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HYDROFOR: Assessment of the Impacts of Forest Operations on the Ecological Quality of Water

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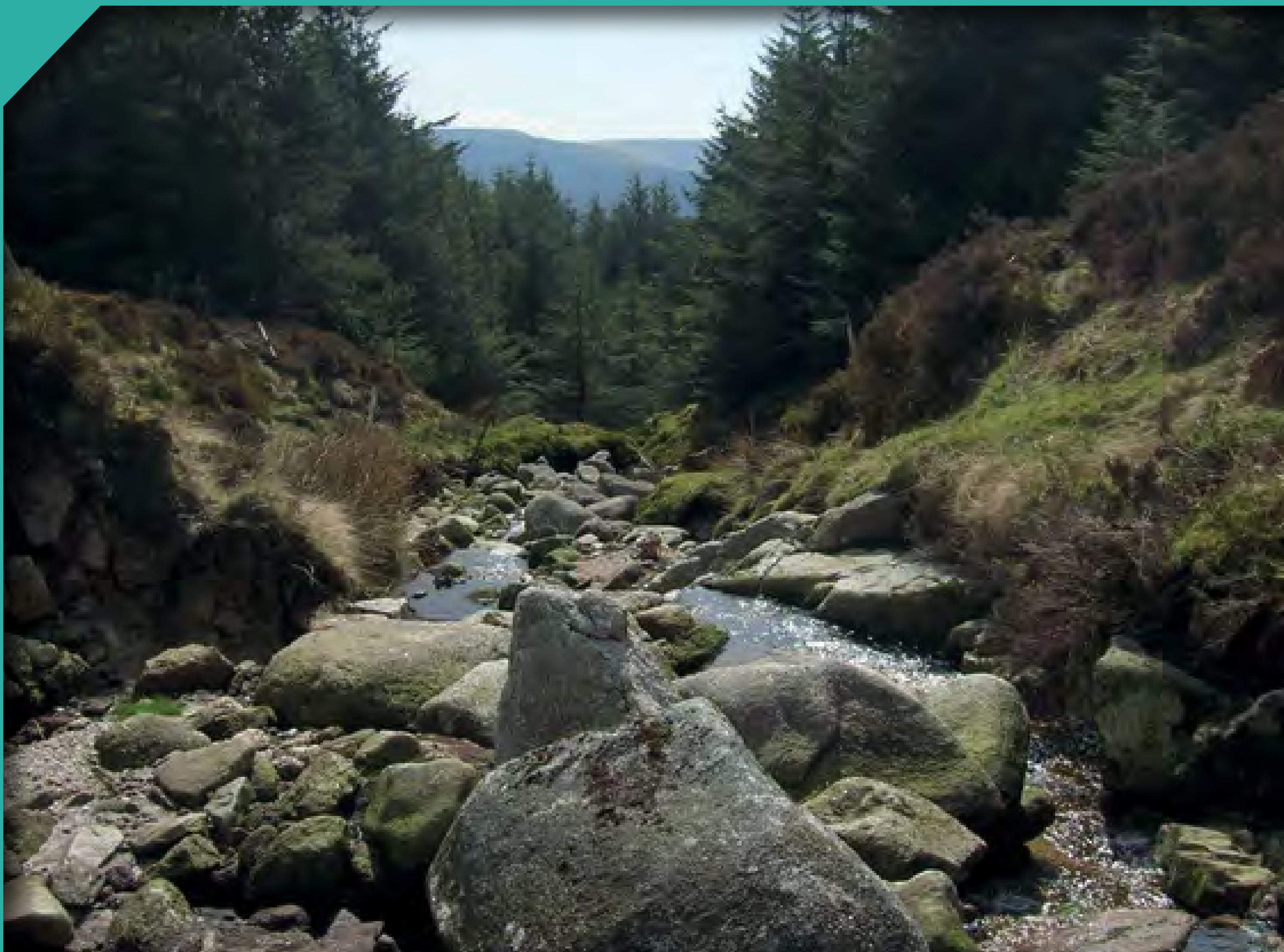

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government

Department of Agriculture, Food and the Marine
An Roinn Talmhaíochta, Bia agus Mara

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EPA Research Programme 2014–2020

Assessment of the Impacts of Forest Operations on the Ecological Quality of Water (HYDROFOR)

(2007-WQ-CD-2-S1)

EPA Synthesis Report

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Executive Summary

Assessment of the Impacts of Forest Operations on the Ecological Quality of Water, also known as the HYDROFOR Project, was a 7-year (2008–2014 inclusive), inter-institutional co-operative project funded by the Environmental Protection Agency (EPA) and the Department of Agriculture, Food and the Marine (DAFM). A multi-disciplinary group of researchers at University College Dublin (UCD), University College Cork (UCC) and the National University of Ireland, Galway (NUIG) investigated the relationships between conifer forests, forestry operations, and surface water quality and ecology in Irish rivers and lakes. The research was designed to build on the existing knowledge base from completed research projects on forest–water interactions in Ireland and to address specific knowledge gaps that would inform the further development of the Water Framework Directive (WFD, Directive 2000/60/EC) Programmes of Measures (POMs) relevant to forest operations.

Investigations

Fourteen investigations were undertaken of pollutants potentially reaching rivers and lakes from closed-canopy conifer forest, and from harvesting and planting operations. Seven of these related to rivers, four addressed the nature and drivers of acid inputs from closed-canopy forests, and the other three dealt with inputs of nutrients and sediment from harvesting and windrowing. One of these three studies assessed the efficiency of a riparian buffer zone in retaining sediment and phosphorus. Four studies examined nutrient and sediment loads originating from planting operations. One involved tree planting and three produced new information on the effects of windrowing operations to prepare harvested grounds for replanting. Three lake studies investigated the potential effects of forests and forestry operations on water chemistry, macroinvertebrates, zooplankton and trout populations in small peatland waters. The main conclusions from the investigations are summarised below.

Conclusions

Overall, HYDROFOR highlighted the potential impacts on surface water quality throughout the life cycle of a forest. While there was evidence from previous research for some recovery in pH in streams in forested catchments since the 1990s, HYDROFOR analyses indicated that higher episodic acidity or greater alkalinity loss is still associated with streams draining catchments with closed-canopy conifer forest, despite significant reductions in atmospheric acid deposition. The primary driver of episodic acidity was organic anions, with base-cation dilution also prominent in western and southern regions. This also represents an elevated loss of dissolved organic carbon (DOC) from peatlands and is of concern. The higher acidity affects aquatic macroinvertebrates, and reduced numbers of acid-sensitive taxa were recorded in some forested streams in all regions, especially where there was extensive catchment forest cover. There was some evidence of recovery from acid stress during the summer in comparison with winter. The lack of suitable sites within the lower end of the forest cover gradient (e.g. only one forested site with <20% catchment forest cover and four sites with from 20% to 30% forest cover) precluded identification by this project of a safe threshold for catchment forest cover. Longitudinal studies on a number of forested streams adjacent to the forest, and known to be ecologically impaired, did not detect an impact on macroinvertebrate communities 2.5 km downstream of the forest.

Tree harvesting and windrowing, in preparation for replanting, resulted in elevated episodic inputs of nutrients (mainly phosphorus) and sediment to watercourses that exceeded water quality standards, with the largest releases near the end of the operations. With careful design, sediment traps and aquatic buffer zones might reduce sediment exports, but phosphorus retention on peaty soils is more challenging.

Lakes within forested catchments typically had elevated levels of plant nutrients, heavy metals and DOC and reduced concentrations of dissolved oxygen, especially where clearfelling had occurred. The biological responses to catchment forestry, in terms of planktonic and benthic invertebrate communities and brown trout populations, were consistent with conifer forests exerting a trophic, rather than an acidic or toxic, effect on lake ecosystems. The biological changes detected were greatest where catchments had been subjected to forest clearfelling.

Policy recommendations

The project outputs (reports and peer-reviewed publications) will inform the development of forestry policy and guidelines, as well as the implementation of the WFD.

- Sediment release to water courses during felling and replanting may be reduced by careful onsite management of felling and windrowing operations, installation of silt traps and greater application and oversight of best practice guidelines.
- A combination of several sediment traps may be more effective at trapping a range of sediment particle sizes than single isolated traps.
- Retention of phosphorus requires attention, as it is more challenging on peat soils and will depend on the occurrence of mineral content in riparian soils or installation of mineral barriers.
- Based on the suite of impacts from planting to harvesting, including elevated DOC, nutrient and sediment release, and aquatic biodiversity concerns, cessation of afforestation[1] on peat soils in acid-sensitive headwater[2] catchments is recommended by the project team. In relation to reforestation of sites in such catchments, there are serious concerns with respect to the aforementioned impacts. Where replanting is considered, the design should be hydrologically informed and demonstrate empirically on a site-specific basis that it can mitigate impacts on water quality and aquatic biodiversity through the forest management cycle, as highlighted in this report. A number of mitigation measures (riparian buffer zones and sediment traps) were investigated in this study, and the research evidence highlighted their ability to reduce some pollutant inputs. Their effectiveness is likely to be site specific and other measures, not investigated in this project, e.g. reduced catchment tree cover,[3] minimising drainage and soil disturbance, may reduce impact, but these remain to be validated by further research.

Recommendations for further research

- Establish long-term monitoring sites to track changes in hydrology, hydrochemistry and aquatic ecology in forested catchments into the future.
- Characterise the chemical composition of DOC, its source and processes leading to its current release from peaty soils to better understand forest–water interactions and impacts on freshwater biology.
- Determine the sources, pathways and processes releasing soluble nitrogen and phosphorus, and sediment from felled sites to water courses.
- Further develop and evaluate mitigation measures and management approaches to reducing nutrient and sediment inputs to streams from forestry operations.
- Characterise changes in stream hydrology, hydrochemistry, ecology and associated management issues (e.g. measures to promote bog restoration and to control conifer regeneration and colonisation by invasive species) in felled catchments that will not be replanted, or in catchments within which forests will be converted from the clearfell system to less intensive continuous cover forestry (CCF) systems, based on Scots pine, birch, rowan, etc., or to alternative non-forest land uses. Establish a forest-cover threshold at which reforestation on peat soils in acid-sensitive catchments can be considered.
- Determine the factors and conditions that facilitate ecological recovery of impacted watercourses.

The HYDROFOR Synthesis Report is available at: http://erc.epa.ie/safer/reports. The HYDROFOR database is available at http://erc.epa.ie/safer.

The full technical report, which includes more detail on the results, including statistical analysis, is available at http://erc.epa.ie/safer/reports. The published papers listed in Appendix 1 can also be consulted.

1 The current *Afforestation Grant and Premium Scheme 2014–2020* (DAFM, 2015a) excludes infertile and designated blanket and raised bogs from funding, but afforestation on shallow peats may be considered where it is capable of producing at least yield class 14 and where there are no adverse environmental impacts.

2 Headwaters are normally defined as comprising first- and second-order streams but small third-order streams may also be included (Furse, 2000; Meyer *et al*., 2007; Dunbar *et al*., 2010; McGarrigle, 2014). A first-order stream is one with no tributaries, while a second-order stream starts where two first-order streams converge. First- and second-order streams can be permanent, ephemeral or intermittent.

3 The lack of suitable sites within the lower end of the forest cover gradient (e.g. only one forested site with <20% forest cover and four sites with 20% to 30% forest cover) precluded identification of a safe threshold for catchment forest cover.

1 Introduction

Assessment of the Impacts of Forest Operations on the Ecological Quality of Water, also known as the HYDROFOR Project, was a 7-year project (2008–2014 inclusive) funded by the Environmental Protection Agency (EPA) and the Department of Agriculture, Food and the Marine (DAFM) involving a multi-disciplinary team of researchers at University College Dublin (UCD), University College Cork (UCC) and the National University of Ireland, Galway (NUIG), who worked together to advance knowledge of the relationships between conifer forests and forestry operations in Ireland and of surface water quality and ecology. The project was also supported by advisors representing Coillte Teoranta, National Parks and Wildlife Service, Inland Fisheries Ireland and the Marine Institute. The HYDROFOR final technical report is available at: http://erc.epa.ie/safer/reports. The HYDROFOR database is available at http://erc.epa.ie/safer.

1.1 Forestry in Ireland

At present, 10.5% (or approximately 700,000 ha) of Ireland is under forest cover (Forest Service, 2014), three-quarters of which is made up of conifers and one-quarter of broadleaved species. It is estimated that 59.6% (417,200 ha) of forestry in Ireland is on blanket peat and approximately 300,000 ha of forest is on upland peat areas. *Picea sitchensis* (Sitka spruce) is the most common tree species comprising over half (52.4%) of the forest area (Forest Service, 2014). Other conifers, including *Pinus contorta* (lodgepole pine) and *Piceas abies* (Norway spruce) make up over one-tenth of the forest area (Forest Service, 2014). During the 2007–2013 period approximately 48,000 ha of new forests were established under the various afforestation schemes, including the Forest Environmental Protection Scheme (FEPS) and Native Woodland Scheme, and approximately 945 km of new forest roads were constructed to facilitate harvesting (DAFM, 2014). The planting target for the new 2015–2020 programme is 10,000 ha of new forests and woodlands per annum to increase Ireland's forest cover to 18% (DAFM, 2015a).

The Forest Service promotes sustainable forest management, a key component of which is protection of water quality, and aquatic species and habitats. Grant aid under the 2014–2020 programme is contingent on compliance with environmental protection (DAFM, 2015a). A suite of guidelines has been produced in relation to protection of water quality, archaeology, biodiversity, landscape and the pearl mussel, as well as best practice guidance in relation to harvesting. An Environmental Impact Assessment (EIA) is required where the area proposed for afforestation is 50 ha or more. Applications for planting smaller areas undergo screening to assess the need for an EIA, which may be requested where a significant environmental impact is possible. In relation to Natura sites [i.e. Special Areas of Conservation (SACs) and Special Protection Areas (SPAs)], as required under the Habitats Directive (Directive 92/43/EEC), the Forest Service also undertakes appropriate assessment screening and, where necessary, appropriate assessment, in order to evaluate (1) whether or not (where previously uncertain) the possibility of a significant effect on a Natura site exists; (2) the nature of the possible significant effect (including in combination) on the Natura site; and (3) the effectiveness of any proposed mitigation measure(s) designed to avoid the risk of the significant effect (DAFM, 2015a,b).

The Forestry and Water Quality guidelines include criteria for the designation of acid-sensitive and erosion-sensitive systems, and define buffer zone widths in relation to the slope of the riparian zone and in situations where soils are highly erodible. Best practice is provided in relation to ground preparation and access for planting, application and storage of fertilisers and other chemicals, and for harvesting. Under S.I. (Statutory Instrument) 25/2012, aerial fertilisation of forests in Ireland requires a licence from the Forest Service. In terms of the Water Framework Directive (WFD, Directive 2000/60/EC), a Programme of Measures (POM) and Standards for Forest and Water (ESB International, 2008) was compiled by the Western River Basin District Project on behalf of the WFD National Programmes of Measures (Forest and Water Working Group). This document highlighted knowledge gaps that need to be addressed before the proposed new measures can be applied, some of which (e.g. drivers of acid episodes, efficacy of riparian buffer zones for nutrient uptake and sediment capture, impact of forestry operations on upland lakes) are within the scope of research undertaken by the HYDROFOR project.

1.2 Forestry and Potential Risk to Surface Water Quality

Implementation of the WFD requires identification and quantification of anthropogenic pressures on water resources and the introduction of a POM to minimise impact. The *National Characterisation Report for Ireland* (EPA, 2005), produced during the first WFD management cycle, identified forestry as one of the land-use activities posing potential risks in terms of diffuse pollution. The pressures highlighted as arising from forestry were increased acidification from plantations in acid-sensitive catchments, sedimentation from clearfelling, harvesting, new plantations, road construction and erosion on steep catchments, and eutrophication from fertilisation on steep catchments and forest harvesting on peat soils. The potential for impact depends on the magnitude of the pressure and the susceptibility of the pathway, as well as the sensitivity of the receptor.

1.3 HYDROFOR – Origins

HYDROFOR was designed to build on the knowledge base from completed research projects on forest–water interactions in Ireland (Allott *et al*., 1990, 1997; Bowman, 1991; Farrell *et al*., 1997; Giller *et al*., 1997; Kelly-Quinn *et al*., 1997, 2008; Clenaghan *et al*., 1998; Hutton *et al*., 2008; Rodgers *et al*., 2008) and to address specific knowledge gaps to inform the development of POMs relevant to forest operations. In terms of acidification, Kelly-Quinn *et al*. (2008) highlighted the need to identify the drivers of acidity, especially with respect to organic acidity and influence of catchment forest cover, as well as seasonal and longitudinal changes in the aquatic communities in response to acid inputs. The research by Hutton *et al*. (2008) drew attention to the potential risk from elevated sediment and nutrient inputs associated with felling, and the need for further research to identify the processes/activities responsible for these inputs.

HYDROFOR sought to address these research needs by taking on board the range of operations and potential pressures that occur through the forest cycle from planting to harvesting. The emphasis was on quantification of inputs and impacts, and gaining an understanding of mechanisms responsible for their delivery and mitigation. The ultimate objective of HYDROFOR was to construct a knowledge base of key forest and water interactions from which improved predictions about critical impacts could be made and which could inform the development of appropriate POMs. The project was not scoped to complete a comprehensive scientific characterisation of all forest and water interactions or to conduct economic analyses of mitigation measures or water status objectives. Thus, HYDROFOR has not made prescriptive policy recommendations relating to measures in this final report.

1.4 HYDROFOR – Objectives

The project objectives were as follows:

1. undertake a review of international and national literature on potential impacts of forestry on surface water quality with respect to acidification, eutrophication and sedimentation at the various stages of the forest life cycle;
2. compile a database of relevant data from previous projects dealing with forest–surface water interactions and explore the data for relationships between factors;
3. undertake temporal and spatial assessment of inputs from forest activities and impacts (acidification, eutrophication, sedimentation) from planting to felling on the hydrochemical and ecological quality of water taking into account mitigation measures;
4. quantify nutrient and sediment losses to water in relation to the nature, scale and duration of forestry activities in a subset of instrumented catchments;
5. test the effectiveness of riparian buffer zones in ameliorating inputs of nutrients and sediments from forest operations and consider design guidelines for their planning, construction and maintenance;
6. evaluate the likely impact of expansion of forest cover in Ireland on hydro-ecology.

Objectives 3 to 6 were addressed in 14 investigations (Boxes 1.1–1.3) of inputs from closed-canopy forest, harvesting and planting relating to both rivers and lakes. Eleven of these related to rivers, four were on the nature and drivers of acid inputs from closed-canopy forests and three dealt with inputs of nutrients and sediment from harvesting. One of the latter assessed the efficiency of a riparian buffer zone in retaining sediment

Box 1.1. River studies: closed-canopy forest

1. *Acid inputs to upland streams.* This research characterised the nature and drivers of episodic acidity in 34 upland streams in three geologically distinct areas (east, west and south) with varying forest cover from zero (moorland) to > 50%.
2. *Influence of weather conditions on the hydrochemical characteristics of episodic acidity.*[4] An examination of the hydrochemical characteristics of storm event samples collected under varying antecedent airflow was undertaken at one instrumented site in County Wicklow.
3. *Potential impact of acid inputs on macroinvertebrate communities.* Sampling of aquatic macroinvertebrates was undertaken at the sites examined for hydrochemistry on six dates between October 2009 and March 2011.
4. *Longitudinal extent of acid impact on macroinvertebrate communities.* This study sampled macroinvertebrates in sites at 500 m intervals along two forested (with known impact on aquatic ecology) and non-forested streams to determine the point where impact was no longer evident.

Box 1.2. River studies: harvesting and planting

5. *Sediment and nutrient inputs from clearfelling.* This research investigated sediment and nutrient inputs before, during and after forest clearfelling on three peatland sites in Ireland: the Glennamong Forest in the Burrishoole catchment in County Mayo and two first-order tributaries of the River Ow in County Wicklow.
6. *Projected trends and patterns in clearfelling coupe sizes.* Areas for clearfelling from Coillte sales proposal data for the periods 2007–2013 and 2014–2050 were collated and used to calculate annual average coupe sizes and to examine trends.
7. *Assessment of an experimental buffer strip to mitigate nutrient and sediment inputs.* The concentrations of nutrients were measured at various depths below the soil surface in a riparian buffer zone (RBZ) in the west of Ireland, and efficacy of the RBZ in nutrient uptake and sediment removal was determined, along with the survival rate of deciduous trees planted in the RBZ.
8. *Sediment and nutrient inputs from windrowing.* Windrowing of brash material is the most common method of site preparation before replanting can occur. Sediment and nutrient inputs to streams draining three sites in County Wicklow were examined before, during and after windrowing.
9. *Assessment of sediment traps in mitigating sediment inputs.* One of the instrumented sites (Kilcoagh) examined under Investigation 7 was also used for the assessment of silt trap design and location. Trapping efficiency of two traps was assessed by comparing total suspended solids concentrations upstream and downstream of the silt traps.
10. *Hydraulic modelling of mitigated sediment transport at a windrowing operation*. The HEC-RAS hydraulic computed model was used to model flow and sediment transport at the study stream located in Kilcoagh, County Wicklow. Silt traps were incorporated into the model as structures and the model was calibrated using recorded data.
11. *Hydrochemistry of a stream draining a young afforested plantation*. A decade-old afforestation site located at the northern tip of Lough Conn, near Crossmolina in County Mayo, was instrumented during its planting in 2003 under the PEnrich project. Those data were analysed in relation to the data collected during re-instrumentation of the site under HYDROFOR in 2014.[4]

4 Details of this work package are presented in the full technical report, available onlline at http://erc.epa.ie/safer/reports

Box 1.3. Lake studies

12. *Inputs from conifer forests to small upland lakes.* The hydrochemistry of 26 small blanket bog lakes in three distinct catchment land use categories (unplanted blanket bog, closed-canopy conifer plantation forests only and mature conifer plantation forests with recently clearfelled areas) and in two geological settings were examined.
13. *Invertebrate communities of small upland lakes: potential impact from forest inputs.* In this study, the Chydoridae (Cladocera) and benthic macroinvertebrate communities (Hemiptera, Coleoptera and Odonata) of the same 26 small blanket bog lakes in Investigation 11 were sampled to assess the impact of plantation forestry in their catchments.
14. *Brown trout in upland lakes: population characteristics and effects from forest inputs.* The impact of inputs from conifer forests on the growth, energetics and population structure of brown trout (*Salmo trutta*) in peatland lakes (with zero, 30–40% and 80–90% catchment forest cover) was quantified over a 3-month period in the summer of 2010.

and phosphorus. Four studies examined nutrient and sediment loads originating from planting operations. One involved tree planting and three were focused on windrowing operations to prepare harvested grounds for replanting. Each of the three lake investigations incorporated more than one stage of the forest life cycle.

1.4.1 Summary of the HYDROFOR research investigations

This report presents the findings of the research in two main sections relating to rivers and lakes. It aims to draw together the findings relating to the range of investigations associated with the various stages in the life cycle of the forest.

2 River Studies

The locations of the 34 HYDROFOR project river study sites are shown in Figure 2.1.

2.1 Acid Inputs from Closed-canopy Forest

In Ireland, a number of studies in the 1990s detected forest-mediated acidification and associated biological impact in some river sites with a high percentage catchment forest cover on acid-sensitive geology (e.g. Bowman, 1991; Kelly-Quinn *et al*., 1996a,b; Kelly-Quinn *et al*., 1997; Allott *et al*., 1997). In contrast, the forested sites on Old Red Sandstone (ORS) were considered sufficiently well buffered to acidifying inputs (Giller *et al*., 1997). In recent years, the FORWATER study by Kelly-Quinn *et al*. (2008) suggested that the risk of impact on acid-sensitive geology is a function of the level of forest cover in the contributing catchment. However, there was much scatter in the data around some of the potential thresholds. It is likely either that a number of other factors interact to modify thresholds or that the limited temporal hydrochemical sampling missed conditions likely to impact aquatic biota. Further research was deemed necessary to address these knowledge gaps and also to determine the current drivers of acidity.

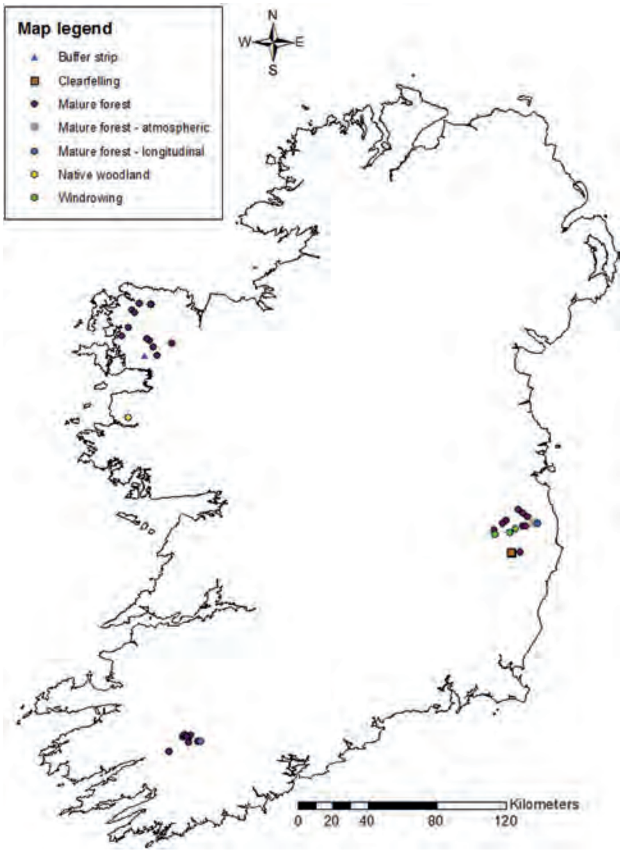

Figure 2.1. HYDROFOR project river study sites.

The major part of the HYDROFOR research on closed-canopy conifer forests was focussed on characterising and comparing acidity levels in streams in three geological settings, east (granite/felsite), west (metamorphic geology) and south (ORS) (Figure 2.1). A total of 34 sites were in catchments with conifer forest cover ranging from zero (moorland) to >50% which was mostly planted in the 1970s and 1980s. Sites were grouped into three bands: no forest cover (NF, e.g. moorland) controls, low forest catchment cover (LF, ~20–50%), and high forest catchment cover (HF, >50%) owing to the limited availability for study of suitable sites within the lower end of the forest cover gradient (e.g. only one forested site with <20% catchment forest cover and four sites with 20–30% forest cover). Typical sites are illustrated in Figures 2.2 and 2.3. The research also identified drivers of episodic acidity and potential impacts of acid inputs on macroinvertebrate communities in those systems and provided an opportunity to compare the current drivers of episodic acidity with results from the AQUAFOR project in the 1990s (Kelly-Quinn *et al*., 1996a,b, 1997; Allot *et al*., 1997; Giller *et al*., 1997). The biological sampling was undertaken at several times in a year to determine the seasonality of any impact detected and a further, less-extensive investigation assessed the downstream extent of impact on macroinvertebrate communities. The final body of research was based on one instrumented catchment to explore the influence of weather conditions on acid inputs.

Episodic surface water acidification is common in many regions worldwide. The driving processes are dependent on a variety of physico-chemical and climatic characteristics, and on acid deposition pressures which have changed significantly over the last two decades. Surface water acidification has been predominantly associated with deposition of acid pollutants (e.g. sulphate and nitrate) and further enhanced by canopy

Figure 2.2. Cloghoge River, County Wicklow (photograph: Hugh Feeley, UCD).

Figure 2.3. Tributary Inchavore River, County Wicklow (photograph: Hugh Feeley, UCD).

interception in conifer plantations, influencing the potential for increased freshwater acidification downstream. However, anthropogenic acid pollutants have been reduced significantly over the past 10 to 15 years, reducing the acid deposition pressure on freshwater catchments.

HYDROFOR confirmed that episodic acidity remains a feature of upland streams, both moorland and forested, draining acid-sensitive geology in Ireland. While there is evidence for some recovery in pH in forested sites since the 1990s, the analyses indicated that higher episodic acidity/greater alkalinity loss is still associated with streams draining catchments with a high proportion of closed-canopy forest cover, despite significant reductions in atmospheric acid deposition. Both the differences in pH between base and storm flow (ΔpH) and the number of pH values less than or equal to the biological threshold of 5.5 (pH_{BT}) were generally higher in forested streams. Interestingly, the low forest cover (LF) sites recorded a greater number of pH_{BT} values <5.5 than those with no forest or high forest cover in the west, which may be due to carbonate intrusions in the catchments with higher forest cover (HF) as indicated by higher base flow acid neutralising capacity (ANC).

Dissolved organic carbon (DOC), as will be shown later, is a key driver of episodic acidity. In the west both LF and HF sites had higher DOC concentrations than NF sites (Table 2.1). However, during storm flow DOC increased significantly in the increasing order: NF (5.4 mg/L), LF (11.6 mg/L), HF (14.2 mg/L). Similarly in the south, both LF and HF sites had higher DOC concentrations than non-forested, moorland sites (NF) during base-flow conditions, while mean storm-flow concentrations of DOC increased in the increasing order: NF (9.7 mg/L), LF (12.9 mg/L), HF (17.3 mg/L). In contrast, the moorland sites (10.13 mg/L) in the east had significantly higher DOC values than the forested sites (6.3 mg/L) at base flow; this was due to one site (WM2 – a tributary of the River Liffey, moorland DOC = 7.50 mg/L when WM2 is excluded) which had high levels of disturbance owing to previous peat extraction and consequently poor vegetation coverage of the peat in places. The differences during storm flow were not statistically different.

Increases in aluminium (Al^{n+}) concentrations are associated with episodic acidity and were shown by

Table 2.1. Mean values (with ranges) of pH, the number of sites with pH ≤the biological threshold of 5.5 (pH_{BT}), Al^{n+} (µg/L) and DOC (mg/L) at base flow and storm flow across land use within each region, and mean ∆pH (with ranges) between base flow and storm flow for each land use

Region	Land-use	Flow	pH	pH_{BT}	∆pH	Al^{n+}	DOC
West	All sites	Base	7.13 (4.43–7.91)	2	–	66.02 (1–219)	10.21 (2–33)
		Storm	6.01 (4.00–7.22)	15	1.13 (0.22–2.50)	121.42 (14–388)	16.44 (6–34)
	No forest	Base	7.44 (7.19–7.85)	0	–	22.90 (5–48)	5.43 (2–11)
		Storm	6.48 (5.80–7.22)	0	0.76 (0.02–2.33)	77.38 (14–211)	11.38 (6–17)
	Low forest	Base	6.92 (5.42–7.91)	1	–	91.93 (11–219)	11.63 (2–21)
		Storm	5.74 (4.56–7.15)	11	1.13 (0.40–2.51)	142.76 (85–313)	17.10 (7–31)
	High forest	Base	7.05 (4.43–7.89)	1	–	80.33 (1–184)	14.22 (5–33)
		Storm	5.78 (4.00–6.99)	4	1.48 (0.28–3.10)	152.03 (47–338)	23.25 (14–34)
East	All sites	Base	6.12 (5.03–6.94)	9	–	135.76 (43–278)	7.65 (2–25)
		Storm	4.66 (3.93–6.09)	52	1.41 (0.07–2.17)	287.29 (63–581)	18.61 (9–34)
	No forest	Base	6.05 (5.12–6.94)	3	–	139.79 (43–268)	10.13 (3–25)
		Storm	4.63 (4.09–6.09)	20	1.34 (0.07–2.07)	180.81 (63–348)	19.04 (9–34)
	Forest	Base	6.16 (5.03–6.91)	6	–	133.60 (43–348)	6.32 (2–34)
		Storm	4.68 (3.93–5.59)	32	1.45 (0.46–2.17)	359.54 (118–581)	18.32 (10–30)
South	All sites	Base	7.19 (6.61–7.82)	0	–	40.58 (5–143)	5.59 (1–15)
		Storm	6.03 (4.06–7.05)	15	1.17 (0.02–3.10)	98.51 (15–218)	13.88 (3–26)
	No forest	Base	7.21 (6.73–7.82)	0	–	14.27 (5–27)	2.61 (1–7)
		Storm	6.45 (5.02–7.05)	2	0.96 (0.22–1.55)	70.88 (27–137)	9.71 (3–17)
	Low forest	Base	7.23 (6.84–7.61)	0	–	41.99 (17–95)	6.94 (3–12)
		Storm	6.10 (4.86–6.70)	3	1.15 (0.51–2.33)	93.37 (16–199)	12.92 (5–18)
	High forest	Base	7.16 (6.61–7.67)	0	–	56.58 (21–143)	6.84 (2–15)
		Storm	5.70 (4.06–6.80)	10	1.38 (0.50–2.50)	120.01 (15–218)	17.28 (5–26)

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Kelly-Quinn *et al*. (1997) and Allott *et al*. (1997) to be elevated in some forested streams. HYDROFOR showed that with the exception of the sites in the west, Al^{n+} differed with respect to forest cover only during high-flow conditions. In the west, Al^{n+} was higher in the forested (both LF and HF) sites compared with the NF moorland sites in both base and storm flows. In the east, the forested sites (359.5 µg/L) recorded significantly higher concentrations of Al^{n+} compared with moorland sites (180.8 µg/L) during storm-flow conditions, while in the south Al^{n+} concentrations increased significantly in the increasing order: NF (70.9 µg/L), LF (93.4 µg/L), HF (120.0 µg/L).

2.1.1 Drivers of episodic acidity

The key drivers of episodic acidity were shown to be organic acidity together with base-cation dilution. Six possible sea salt-driven acid episodes were recorded in the west. In both the west and south, base-cation dilution was significantly greater in non-forested streams than in the forested streams. In the east, it was the forested streams which had significantly greater base-cation dilution which was most likely due to higher discharge from the drainage network as shown by Kelly-Quinn *et al*. (1997).

This contrasts with the 1990s when excess sulphate and nitrate were identified as the main drivers of higher episodic acidity within forested catchments, although DOC, together with loss of potential buffering due to the drainage network, and sea salt spray were also contributing factors (Allott *et al*., 1990, 1997; Kelly-Quinn *et al*., 1996a, 1997). In the present study, concentrations of dissolved organic acid were higher in the forested streams and this can account for the aforementioned differences in episodic acidity. It has been shown in Scandinavia that organic acidity may episodically depress pH by up to 2 pH units (Laudon *et al*., 2001). Interestingly, the DOC concentrations recorded by HYDROFOR are higher than values from the 1990s. Similar trends of increasing DOC have been reported from the UK and Europe since the 2000s (e.g. Harriman *et al*., 2001, 2003; Skjelkvåle *et al*., 2003; Davies *et al*., 2005) and for small upland lakes in Ireland which were resampled in recent years by Burton and Aherne (2012). Some studies relate the increase in organic acidity to climatic change (e.g. Tipping *et al*., 1999; Freeman *et al*., 2001; Clark *et al*., 2005; Evans *et al*., 2005), while others propose a link to persistent and increased nitrogen interception (Harriman *et al*., 1998; Pregitzer *et al*., 2004; Findlay 2005), reductions in sulphate deposition, and sea salt events (Evans *et al*., 2006, 2008; Monteith *et al*., 2007, 2014; Chapman *et al*., 2008; Dawson *et al*., 2009; Moldan *et al*., 2012), as well as changes in hydrology (e.g. lowering of the water table) and land use (Evans *et al*., 2005). Although the processes operating are unknown, it is evident from the results that organic acidity, driven by high concentrations of DOC, increases when conifer forest is present on peaty soils.

2.1.2 Stream macroinvertebrates and acid impact

The response of benthic macroinvertebrates to acidification pressures in freshwater systems across Europe is relatively similar, with complete and/or periodic species loss and reduced abundances of acid-sensitive taxa (e.g. Baetidae, Figure 2.4) known to result from low pH and elevated aluminium levels (e.g. Harriman and Morrison, 1982; Tierney *et al*., 1998; Dangles and Guérold, 2000; Guérold *et al*., 2000; Lepori and Ormerod, 2005; Kowalik and Ormerod, 2006; Tixier *et al*., 2009). The research from the 1990s showed mixed responses of macroinvertebrate communities to episodic acidity, with streams in the east and west having reduced abundance and/or loss of acid-sensitive taxa with increasing catchment forest cover (Allott *et al*., 1997; Kelly-Quinn *et al*., 1997; Tierney *et al*., 1998). In contrast, no association between forest cover and macroinvertebrates was found in streams in the south overlying ORS (Giller *et al*., 1997; Clenaghan *et al*., 1998). However, a study by Kelly-Quinn *et al*. (2008) found that the greatest ecological impairment (assessed in spring 2007) was predominantly associated with peaty soils (e.g. blanket peat, peaty lithosols/podzols) and high catchment forest cover (> 50% above sampling point) in all three regions, although the authors noted a high degree of variability, with some stream communities showing little or no divergence from non-forested moorland reference streams, while some were highly impacted and others displayed a range of responses. All of this earlier research was based on sampling at one or two timepoints and was not adequate to detect short-term effects on ecology. HYDROFOR addressed this shortcoming by examining macroinvertebrate communities of the 34 sites sampled for water chemistry on six occasions between October 2009 and March 2011.

Figure 2.4. ***Baetis rhodani*****, an acid-sensitive taxon (photograph: Jan Robert Baars, UCD).**

HYDROFOR has highlighted the distinct communities of episodically acidic stream, typically dominated by Plecoptera, with relatively low taxon richness per individual site and low overall abundances. The species-level Acid Water Indicator Community index (AWICsp) (Hildrew *et al*., 2010; Murphy *et al*., 2013), adapted from the Acid Water Indicator Community index (AWIC) (Davy-Bowker *et al*., 2005), was calculated to compare communities at non-forested and forested sites. The AWICsp index scores taxa between 9 (extremely acid-sensitive) and 1 (extremely acid-tolerant), and is based on the relationship between the occurrence of taxa and observed mean pH. A threshold of 7.38 has been adopted for WFD reference communities in the UK for humic waters (> 10 mg/L DOC) (WFD-UKTAG, 2014). The communities in the forested streams had on average fewer acid-sensitive taxa, in particular Ephemeroptera, than the moorland streams in all three regions. In the west, moorland streams recorded significantly higher AWICsp scores than sites with both low and high catchment forest cover, indicating a more acid-tolerant community where forestry was present (Figure 2.5). In contrast, in the east and the south, only the streams in catchment with high forest cover recorded lower AWICsp scores, and thus more acid-tolerant communities, compared with NF and LF streams. However, in late summer (July 2010), there were improvements in the numbers of acid-sensitive taxa across all sites and regions, suggesting potential for seasonal recovery from acid stress (Figure 2.5). While forested streams in the east and west now show less impact than in the 1990s, streams in the south (previously reported in the 1990s to be unaffected by acid inputs) now show more evidence of ecological impact. This is due to episodically low pH during storm events resulting from the higher organic acidity in the forested areas of this region relative to the non-forested moorlands. Overall, the results suggest some improvements relative to the 1990s, though there is still the potential for acid impact in forested streams, albeit seasonal. Based on the 34 sites examined and the lack of an adequate forest cover gradient for investigation, it is not possible to propose a safe threshold for catchment forest cover. Impact on hydrochemistry and aquatic macroinvertebrates was shown in catchments with both low and high forest cover (as defined above), but not consistently.

2.1.3 Longitudinal extent of acid impact

A further consideration is the longitudinal extent of impact downstream of forest blocks. HYDROFOR examined macroinvertebrate communities in two headwater streams (one forested, one non-forested) draining Ordovician sedimentary geology and two headwater streams (one forested, one non-forested) draining ORS geology. Sampling was undertaken in summer (June) 2008 and spring (February) 2009. The greatest impact was recorded within and downstream of the forest

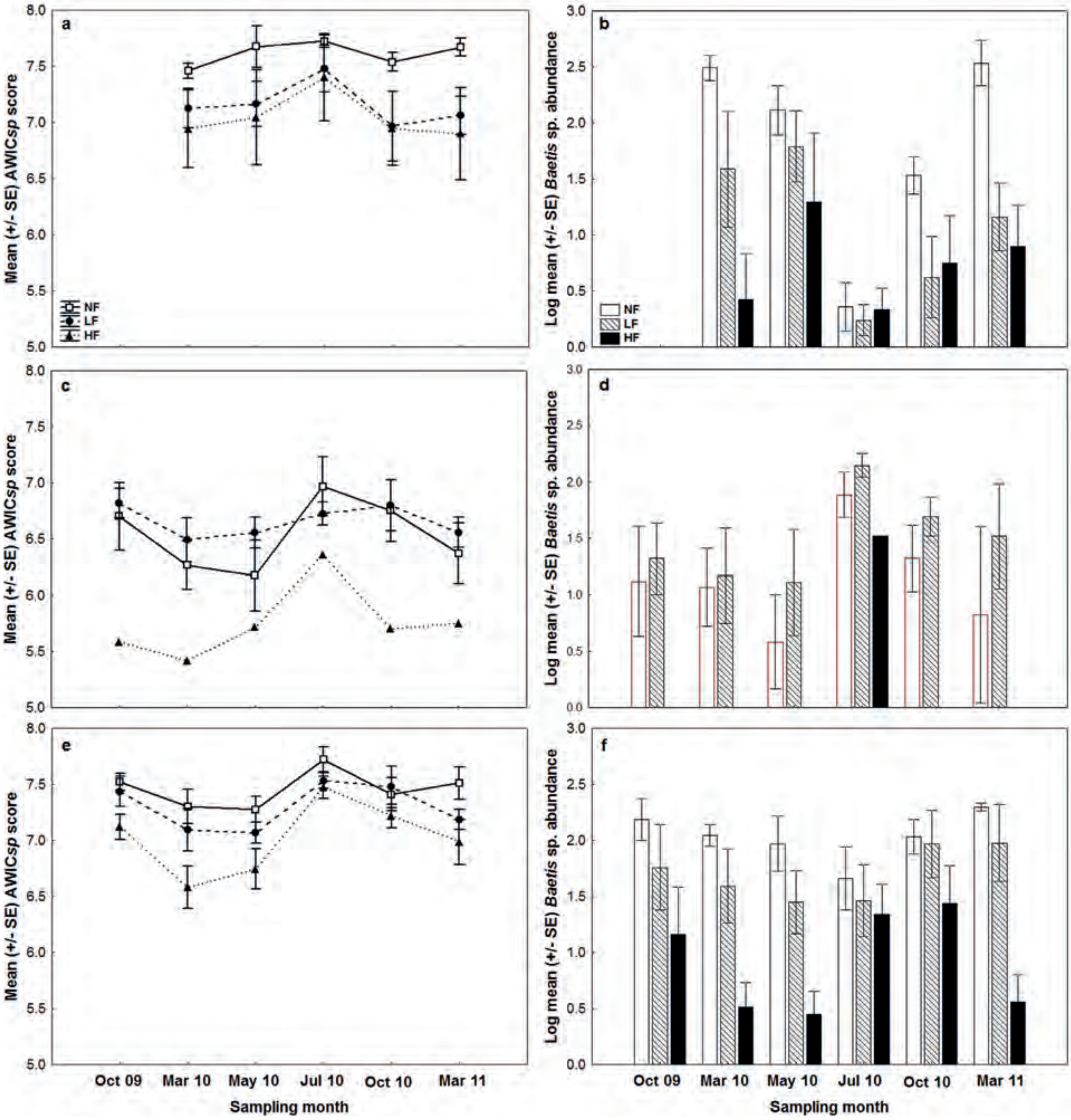

Figure 2.5. The mean (± standard error) AWICsp score and log mean *Baetis* abundance (2-min sampling period), at each sampling date in the west, (a) and (b); the east, (c) and (d); and the south, (e) and (f). Macroinvertebrates were not sampled in the west in Oct 2009. NF, no forest; LF, low forest; HF, high forest. Reproduced from Feeley and Kelly-Quinn (2014), with permission from the Royal Irish Academy.

plantation (i.e. 0.5–1.5 km) where the community was dominated by acid-tolerant taxa (Figure 2.6). Impact and recovery from episodic acidity varied between seasons, with the most marked effects on acid-sensitive Ephemeroptera. Species such as *Baetis rhodani* and *Rhithrogena semicolorata* were absent or had reduced abundancies at many sites in spring, but were recorded in the summer samples. The differences in total taxonomic and ephemeropteran richness between seasons may reflect the higher and more prolonged occurrences of acidic events in these sites during the winter and early spring than in late spring and summer. For the streams examined, impact on macroinvertebrate communities was not detected 2.5 km downstream of the forest. While such impacts may not be detected at the first WFD water body monitoring site, they may have implications for catchment biodiversity, as headwater can support up to 29% of a catchment's macroinvertebrate

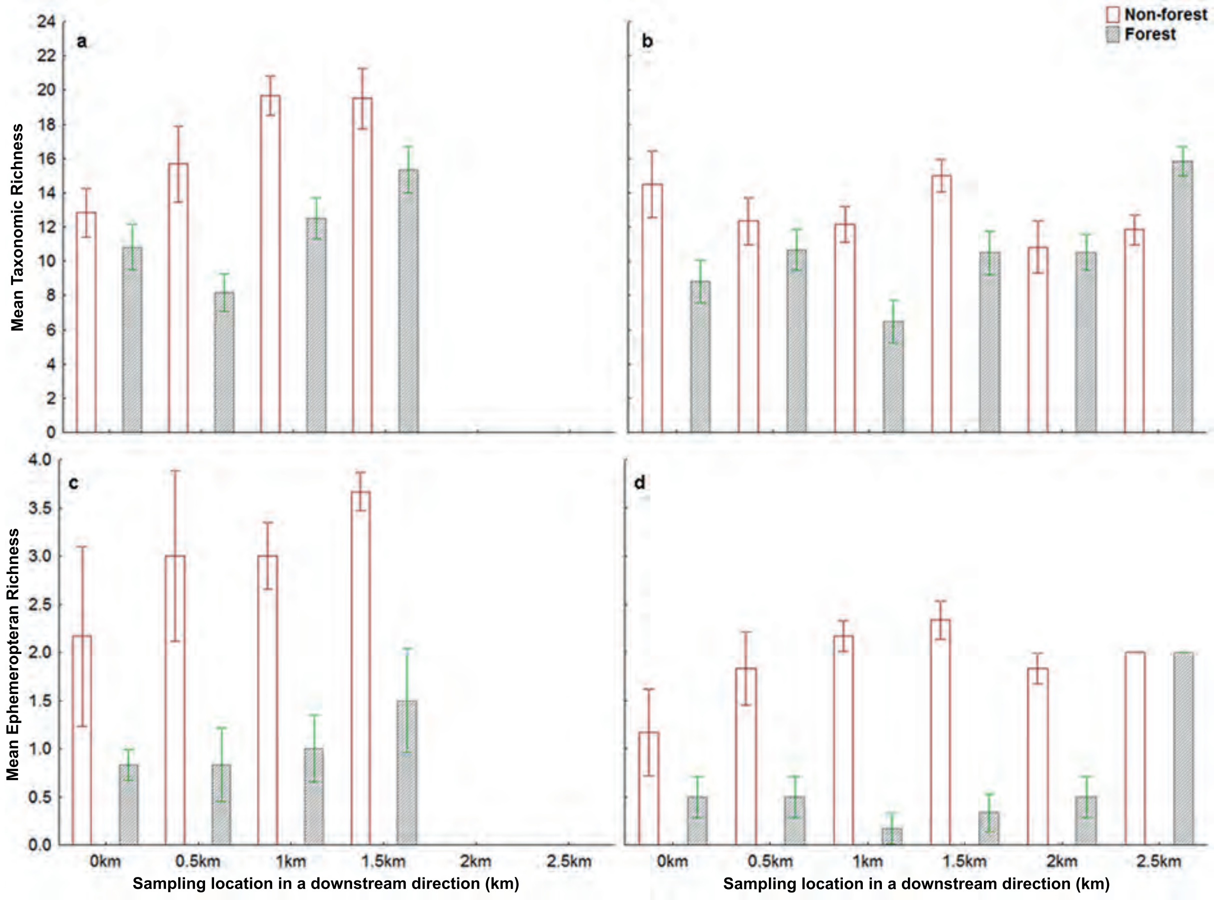

Figure 2.6. Longitudinal change in mean taxonomic richness in (a) summer and (b) spring; mean ephemeropteran richness in (c) summer and (d) spring (individuals min/min; ± standard error) in a downstream direction for non-forested moorland and forested streams. Reproduced from Feeley *et al.* (2011), with permission from Springer.

species (Feeley and Kelly-Quinn, 2012; Callanan *et al.*, 2014).

The full technical report which includes more detail on the results, including statistical analysis, is available at http://erc.epa.ie/safer/reports.

2.2 Harvesting and the Potential for Eutrophication and Siltation of Surface Waters

2.2.1 Sediment and nutrient inputs from tree harvesting

Harvesting, i.e. the removal of trees, is a part of the life cycle of a commercial forest. Clearfelling is the removal of all trees from a particular area (coupe) and it has the potential to cause sediment and nutrient inputs into the streams draining the forest. The amounts and timing of these undesirable inputs depend on the harvesting method and approach. Previous studies showed that the most severe impacts could be expected for forestry on peatland and particularly on granite bedrock (Hutton *et al.*, 2008; Kelly-Quinn *et al.*, 2008). Thus, for these conditions, HYDROFOR investigated the following issues relating to the impact on water quality:

1. the amounts of sediment and nutrients introduced into streams by clearfelling;
2. the trends and consequences of clearfelling coupe sizes; and
3. the effectiveness of measures used to reduce the amount of contaminants reaching the streams.

The study involved two different climatic areas, one in County Mayo in the west of Ireland and the other in the east of Ireland in the Wicklow Mountains. In County Mayo, two sites draining into the Glennamong River in the Burrishoole catchment were instrumented, one

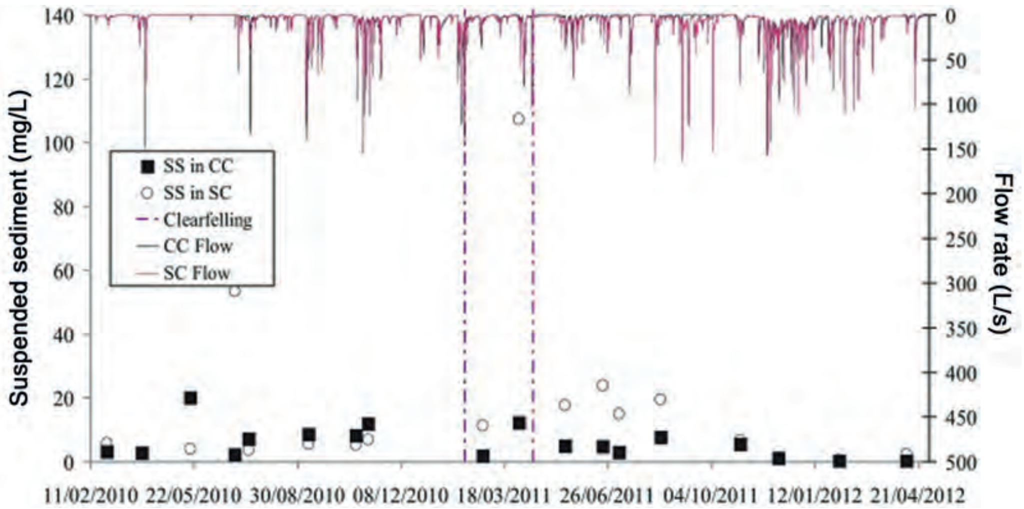

Figure 2.7. Flow-weighted mean concentrations of suspended sediment (SS) (mg/L) measured in the control catchment (CC) and the study catchment (SC) from February 2010 to May 2012. Reproduced from Finnegan *et al*. (2014), with permission from Elsevier.

draining the Glennamong forest and the other an adjacent moorland. Both these sub-catchments were about 10 ha in area and while one, 'the study catchment', was clearfelled, the other was maintained as a control so that comparisons could be made between the two and the differences attributed to clearfelling. Conditions in both catchments were monitored for a year prior to the clearfelling and for 15 months afterwards. The focus of this investigation was to measure the mobilisation of sediment and nutrients by clearfelling. Flow-weighted mean concentrations of total suspended solids (TSS) exported from the study catchment were marginally higher than from the control catchment for the first six months after clearfelling, but became similar over the following six months (or within a year following clearfelling) (Figure 2.7). The highest flow-weighted mean TSS concentration was measured during a storm which occurred during the clearfelling period in early April 2011. However, following installation of silt traps and extra brash placement on rutted extraction routes, the TSS concentrations were reduced considerably.

Phosphorus exports were higher in the study catchment during clearfelling than in the control catchment. Exports of soluble reactive phosphorus (SRP), estimated using measured data, indicated that the SRP export from the study catchment was 0.4 kg/ha per year compared with 0.2 kg/ha per year from the control catchment 1 year following clearfelling (Figure 2.8). Similarly, total phosphorus (TP) exports were greater for the study catchment than the control catchment. However, the impact on the receiving water, the Glennamong River itself, was negligible, primarily due to dilution.

In the Wicklow forests, two streams in sub-catchments of the River Ow were instrumented and studied. One was about 9 ha in size and the other 22 ha. In both, areas of 2.2 ha and 1.5 ha were clearfelled. Here, special attention was paid to the high temporal resolution of the water quality impacts of individual storm events, both prior to felling, during felling and after felling. Sediment and nutrient concentrations were measured for the rising limb, peak and recession limbs of storm events, showing in detail the pattern of sediment and nutrient mobilisation. Here, TSS concentrations in the streams increased during felling operations (Figure 2.9). Peak values during storms increased by up to 50 times the pre-felling concentrations and the magnitude depended on the percentage of the coupe clearfelled at the time of the storm. While rainfall magnitude also had an influence on these values, high rainfall events prior to the clearfelling period did not produce sediment loads comparable to similar rainfall during clearfelling. After felling operations ceased on site, the TSS concentrations during storms were considerably lower than during felling, but were over twice the pre-felling values, and this continued for up to 18 months after clearfelling. Silt traps were not present at these sites and any other mitigation measures did not prevent the high sediment and nutrient loads reaching the river. Deep rutting within the felled area along with a streamside extraction route may have contributed to the magnitude of the measured

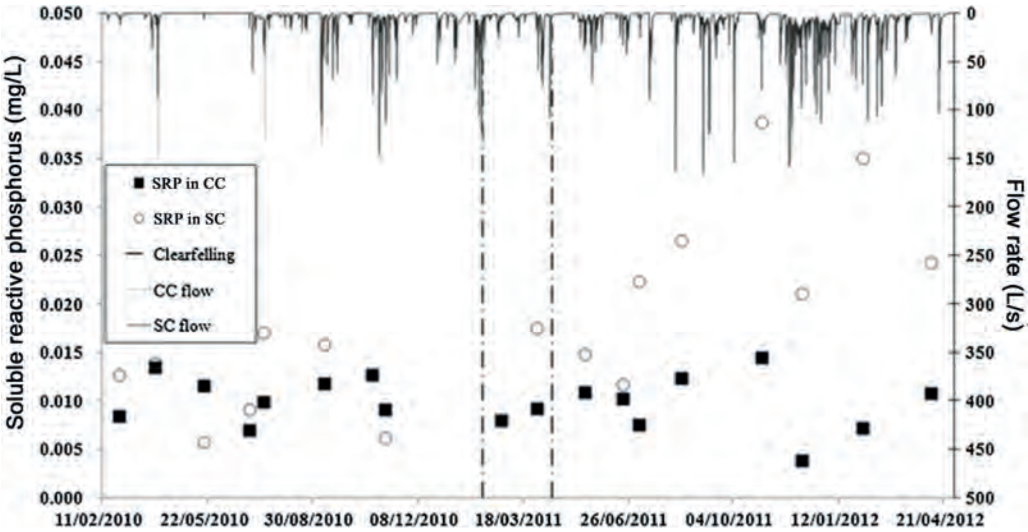

Figure 2.8. Flow-weighted mean concentrations of soluble reactive phosphorus (SRP) (mg/L) measured in the control catchment (CC) and the study catchment (SC) from February 2010 to May 2012. