An Integrated Study of Forested Catchments in Ireland

P. S. Giller[1], J. O'Halloran[1], R. Hernan[1], N. Roche[1], C. Clenaghan[1], J. Evans[1], G.K. Kiely[2], P. Morris[2], N. Allott[3], M. Brennan[3], J. Reynolds[4], D. Cooke[4], M. Kelly-Quinn[5], J. Bracken[5], S. Coyle[5], E. P. Farrell[6].

[1]Department of Zoology, University College Cork.
[2]Department of Civil & Environmental Engineering, University College Cork.
[3]Environmental Sciences Unit, Trinity College Dublin.
[4]Department of Zoology, Trinity College Dublin.
[5]Department of Zoology, University College Dublin
[6]Department of Environmental Resources Management, University College Dublin.

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 $0.1 mgl^{-1}$ 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

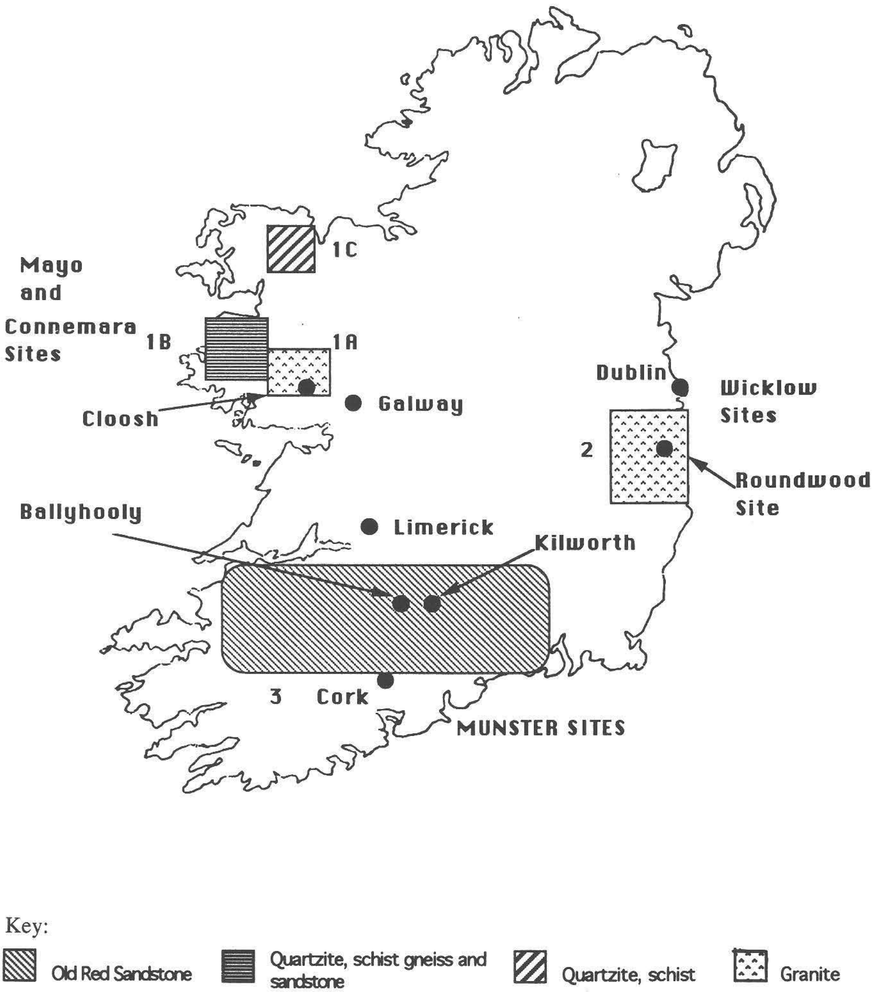


Figure 1: Location map of Study Areas 1-3, intensive sites and predominant underlying geology.

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

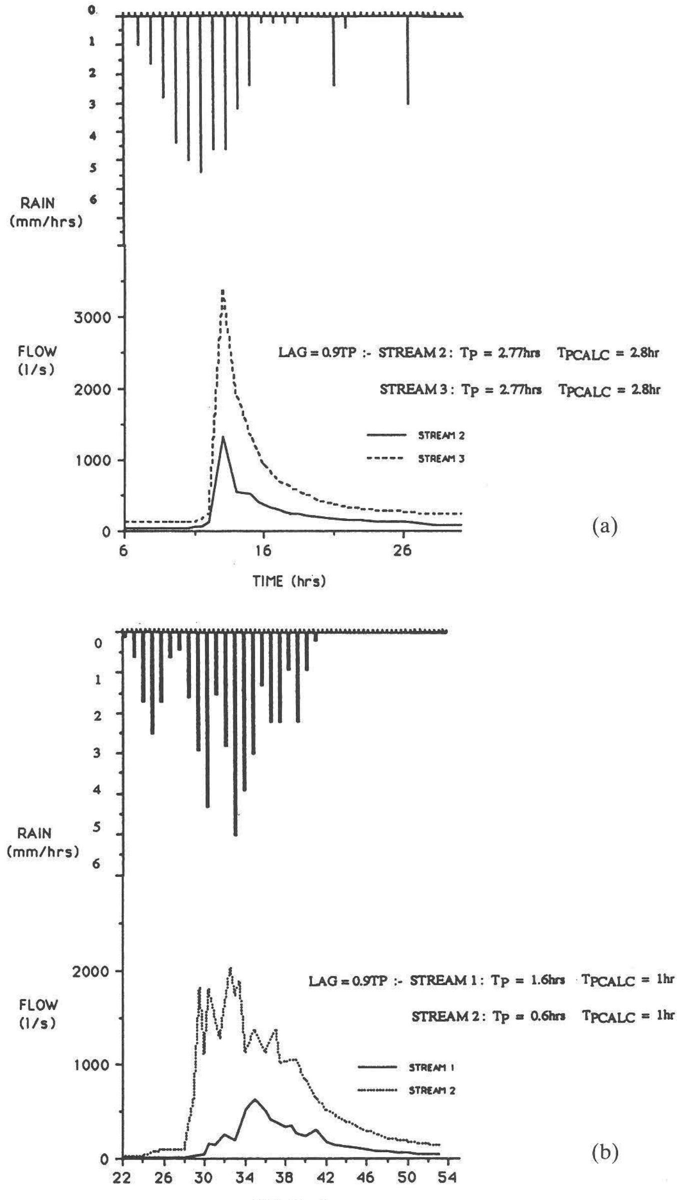


Figure 2: Stream hydrographs in relation to rainfall events in two streams in (a) Kilworth Forest and (b) two moorland tributary streams of the Araglin River in Study Area 3.

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.

