only about 1.5% of the land was forested. The process of reafforestation began early in this century and has been based almost entirely on the exotic coniferous species. Today, about 6-7% of the land area is forested, with small units of intensively managed and highly productive coniferous plantations and there is an accelerating programme of planting designed to achieve an annual planting target of 30,000 ha by 1995 (Anon. 1991). The principal species used in coniferous plantations is Sitka spruce (*Picea sitchensis* (Bong.) Carr.).

The influence of the surrounding landscape and land use on the streams and rivers in the catchment has been highlighted as one of the most important factors governing the nature and ecology of aquatic systems (e.g. Hynes 1975). Concern has therefore been expressed in recent years that plantation forest, or any number of forest operations, may impact negatively on surface water quality and fish populations in important fishery regions. This concern is based in part on research that has been carried out on the interaction between afforestation and freshwater systems in other countries (see O'Halloran and Giller, 1993, for a review). In certain geologically sensitive catchments of Wales and Scotland, i.e. those with poor buffering capacity (such as granite and quartzite bedrocks) and in areas under the influence of atmospheric pollution, streams and rivers draining coniferous afforested catchments were found to be more acidic and/or contain higher aluminium concentrations than those in adjacent moorlands with similar soils and geology. Plantation forests, in keeping with all terrestrial ecosystems, do generate acidity by a number of natural processes which occur within the ecosystem (see Farrell *et al.,* 1993). However the ability of forest vegetation to intercept dust and aerosol particles from the atmosphere, particularly important with evergreen coniferous forest, leads to the concentration of most ions in the throughfall of rain under the canopy to be much greater than in the open (see Farrell *et al.,* 1993). In polluted environments, the throughfall is acidified and in geologically sensitive catchments, this may lead to an increase in acidity in the soil and an increase in the solubility of potentially toxic aluminium ions in soil water. The consequences for the ecology of aquatic systems and particulary to fisheries, can be profound when significant changes in stream water chemistry occur (see O'Halloran and Giller, 1993).

Being on the Western European seaboard, Ireland receives less atmospheric pollution than most other countries in Europe, but to date, very little information is available on the interactions between forestry and the aquatic environment here. In an earlier study of surface waters in Connemara and south Mayo (Allott *et al.*, 1990), it was concluded that in poorly buffered catchments, there was a correlation between percentage forest cover and certain chemical characteristics of the streamwater, principally acidity, aluminium and dissolved organic carbon concentrations. Subsequently, three major research projects (the SALFOR, ARAGLIN and AQUAFOR projects) have been conducted, involving interdisciplinary teams from University College Cork, University College Dublin and Trinity College Dublin. This national research group, known as AQUAFOR, is investigating the interaction between plantation forest and freshwater stream ecosystems, on a nationwide scale. This work is complemented by information supplied by a network of forest ecosystem monitoring plots, with the objective of obtaining more direct information on the influence of the forest on soil water (see Farrell *et al.*, 1993).

The objectives of the research undertaken by AQUAFOR are fourfold:

1. To examine the ionic composition of bulk deposition (precipitation) and changes through the forest canopy and into the soil.
2. Examine the physical effects on catchment hydrology in selected afforested catchments.
3. To examine the concomitant changes in stream water chemistry in afforested catchments on both sensitive and non-sensitive geologies.
4. To investigate the influence of such physical and chemical changes on the biota (macroinvertebrates birds, and fish) and ecology of running water ecosystems in afforested catchments.

Although the overall research is in its early phases, we believe that it is useful to present some of the preliminary results of this large scale research programme at this time, given the level of interest in the interactions between forestry and aquatic ecosystems, particularly in relation to the forest/fisheries guidelines.

2. Study Areas

The locations of the AQUAFOR study areas are outlined on Figure 1.

Study Area 1 is on the west coast and is subsectioned into sites 1A, 1B and 1C. (see Figure 1). 1A, in south Co. Galway (including Owenboliska and Casla catchments) is underlain with granite. 1B, extending into south

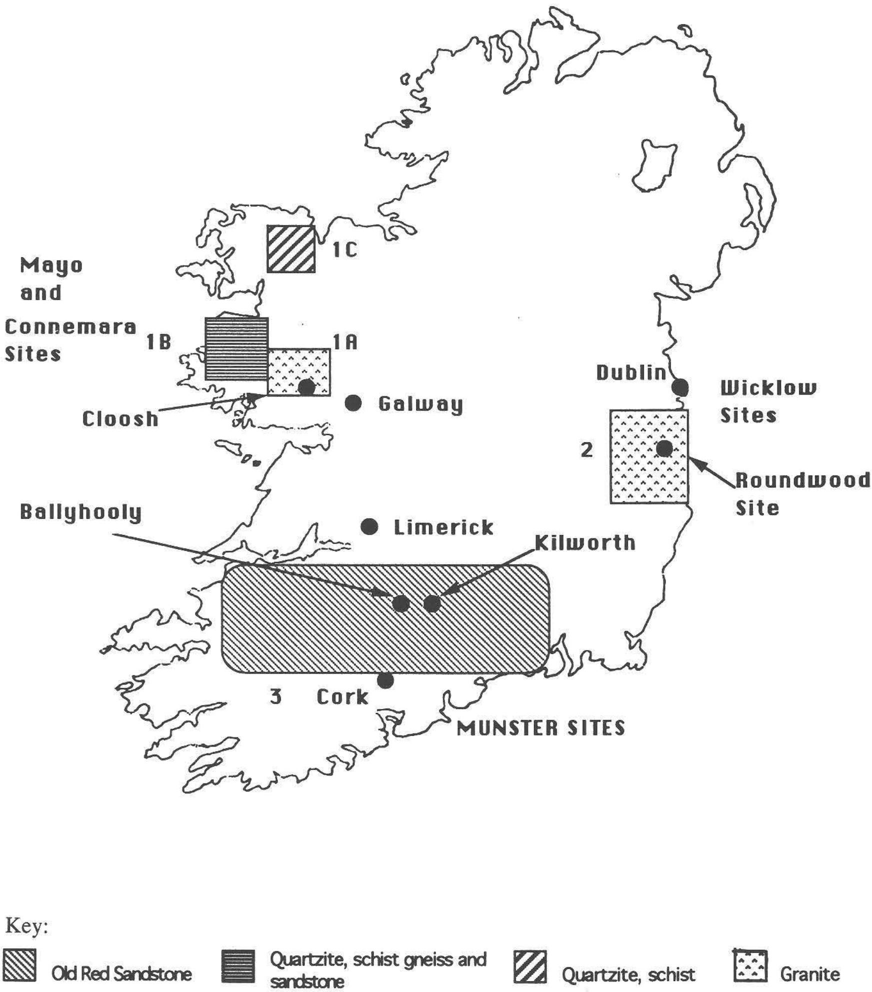


Figure 1: Location map of Study Areas 1-3, intensive sites and predominant underlying geology.

Co. Mayo (Burrishole catchment) is of mixed geology with quartzite, schist gneiss and sandstone, whilst 1C (including Invermore catchment) is chiefly quartzite and schist. An intensive small forest ecosystem monitoring site is located in Cloosh in County Galway within site 1A, on granite. Forest cover in catchments ranges from 0-100%.

Study Area 2 is on the east coast, south of Dublin in the Wicklow mountains and includes streams in the catchments of the Liffey, Kings and Avonmore rivers and Lough Dan/Tay and Vartry reservoir. The underlying geology is predominantly granite. A small forest ecosystem monitoring site is located within Study Area 2, on granite near Roundwood, Co. Wicklow.

Study Area 3 is in the south of the country, incorporating sites from east to west Munster, including tributaries of the Lee, Blackwater, Araglin and Tar, and streams in the Currane system in Kerry and near Glengariff, W. Cork. The area is largely underlain with old red sandstone and shales, although some sites have gravelly glacial drift and a few possess areas of carboniferous limestone. Kilworth forest (with a catchment area of 17.76 sq. km.) is an intensively studied catchment area in the Araglin valley, 25kms north of Cork City and Ballyhooly is a small forest ecosystem monitoring site relatively close by.

Most of the sub-catchment streams are in upland areas and are 0.5-4m in width but main catchment rivers are up to 12m in width in their lower reaches. The majority of the study streams are fast flowing and are subject to spate conditions. Sampling sites range from typical open moorland streams to those running through closed canopy coniferous forest and/or agricultural land. Afforested sites vary in the degree of forest cover and tree age.

3. Materials and Methods

3.1 Bulk Precipitation, Throughfall, Humus and Soil Water.

These parameters are being monitored at the three intensive forest monitoring sites, Cloosh, Roundwood and Ballyhooly (Figure 1). Details of the equipment and analytical techniques are given by Farrell *et al.*, (1993) and Farrell and Boyle (1991).

In Kilworth forest, there is a continuous rainfall recorder of the electronic tipping bucket type, set in an open area within the forest boundaries. This allows matching of rainfall data to the stream hydrographs generated by the continuous stream water level recorders (see below). There is also a similar rain gauge in the Araglin moorland catchment, to the east of Kilworth (catchment area 1.5 sq. km.).

3.2 Stream Flows and Bed Load Sediment

The Kilworth forested site and Araglin moorland sites are fully instrumented for these parameters. There are five water level recorders in Kilworth and two on the Araglin moorland sites. The continuous automatic water level recorders are zero set to the crest of the downstream end of a sediment trap, which forms a pseudo-broad crested weir. As the level recorded is zeroed to the sediment trap, a laboratory calibration for flow was required, as the geometry of the sediment trap was not comparable to a standard broad crested weir. The laboratory calibration yielded an equation for flow different to the broad crested weir equation:

$$Q = 1.750B\,H^{3/2} \text{ (Broad Crested Weir)}$$
$$Q = 2.54B\,H^{1.56} \text{ (Sediment Trap Equation)}$$

where Q = Flow, B = Width of weir, H = Height of water over weir. Continuous flow records at the five locations in the Kilworth forested site and at the two locations in the moorland are available. Water level recorders on simple weirs have also been established at three stations in the Owenboliska catchment in Connemara to relate episodic chemical changes to the stream hydrogaph under afforested and unafforested conditions.

3.3 Stream Water Chemistry

Samples were collected, stored and analysed in accordance with the routine analytical procedures outlined in Standard Methods (Clesceri *et al.*, 1989). Chemical parameters determined in stream water include, pH, alkalinity, calcium, magnesium, sodium, potassium, chloride, nitrate, sulphate, total organic carbon and total and labile monomeric fractions of aluminium. Sampling intensity varied between fortnightly (November-May) at approximately 25 intensively monitored sites in Study Areas 1 and 2, to seasonally at extensive sites in Study Area 3. Remote automatic water samplers have been installed in each of the three study areas to respond to rising water levels in order to characterise the water chemistry during spate events.

3.4 Stream Water Ecology

Biological sampling has been carried out on an extensive scale during spring and autumn, but approximately monthly at several intensively monitored sites in Study Area 3. Invertebrates were collected from riffle zones using a 0.062m^2 Surber sampler. Five random replicate samples were collected from each site and taken to the laboratory, sorted and identified to the operational taxa (species, family, order depending on animal type). Initial analysis of invertebrate data comprised estimation of density, taxon richness and diversity and the abundance of potential indicator species (such as pH sensitive forms).

Salmonid fish populations were determined using the removal method (Zippen, 1956). Thirty or fifty metre stream lengths were enclosed using stop nets and electrofished. Fish were identified, weighed, measured and scales removed from representative individuals for age determination

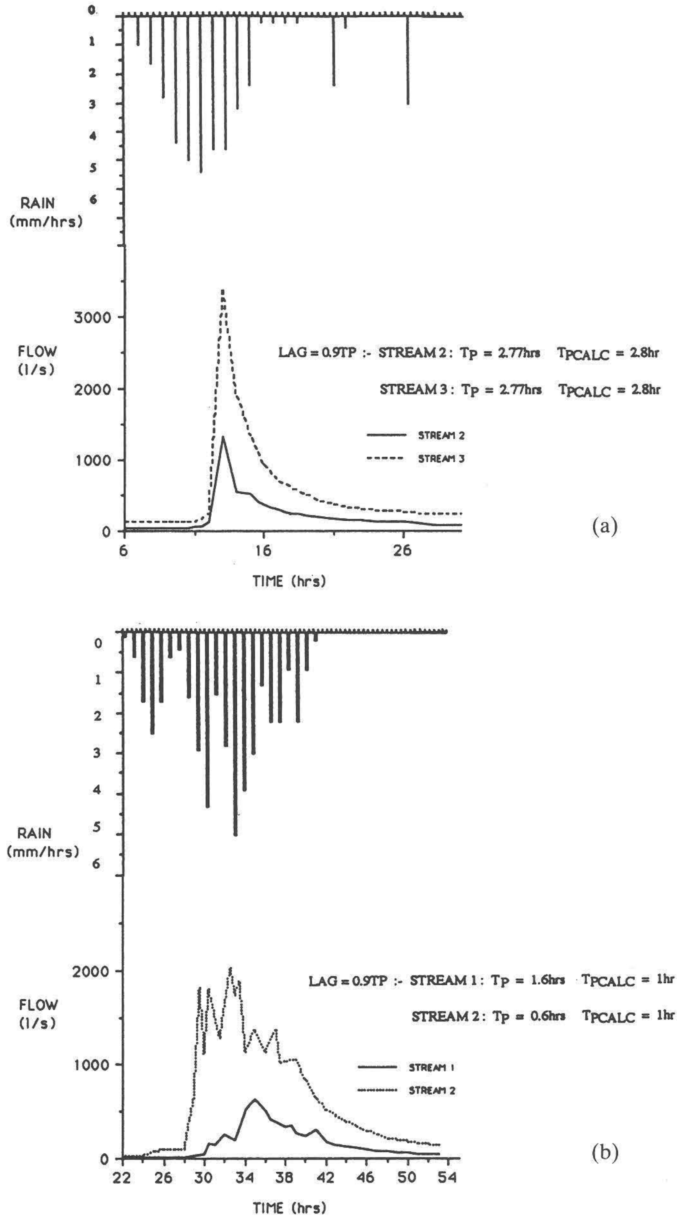


Figure 2: Stream hydrographs in relation to rainfall events in two streams in (a) Kilworth Forest and (b) two moorland tributary streams of the Araglin River in Study Area 3.

before release. On each sampling occasion, flow rate (high, medium and low), pH, conductivity, oxygen and temperature were recorded. Vegetation, substrate type and detailed catchment characteristics were also assessed. Fish density, (numbers per m^2) was calculated at each site based on the area of the stream within the 30-50 m stretch sampled (average width (m) x 30-50). Fish condition (k) was calculated as $100.W(g)/L(cm)^3$; W-weight, L-fork length, (Bolger and Connolly 1989).

4. Results

4.1. Changes in the Ionic Composition of Precipitation

Results from the forest ecosystem monitoring studies are reported in Farrell *et al.*, (1993). They illustrate clearly the interceptive effect of the forest canopy. They also show a marked difference between regions. The Cloosh site is relatively unpolluted. Nitrogen inputs are very low. Rainfall acidity, however, is greater than expected and about 25% of throughfall sulphate is of non-marine origin, indicating a small, but significant pollution influence.

The Roundwood site, by contrast, is quite seriously polluted. Deposition of non-marine sulphate, ammonium and nitrate is high in both rainfall and throughfall. At Ballyhooly, ammonium inputs are significant. While ammonia, from dairy farms in the locality, neutralises protons in the rainfall, it generates increased acidity in the soil through uptake of ammonium and/or conversion to nitrate.

4.2 Physical Effects – Stream Hydrology

The most detailed information is available from Study Area 3, particularly in the Douglas river streams flowing through Kilworth forest and on two headwater tributary streams of the River Araglin on nearby moorlands. Preliminary results from hydrological studies indicate traditional methods (i.e. catchment characteristics/unit hydrograph) of stream flow computation are unsatisfactory. This is due to the forest land-use and the small size of the catchment areas , neither of which are accommodated in the traditional methodology. Autographic rainfall recorders and continuous water level recorders (at seven locations) will yield data that will be used to establish rainfall/runoff relationships in these catchments.

Preliminary analysis of stream response times to rainfall events is indicated by the time to peak of the flood event. These time values are much shorter on the moorland (approx. 1 hour) than on the forested catchment (2.5-3.4 hours). Forested areas can absorb more water due to trees, humus and soils than moorlands, so forested catchments should be expected to respond slower. There are also marked differences in flood magnitude on the different land types (Figure 2). Additionally, streams within the forested catchment differ in the degree of potential flood disturbance. The

Table 1: Details of site catchments and important chemical parameters for the main group of catchments in Study Area 1 (Non-Marine Ions indicated by NM). The sites are mostly located in the Owenboliska catchment, Co. Galway.

Site	Area km^2	Forest %	H^+ $\mu eq\ l^{-1}$	Cond μScm	DTO C $mg\ l^{-1}$	LM–Al $\mu g\ l^{-1}$	Ca^{2+}	Mg^{2+}	NM Ca^{2+}	NM Mg^{2+}	NM SO_4^{2-}	NM Na^+
Ob7	1.18	100.0	88	263	14.9	108	169	338	94	13	4	-161
Ob1	0.42	100.0	86	259								
Ob8	1.15	100.0	54	231	12.5	80	155	313	73	19	11	-114
Lc1	0.42	66.8	46	199	5.8	87	97	297	48	35	49	-111
Ob2	1.37	100.0	44	219	10.3	73	165	285	107	10	20	-113
Ob13	0.61	0.0	38	154	5.4	12	51	171	23	5	35	-14
Ca5	2.3	0.0	20	166	5.7	16	73	253	42	36	35	-67
Ob9	1.35	35.9	18	159	7.0	36	117	234	70	27	27	-53
Ob14	0.17	0.0	17	141								
Cr2	11.8	0.0	15	163	3.8	12	76	237	46	24	38	-66
Ob5	8.11	30.4	15	169								
Ob3	3.95	18.4	14	165	5.6	48	129	242	86	31	25	-91
Ob12	2.63	14.5	13	159								
Ca6	9.85	0.3	8	167								
Ca2	2.33	2.4	6	153	4.2	21	113	226	72	20	19	-70
Ob10	3.7	0.0	6	160	6.8	26	159	210	121	32	31	-50
Ob11	1.17	0.0	4	165	5.5	22	145	187	107	17	25	-49
Ob4	2.46	0.0	2	151								

DTO = Dissolved Total Organic Carbon
LM-AL = Labile Monomeric Aluminium

role this has in regulating the fish and invertebrate communities has yet to be examined.

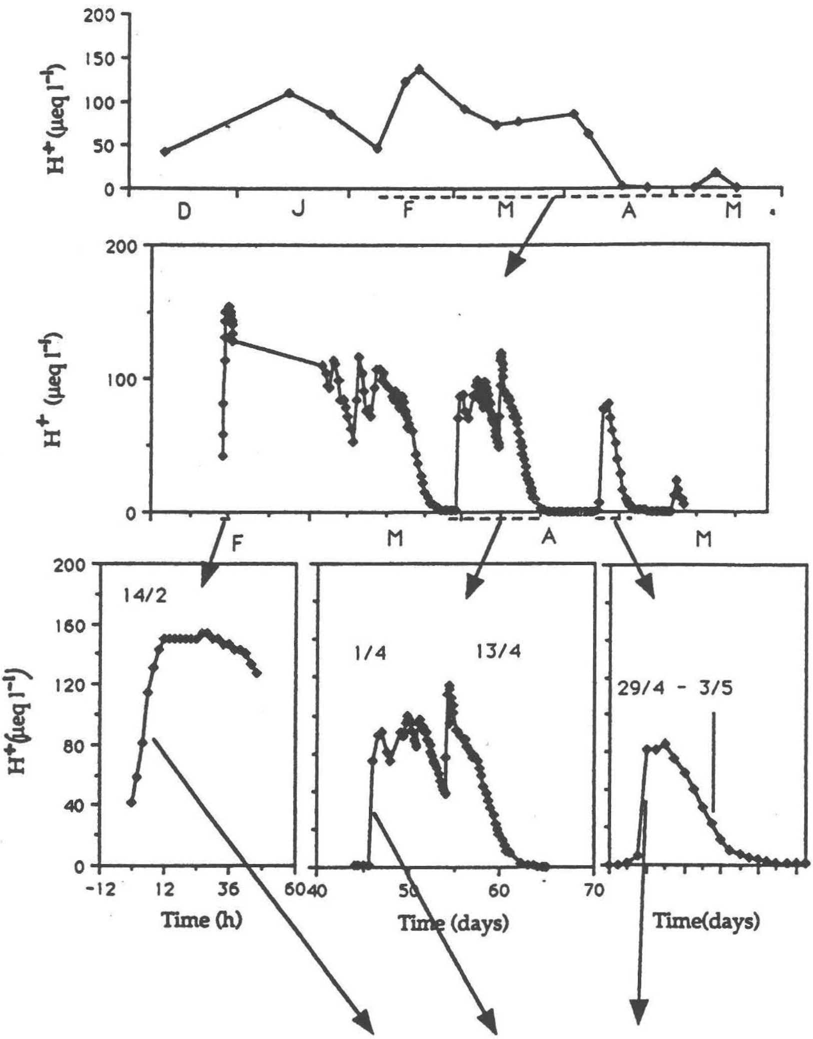
4.3. Stream Water Chemistry

Results are presented separately for study areas on sensitive (poorly buffered) and non-sensitive geologies.

(i) Sensitive Geologies

Intensive studies have been carried out at 18 sites in Study Area 1A, largely based around the Owenboliska catchments (Fig. 1). Mean results for the more important parameters are presented in Table 1. The non-marine (NM) components were calculated by using the average ratio of the ion to chloride in seawater as a correction factor.

The highest levels of hydrogen ions (H^+) in stream water were associated with the catchments with the highest percentage forest cover. These sites also had the highest conductivity. This result is explained by the interception effect by coniferous forest (see Farrell *et al.*, 1993). Because of the proximity of the Atlantic, the interception of sea salts by the tree canopy may be implicated in particular. Levels of total organic carbon tend to be higher in stream waters in afforested catchments than in unafforested ones. This is presumably the result of a relatively high rate of peat decomposition which



NM Na (μ eq/l)	-202-> -218	-55-> 41	258-> 263
DTOC (mg/l)	3-> 4	12-> 17	13-> 19
NM SO_4 (μ eq/l)	2-> 42	-20-> 37	31-> 27

Figure 3: Trends in H^+ over time (months and 2-24hr intervals) at site OB8 on the Galway granites (100% upstream forest cover). The arrows indicate which portion of one graph is represented in another. The lower group of arrows point to changes in non-marine sodium NM Na^+, dissolved total organic carbon (DTOC) and non-marine sulphate (NM SO_4^{2-}) that corresponds to periods when H^+ increased sharply.

could result from improved drainage in the afforested catchments. Levels of labile monomeric aluminium are also greater in afforested catchments than in unafforested ones. Labile monomeric aluminium is the fraction of aluminium that is toxic to organisms.

Non-marine (NM) Ca^{2+} is one estimate of a catchment's ability to neutralise acidity. The values for NM Ca^{2+} show that sites OB7 and OB8 (two of the most acidic sites which are heavily afforested) are not particularly vulnerable to acidification compared to the other sites; however, this interpretation may be problematic due to soil ion-exchange factors and is an area of interpretation currently being studied. The catchment of site OB13, which is unafforested, would appear to be extremely vulnerable to acidification (average NM Ca^{2+} of 23 μ eq 1^{-1}) and yet the maximum concentration of H^+ at OB13 was about one half to one third of that at the afforested sites.

Figure 3 gives selected results for one site (OB8, 100% upstream forest cover) on which an automatic sampler was installed. The top graph shows the trend in H^+ between mid December and May (1991) based on the regular manual samplings. The middle graph shows that the trends in H^+ are much more episodic than is implied by the regular samplings. Detailed trends of selected episodes are shown in the lower graph of Figure 3 along with associated changes in NM Na^+, DTOC and NM SO_4^{2-} which

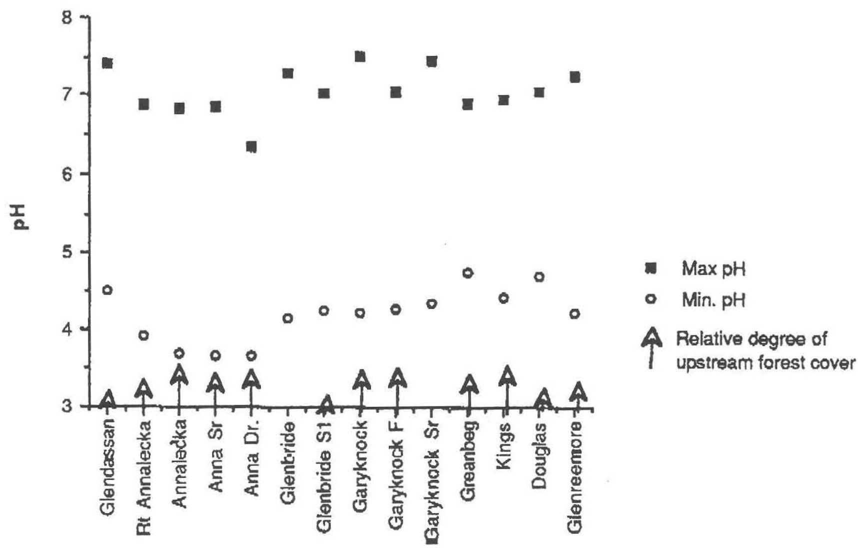


Figure 4: Mean, low and high pH values for streams in the Kings River catchment. Relative degree of upstream forest cover is also indicated.

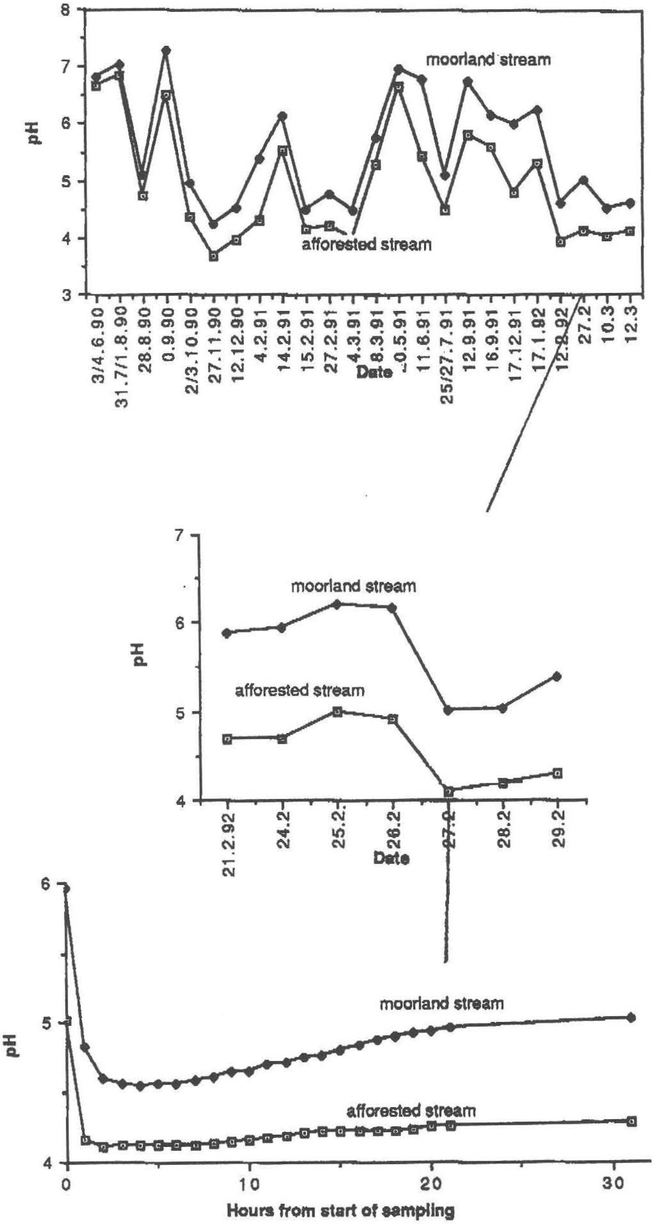


Figure 5: Monthly (a), daily (b) and diel (c) variation in pH from a moorland (Ballinagree) and afforested (Annalecka) stream.

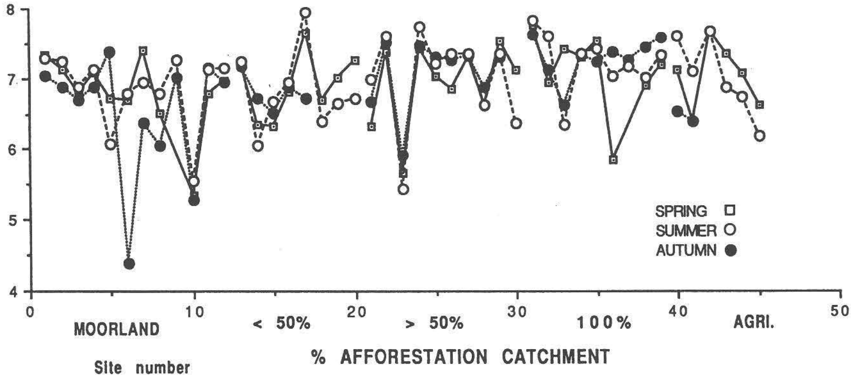


Figure 6: Variation in pH with season and land use (moorland, agriculture and variable % afforestation) across all sites in Study Area 3

give clues to the source of acidity. The February event appears to have been caused by NM SO_4^{2-} while the first March event had a NM SO_4^{2-} and a seaspray component (the forest ecosystem data from Cloosh provides direct evidence of this deposition). The late March event appears to have been caused by NM SO_4^{2-} while the April event may have been caused by an increase in organic acidity. The NM SO_4^{2-} driven events result from episodes of acid rain.

Extensive monitoring was carried out at three stations on 15 of the sites on sensitive geologies in Study Area 2, however only twenty of these were sampled intensively. Conductivities generally ranged from 50-130 μS cm^{-1} on granite and 60-100μS cm^{-1} on Silurian/Ordivician geology. During low water conditions, most sites had recorded pH values greater than 6, however, when streams were in flood, pH fell well below 5 and a value of 3.7 has been recorded. During these episodes, the pH of afforested streams was up to 1 unit lower than adjacent non-afforested sites (Figure 4). Continuous monitoring of pH during spate conditions indicates a rapid fall in response to rising water levels and again a consistantly lower pH associated with the afforested system (Figure 5). Aluminium levels were well below the critical level (0.2mgl^{-1} labile monomeric) during low water conditions. However, once again, when water levels were high, these values exceeded 0.2mgl^{-1} and reached 0.8mgl^{-1} at a small number of streams which drain closed canopy forestry for almost their total length. These results support those from Study Area 1 in the west, indicating that afforested streams on these sensitive geologies tend to have lower pH and higher aluminium levels than adjacent non-afforested sites.

(ii) Non-Sensitive Geologies

In contrast to the data from Study Areas 1 and 2, most pH levels did not drop below 6 at the 45 sites in Study Area 3. This area was sampled seasonally across a range of catchments of differing land use (moorland, <50% afforestation; >50% afforestation; 80-100% afforestation, agricultural; Figure 6). Similarly, there were no apparent trends between stream water hardness or conductivity and catchment land use (hardness range – winter 5-72mgl^{-1}, spring 6.5-51 mgl^{-1}, summer 7-64 mgl^{-1}; conductivity range – winter 53-199.5 μS/cm, spring 53-159 μS/cm, summer 49-186 μS/cm). Whilst several sites would be classed as potentially sensitive to acidification (i.e. hardness values of less than 12 mgl^{-1}), this classification applied to both moorland and afforested sites equally. Aluminium levels recorded to date have all been low, with total Aluminium values below 0.2 mg/l (most below 0.1mgl^{-1}). During flood events, 48hr records from the intensive site at Kilworth show a decline in pH with rise in water levels, but generally of less than one pH unit (e.g. from 7.2 to 6.6). Aluminium levels showed no pattern of change during such events. From these preliminary results, afforestation on the non-sensitive geologies in Study Area 3 does not appear to show any marked effect on water chemistry in comparison with adjacent moorland sites in contrast to the findings in the other two Study Areas.

4.4 Stream Ecology

Results have been presented separately for Study Areas on sensitive (poorly buffered) and non-sensitive geologies.

(i) Sensitive Geologies

Several of the intensively studied sites in Study Area 1 were quite small and would not be expected to hold a wide range of invertebrates or fish. Nine of the eleven suitable sites had a good range of invertebrates (including the acid sensitive Ephemeroptera) and fish, chiefly brown trout (*Salmo trutta*) and eels (*Anguilla anguilla*), were present. Of the remaining two sites (both heavily afforested), one (LC1) had reasonable numbers of invertebrates but reduced diversity, while the other (OB8) had both reduced diversity and reduced numbers of invertebrates. Neither LC1 nor OB8 had any Ephemeroptera and the two sites appear to be fishless.

In Study Area 2, a total of 63 sites were electrofished over a two year period. The only salmonid encountered was *Salmo trutta* L. (brown trout). Minnow (*Phoxinus phoxinus*), stoneloach (*Noemacheilus barbatulus*) and stickleback (*Gasterosteus aculeatus*) were recorded at some sites in the Vartry catchment. The trout examined were slow growing fish reaching a length of 4-8cm at the end of their first year and 8-15 cm at the end of year two. With the exception of the Shankill river and a number of sites in the Vartry catchment, trout populations were well below 0.5 fish/m^2 which is typical of acid streams. Above 270-300m populations fell below 0.1 fish/m^2.

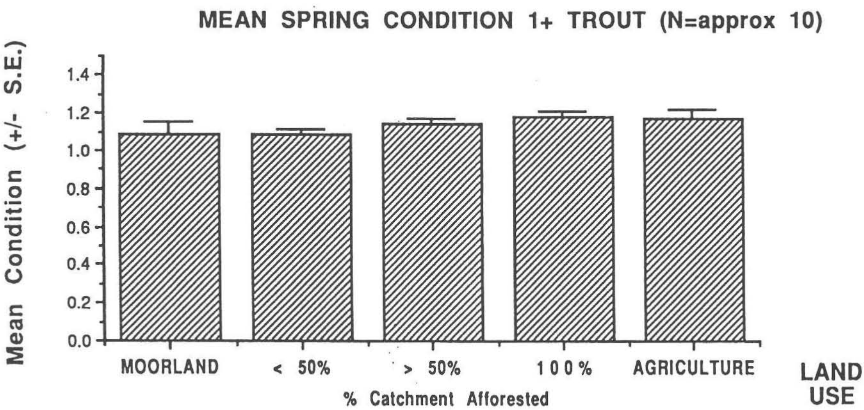
Trout were recorded as high as 460m but they were generally not found in stretches of stream higher than approximately 400m. Six non-afforested sites had no trout at the time of sampling, all of which are above 400m. With regard to afforested sites only 9 (5 streams) of the 19 sites fished were fishless.

Macroinvertebrate samples have been taken from over 50 sites in Study Area 2 in April/May 1990 and sampling repeated at 20 of these in May 1991. In general, upland streams flowing over granite supported a less diverse fauna than those flowing over Silurian and Ordovician beds. However within each geological type, the non-afforested streams carried a more diverse fauna than adjacent afforested sites. Ten mayfly (Ephemeroptera) species have been identified, a group extremely sensitive to reductions in pH. *Baetis rhodani* was the most common mayfly recorded. Two species, *Ameletus inopinatus* and *Siphlonurus lacustris* have been found in small numbers in the high altitude sites. All study streams supported a diverse mayfly fauna with the exception of nine of the afforested sites, in which only the most acid tolerant species occured. These were the same sites which were devoid of fish. Stoneflies (Plecoptera) were more abundant than Ephemeroptera in the majority of sites and seven species were recorded.

(ii) Non-sensitive Geologies

Spring and Autumn sampling of 45 sites in Study Area 3 has shown fish to be absent from only 7, including both moorland and afforested sites. In these cases, it is more likely that physical barriers (e.g. waterfalls) rather than stream water quality are responsible. Brown trout (*Salmo trutta*) was the dominant salmonid species, although salmon (*Salmo salar*) were also present at 8 sites, including some afforested systems. Salmonid densities were higher in general in Study Area 3 than either of the other areas (particularly with respect to afforested catchments) and also were higher in autumn than in spring in most sites. The general trend was for fish density to be lowest in moorland catchments (mean 0.1-0.2/m^2), highest in agricultural catchments (mean 0.35-0.7/m^2) and to show a trend of decreasing density with increasing catchment afforestation (Figure 7). However, fish condition (a measure of the relative 'well being' of individual fish) showed no significant variation with land use types. Thus while there seems to be some reduction in fish populations as forest cover in the catchment increases, the fish present are in as good a condition as those in sites with large fish populations. This may indicate a negative physical habitat effect rather than chemical (toxic) effect of increased catchment afforestation, but further analysis and sampling is necessary.

In accordance with other field data on the close relationship between stream hydrochemistry and their invertebrate faunas (e.g. Townsend *et al.*, 1983), preliminary analysis of macroinvertebrate communities in Study Area 3 has shown them in general to be more highly associated with



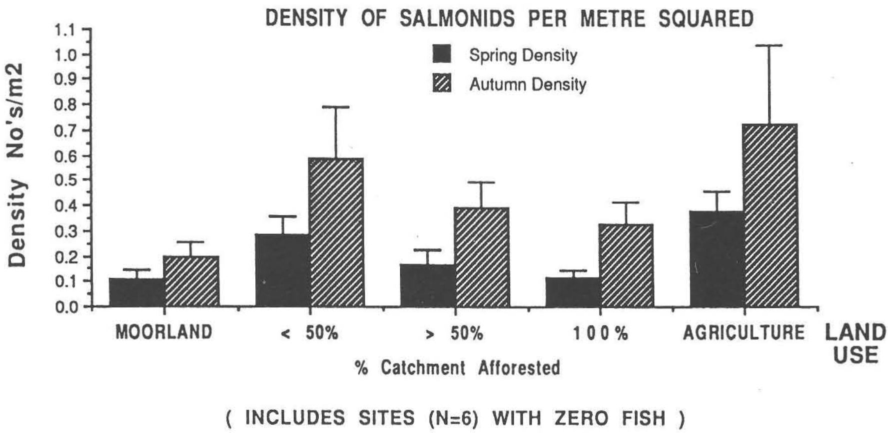


Figure 7: Variation in mean salmonid condition (a) and density (b) with land use (moorland, agriculture and variable % afforestation) across all sites in Study Area 3

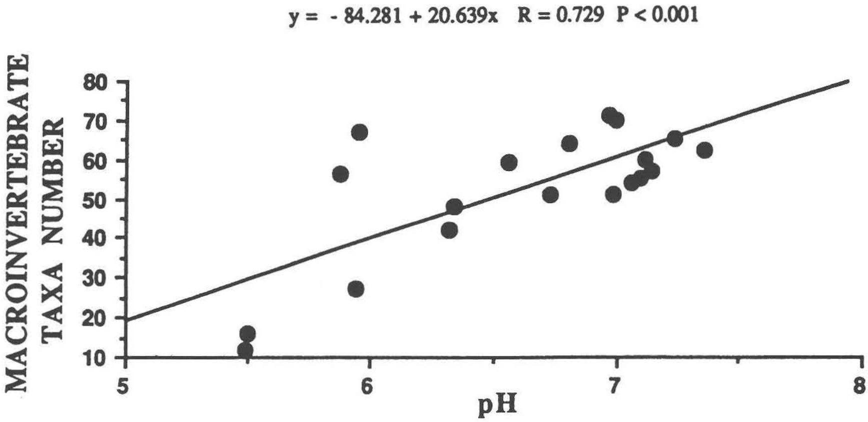


Figure 8: The relationship between macroinvertebrate taxon richness and pH in 19 sites within the Kilworth Forest catchment in Study Area 3.

stream pH, conductivity and hardness than they were with land use in the catchment. For example, in a single afforested catchment of four streams in the intensively studied Kilworth forest, taxa number increased significantly with pH and conductivity along a gradient from moorland through the forest to agricultural areas (Figure 8). Mayfly fauna were well represented throughout the study area, and as in Study Area 2, stoneflies dominated in the more acidic sites (both moorland and afforested).

5. Discussion

The data presented here represents the preliminary findings from some aspects of the overall research programme undertaken by the AQUAFOR group. Whilst it is necessarily incomplete at this stage, the information is amongst the first of its kind in Ireland and is unique in terms of the consistency of approach, geographical area covered and integration of research disciplines. These preliminary findings indicate the extent of the likely differences to be found across the country in respect of the interaction between forestry and aquatic ecosystems.

Preferential interception of atmospheric aerosols by the mature tree canopy (compared to moorland vegetation for example) has been known for some time and has recently been established in Ireland (Farrell *et al.*, 1993). If the aerosol contains an elevated concentration of H^+ ions or of an acidifying ion such as Cl^- or SO_4^{2-} , then the consequence is likely to be an increased concentration of H^+ (acidity level) in waters draining poorly buffered catchments. The results from this overall study are broadly in line with those from Britain (see O'Halloran and Giller, 1993), in that severe stream acidity problems can occur in afforested catchments on rock types such as granite and quartzite (i.e. rocks low in base cations and resistant to weathering) as found in Study Areas 1 and 2. Afforested streams in such areas also tend to have higher aluminium levels than adjacent non-afforested sites. Catchments on Old Red Sandstone, generally speaking, appear to be more buffered and do not seem to be affected by acidity and aluminium problems in the same way. Therefore, on the basis of this short term preliminary study, one may conclude that only a certain proportion of the country as a whole may be expected to be vulnerable to acidity problems related to afforestation. However, the physical effects of afforestation have yet to be examined, and may be of some cause for concern, particularly in relation to land preparation and clearfelling (see O'Halloran and Giller, 1993).

Whilst streams may not appear to be particularly acidic at all times, the stream chemistry data show that acid episodes do occur in vulnerable (sensitive) catchments as a result of acid deposition events associated with rainfall. These might be expected on the east coast, but have been found even in the west of Ireland which is distant from sources of air pollution. The frequency of acid deposition may be expected to vary greatly from year to year depending on the weather. Deposition of sea salts is another possible acidifying factor that may occur periodically in the west of Ireland (Allott *et al.*, 1990) and the high levels of organic carbon in some streams indicates a high level of organic acidity as well.

The preliminary analysis of the biological data to date would lend support to the chemical results. Macroinvertebrate communities and fish populations do seem to be negatively affected by afforestation in comparison with unafforested moorland sites. In areas of sensitive geology in Ireland, these effects seem to correlate with chemical differences in streams between afforested and non-afforested catchments in such areas. Acidic streams draining afforested, poorly buffered catchments are usually found to have a reduced invertebrate diversity (Ormerod *et al.,* 1987, O'Halloran and Giller, 1993). No such obvious chemical differences have so far been identified between afforested and non-afforested systems in the non-sensitive areas in Study Area 3, but the trend for a decrease in fish density with increasing catchment forest cover may point to some adverse physical effects. These have yet to be explored. In contrast, trends for increased faunal diversity and fish densities in certain catchments, such as Kilworth, as one moves from moorland through forest (in association with increasing pH, conductivity and hardness) indicate that a more regional and even local approach to the relationship between plantation forest and aquatic ecosystems may be appropriate. In any event, this work has shown the value of an integrated, large scale collaborative approach and the necessity for considerably more support for research in this important area of the interactions between forestry and the environment.

ACKNOWLEDGEMENTS

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The Effect of Climate Change on Irish Forests

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Summary

Any climatic changes that are projected for Ireland within the next forty years will influence not only the tree crops being planted today, but also many of the trees and forests already growing here.

Rising temperatures and carbon dioxide levels could alter the productivity of our forests, both directly and indirectly. Included here are changes in rates of photosynthesis, water-use efficiency, photosynthate allocation and damage from injurious agencies. Many of the projected responses of trees and forests are difficult to predict, however, as our current climate models are inexact and the forest-level response is unknown.

Irish forestry is currently going through a major transition and future effects of climate change may well be superimposed on even greater changes brought about more by socio-economic reasons than by climatic influences.

Nevertheless, Irish foresters and the Irish forest industry cannot afford to be complacent. Anticipation of potential threats and opportunities could result in significant benefits, a healthier forest estate and a long-term competitive advantage.

1. Introduction

The subject of forestry and climatic change was raised as far back as the 1930's and began to be addressed in forestry text books in the 1970's (Layser, 1980). It was not until the 1980's, however, that the specific effects of climate change on forestry were written on in any comprehensive way (Bolin *et al.*, 1986; Shands and Hoffman, 1987 and Eamus and Jarvis, 1989).

The longevity of trees and forest crops makes them of particular use in tracing past evidence of climatic change. It is also this longevity, however, that makes forests more vulnerable to future change. Although some 'forest' crops e.g. nursery stock, Christmas trees or coppice, may lend themselves to an agricultural-type manipulation, forests are essentially different to agricultural crops.

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For the purposes of this paper, the focus will be on the effects of climatic change on plantation forests and forestry in Ireland. The effects on semi-natural woodland and trees have recently been dealt with elsewhere (Jeffrey *et al.*, 1991).

2. Assumptions

Over the last number of years, climate change has been a very controversial subject with its own share of sceptics and prophets of doom. More recently, however, there is growing scientific evidence that the observed rise in average global temperature is real and that sea levels are rising (Houghton *et al.*, 1990).

Although there is still uncertainty as to the magnitude of certain changes, a framework must be established within which certain assumptions are made for the purpose of this paper. The main assumptions relate to temperature and precipitation (Anon, 1990) while second order assumptions are taken from Rowntree (1990). The changes suggested here are mid-way between 'best' and 'worst' case scenarios.

2.1 First Order Assumptions

It is assumed that the following changes will take place in Ireland between now and the year 2030:

Average annual temperature:	an increase of the order of 2°C
Precipitation :	5 to 10% increase in winter.
:	5 to 10% decrease in summer.

2.2 Second Order Assumptions

Seasonal fluctuation of temperature.
It is assumed that the influence of the temperature increase will be more strongly felt in winter and that the frequency of frost would, therefore, be reduced.

Precipitation
The models are in general agreement about the increase in winter precipitation; there is less consensus for summer.

Snowfall
Because the snow/rain threshold is associated with temperature, it is expected that warming would markedly reduce snowfall frequency.

Evaporation
Changes here are more difficult to predict. A general assumption might be that increased evaporation will lead to larger soil moisture deficits in mid to late summer.

Wind speed
In the long term (beyond the middle of the 21st century) it is expected that mean wind speeds and the frequency of storms will decrease. In the next few decades, however, storm intensity is expected to increase.

Cloudiness
Because of the increases in CO_2 and water vapour, it is expected that clear sky solar radiation will decrease. On the other hand, if soil moisture deficits limit evaporation, then some increases might be expected.

From the above, it can be seen that any projections made on climatic changes are very tentative. The effects on regional changes in climate are even more so. It is proposed, therefore, to deal with broad changes or trends only and to examine how these changes might affect the management of our future forests.

3. Assessing the Impact of Climatic Change on Irish Forests and the Forest Industry

3.1 The Problems

Because of the scale of the anticipated changes to our environment, models are required to project climatic trends into the future. Many such models are already in existence but improvements are required, particularly in fine-tuning the models for regional projections of local climate.

Even if we could be precise in predicting what climatic changes might occur, however, forest biologists are far from being in a position of confidence to predict the individual tree or forest response.

Eamus and Jarvis (1989) summarised the potential problems in this regard:

* Few experiments in this area have lasted more than two years and it would be highly speculative to extrapolate from these to longer time scales.

* Few of these experiments have considered the potential effects from nutrient stress in a natural environment or of variations in soil type.

* There are suggestions from seedling trials that crown morphology and structure may be affected by CO_2 concentration. If this were to persist, it might have a major influence on the total amount of photosynthesis in stands of Sitka spruce (Russell *et al.*, 1988).

* Because of their size, trees do not lend themselves easily to direct measurements of the effects of CO_2. Unlike agricultural crops, therefore, prediction of the broader scale response to changes in climate are difficult.

As in the case of projecting changes in future climate, the only realistic way of assessing the potential effects on trees and forests is through the use of models. But can forest managers wait for such models? The forest profession has always dealt with uncertainty of what the future might hold and foresters plant today with the belief that by the time their crop is harvested it will be what the forest industry of the 21st century requires.

3.2 Appropriate responses

Should foresters now respond to the climatic projections as they stand? If they do, then the response might involve some of the following:

1. Changes in the seed origins for our more commonly grown forest trees.
2. A broader choice of species for planting.
3. Silvicultural manipulation of existing crops.

These will now be dealt with in more detail.

3.2.1. Effects of climatic change on the choice of seed origins for our commonly grown forest trees.

Because of the lack of native productive coniferous species in Ireland, we have relied on imported seed for the majority of our forest plantations. Choosing the correct origin from which to import seed is crucial in the success of crop establishment and in the quality and quantity of timber yield.

From information collected and observations made on established field trials, Irish foresters now know the seed origins that suit their local climates best. These choices, however, may have to be reassessed in the light of suggested climatic changes. Foresters may have to move to more southerly areas when selecting the best origins for Douglas-fir and Sitka spruce.

The effect of climatic changes on the nature and scope of present tree improvement programmes is uncertain. Are todays plant breeders working on material that will be suitable for tomorrows forest or on material that will grow hopefully in a climate similar to that of today? Much of the seed for future forests in fact, will come from seed orchards selected for their performance over the *past* decades (Cannell *et al.*, 1989).

3.2.2. Choice of species

This response is often the one that first arises when climatic change is suggested. Species changes may require, however, that the yield of species currently in use is lowered as a result of climatic change. Our current average productivity of 14-16m^3 ha^{-1} yr^{-1} is significantly greater than other European countries. The sites where the maximum productivities for Sitka spruce are achieved are on wet mineral lowland soils of moderate fertility where climatic conditions such as high rainfall, high humidity, frequent fog and moderate annual ranges of temperature occur.

In western North America, Sitka spruce is confined in its natural distribution to the coastal fog belt. If the number of dry, warm days increases in Ireland, then Sitka spruce may become restricted in some eastern and south-eastern localities. Whether it increases its productivity in the wetter areas depends on other factors. For example, if chilling requirements are not fully met, then it may flush later and fail to exploit the longer growing season.

Other tree species adapted to milder areas, such as Monterey pine, Monterey cypress and some eucalypts, are able to grow almost continuously in milder parts of this country. Although such species have been damaged by frost in the past, the suggested warming may mean that their role in the future of Irish forestry may become more important. The average productivities for some of these alternate species are often higher than those for Sitka spruce.

The selection of any one species will not only depend on projected shifts in climate, however. In Ireland, socio-economic factors will also influence the choice of species that is planted. The level of European Community grant-aid for private planting already differentiates between broadleaf and conifer planting, and the European Community and the National Government may further influence the species that foresters plant in the future (Molloy, 1991).

3.2.3. Silvicultural inputs

The effects of climatic changes on the outplanting success of transplants on either afforestation or reforestation in Ireland is unknown. In the past, survival has generally been high, particularly on afforestation sites. Projected moisture stress in mid to late summer may require a move to containerized planting stock or changes in site cultivation techniques to lessen the impact on certain site types.

Similarly, because of the reduction in the chilling period as a result of milder winters, certain species such as Douglas-fir or noble fir may require additional investments in cold-storage facilities at the nursery stage or more careful site selection.

Silvicultural decisions may also have to be reassessed later in the life of the crop. Stands may have to have rotation length changed or may require more or less inputs in fertilization, pest management, etc.

4. The Forest Industry

Authors argue as to the absolute or relative importance of climatic change on forestry and the forest industry. Eamus and Jarvis (1989) state that the effects of CO_2 increases may be relatively small in relation to future changes in land-use and management practices. Hoffman (1984), on the other hand, argues that the effects of these climatic changes will have a more pervasive influence on forestry than any other single environmental or technical change.

Unfortunately, it is far too soon to be able to predict the biological or economic effects of global warming on forests or the forest products industry. The changes will not happen overnight. The industry, therefore, has time to plan a strategic response through the methods outlined above.

The Industry must also examine the anticipated response to climate change from other sectors which impinge on it. In Ireland, the pool of land available for afforestation is heavily dependent on the agricultural sector. It might, therefore, be important to assess the effect of changes in climate on the productivity of various agricultural crops with which forestry may compete for available land.

As discussed above under choice of species, however, it may be the European Community aid and other factors that will dictate what agricultural crops will be grown on what land rather than the potential effects of climatic warming.

Climatic change will also probably affect the energy industry. This again could influence the profitability of the Irish forest products industry in comparison to our competitors. It could also influence the species that we grow, as forest biomass crops might again become an economic land-use option.

5. Conclusions

The future climate is uncertain. Even the most conservative climatic models, however, project dramatic changes to our climate and these changes will have many effects on trees and forests. How well forest managers anticipate and respond to these changes will depend on the climatic, biological, social and economic factors that have been touched on in this review. The most important considerations may be:

Climatic models

Any form of planning requires forecasts of eventual outcomes. Our current climatic models need to be more precise, particularly in projecting regional climates, before responses can be planned.

Predicting growth responses

The responses of individual plants to increases in CO_2 concentration have generally been established and are quite well understood. The extrapolation of these results to the tree, forest or ecosystem level needs to be carried out through the use of biological models. Current forecasting models of future forest productivity may need to be updated or adjusted as more information is forthcoming. Further information is also required on the effect of climatic change on water-use efficiency, wood anatomy and chilling requirements of our most common tree species.

New genetic needs

It is generally felt that productivities will increase in temperate plantation forests. Can species and populations be bred to anticipate the climatic changes and grow even faster under the new conditions? If climatic conditions do change on specific sites, foresters may have to use alternative species rather than look to other seed origins of the existing species.

Planting and management

Do forest managers now sit back and allow the foresters of the future to deal with problems that might have been anticipated now? Foresters must become more aware of future climatic trends as models improve. Only then will they be in a position to manage the risks through manipulation of silvicultural practices, if changes are required. As forests move to better soils in the future, the choice of species will increase even in the absence of climate change.

Hazards

Changes in temperature, precipitation and wind patterns, and the trees response to them, will cause changes in the ecology of forests. Little precise information is available on how storm patterns will behave in our future climate. We can only anticipate the worst through proper cultivation and planting techniques, choice of species and thinning methods. Sitka spruce may suffer large losses of increment through aphid attacks, particularly on dry sites. We must also maintain vigilance against exotic pests – many of which would enjoy a warmer climate here.

The forest industry

Decisions here will not be taken in isolation. The availability of land for Ireland's major planting targets of the future is dependent on European Community and National Government decisions. How global warming affects agriculture will also affect the forest industry.

The global scene

The future trends in climate change are world-wide. In Ireland, anticipated changes in productivities, markets and income depend also on the response of world governments and world industry to our future climate.

Much of the discussion in this paper is of relevance not only to Ireland but to all the wood producing nations in the world. Climate change is a global issue and will therefore influence world supply and demand for wood and wood products and, therefore, prices and profitability (Pittock, 1987). A global forest sector model has been used to project the production, consumption, prices and trade of a number of forest products (Binkley, 1987). The model makes some interesting projections for national incomes to the year 2030. For example, Finland is set to increase its income by over

22 per cent while Australia and New Zealand are projected as losing almost 25 per cent of their income.

Because of the broad assumptions in Binkley's model, Pittock (1987) states that "the results should not be taken too seriously". Nevertheless, for a small trading nation such as Ireland, it acts as a reminder that whatever strategies are decided upon in relation to climatic change and the forest industry, they must take into account the global picture of wood supply and demand.

Many factors, therefore, will impinge on the future of our forests and forest industry. The changes brought about to our forests by climate change will be superimposed on these factors and, over time, may become inseperable from them. Today's forest managers, however, must not use this as an excuse to do nothing. Trees being planted today will still be growing when the climate will have already changed. A response is needed.

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The Development of an Indicative Forest Strategy With Specific Reference to Co. Clare.

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A pilot project to develop an Indicative Forest Strategy (IFS), using Co. Clare as the study area, is being undertaken by the Forestry Research Department of Teagasc. This project is being funded by the Backup Measures of the forestry grants as administered by the Forest Service.

An IFS embodies the idea of putting the right trees in the right places. The aim of this IFS is to provide a scientific basis to assist future policy decisions about potential locations of forestry, considering such factors as tree productivity, environmental resources and socio-economics.

Development of the strategy is Geographic Information System (GIS) based. This method allows input of a large number of varied spatial information types, which are linked to related database information. These can subsequently be displayed, analysed and queried in an interactive fashion, thus providing answers to questions posed – the 'what if?' scenario.

The data included and the structure of the strategy are designed to allow different scenarios for both broadleaved and coniferous, private, farm and amenity forestry to be examined.

The following spatial and non spatial information are under consideration for inclusion: soil type, bedrock geology, elevation, aspect, exposure, meteorological data, infrastructure, population distribution, existing land uses, level of available grant aid, land prices, agricultural statistics, tourism, water resources, landscape, ecology, heritage, and potential EC special areas of conservation.

These data and their related database information are subjected to a series of geoprocessing techniques to produce composite *thematic* datasets which include yield class, windthrow hazard class, soil-species suitability, water resource sensitivity and an economic evaluation of potential land uses. The resulting information can then be displayed, manipulated and interrogated in an interactive fashion to answer more complex user defined queries relating to various potential locational scenarios.

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The following notes are designed to aid the speedy processing of contributions to the Journal.

1. Two copies of each paper should be sumitted in typescript, with double spacing and wide margins, correct spelling and punctuations expected.

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