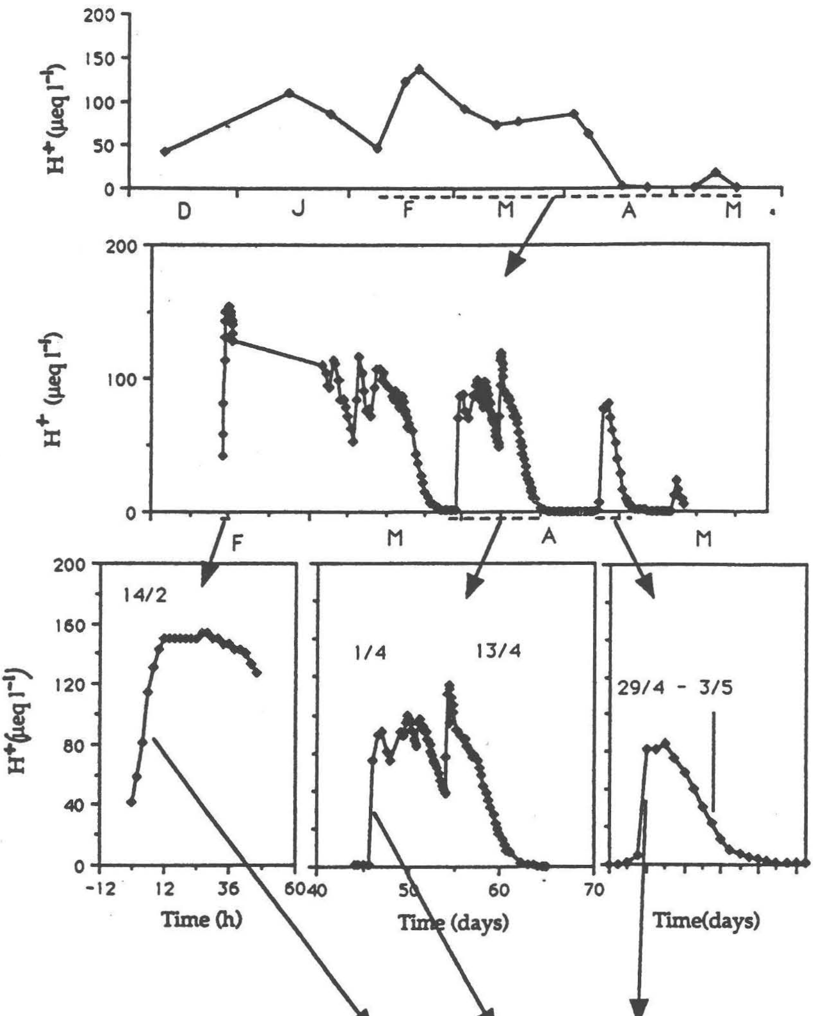
4.3. Stream Water Chemistry

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

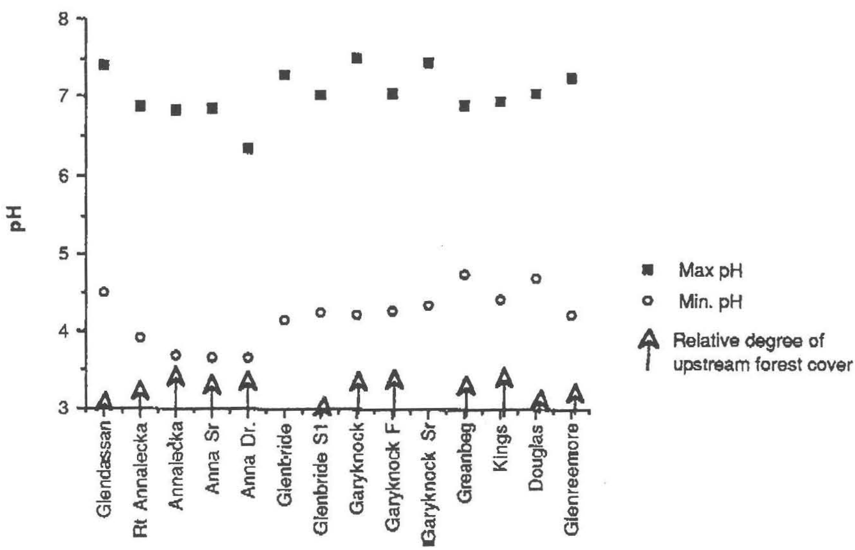


Figure 4: Mean, low and high pH values for streams in the Kings River catchment. Relative degree of upstream forest cover is also indicated.

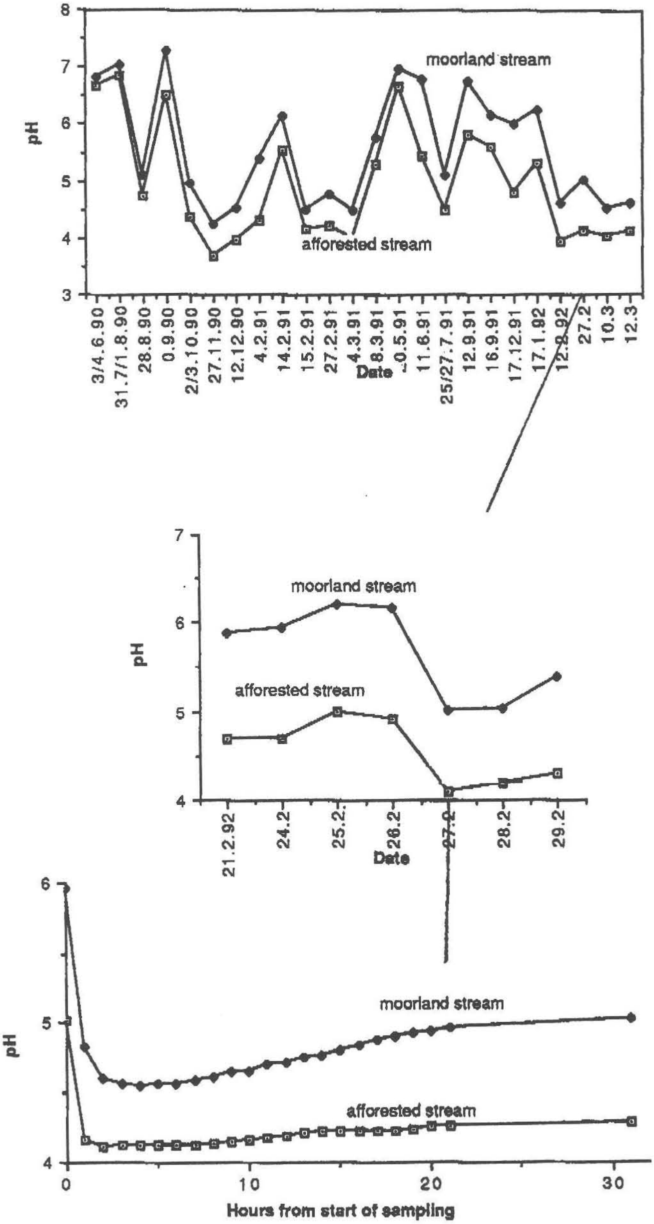


Figure 5: Monthly (a), daily (b) and diel (c) variation in pH from a moorland (Ballinagree) and afforested (Annalecka) stream.

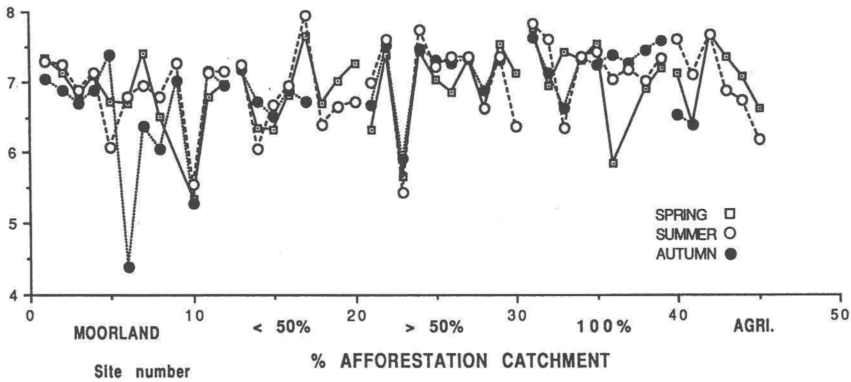


Figure 6: Variation in pH with season and land use (moorland, agriculture and variable % afforestation) across all sites in Study Area 3

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.

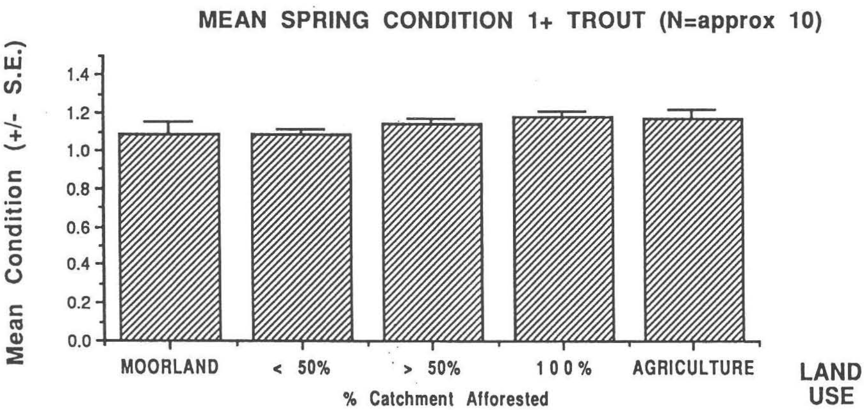
Trout were recorded as high as 460m but they were generally not found in stretches of stream higher than approximately 400m. Six non-afforested sites had no trout at the time of sampling, all of which are above 400m. With regard to afforested sites only 9 (5 streams) of the 19 sites fished were fishless.

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



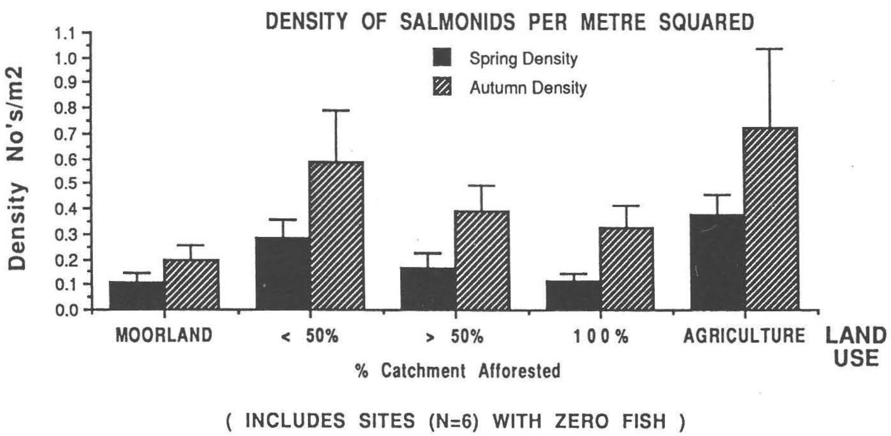


Figure 7: Variation in mean salmonid condition (a) and density (b) with land use (moorland, agriculture and variable % afforestation) across all sites in Study Area 3

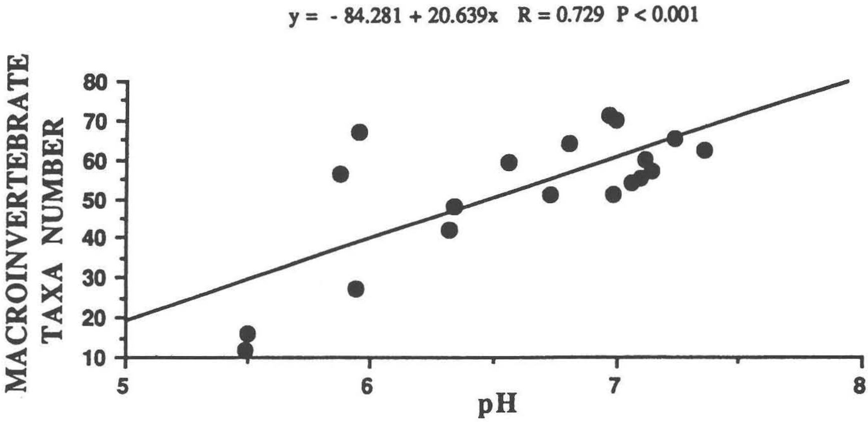


Figure 8: The relationship between macroinvertebrate taxon richness and pH in 19 sites within the Kilworth Forest catchment in Study Area 3.

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.

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REFERENCES

Allott, N. A., Mills, W. R. P., Dick, J. R. W., Eacrett, A. M., Brennan, M. T., Clandillon, S., Philips, W. E. A., Critchely, M. and Mullins, T. E. 1990. *Acidification of surface waters in Connemara and South Mayo. Current status and causes.* du Quesne Limited, Dublin.

Anon 1991. Forestry Operational Programme 1989-1993. Dublin 87pp

Bolger, T. and Connolly, P. L. 1989. The selection of suitable indices for the measurement and analysis of fish condition. *Journal of Fish Biology*, 34, 171-182.

Farrell, E. and Boyle, G. M 1991. *Monitoring of a forest ecosystem in a region of low-level anthropogenic emissions. Ballyhooley project.* Final report. Forest Ecosystem Research Group, Univ. Coll. Dublin.

Farrell, E. P., Cummins, T., Boyle, G. M., Smillie, G. W. and Collins, J. F. 1993. Intensive Monitoring of forest ecosystems. *Irish Forestry*, Vol 50, (1): 53-69

Clesceri, L., Greenberg, A. E. and Trussell, R. R. 1989. *Standard Methods for the Examination. of Water and Wastewater.* American Public Health Association and American Water Works Association and Water Pollution Control Federation.

Hynes, H. B. N. 1975. The stream and its valley. *Verhandlungen der Internationalen Vereinigung fur Theoretische und Angewandte Limnologie* 19, 1-15.

O'Halloran, J. and Giller, P. S. 1993. Forestry and the ecology of streams and rivers: lessons from abroad. *Irish Forestry*, Vol 50 (1): 35-52.

Ormerod, S. J., Mawle, G. W and Edwards, R. W. 1987. The influence of afforestation on aquatic fauna. In: Environmental aspects of plantation forestry in Wales. (Ed. by J. E. Good). Institute of Terrestrial Ecology.

Townsend, C. R., Hildrew, A. G. and Francis, J. E. 1983. Community structure in some southern English streams: the influence of physicochemical factors. *Freshwater Biology*, 13, 521-544.

Zippen, C. 1956. An evaluation of the removal method of estimating animal populations. *Biometrics* 12, 163-189.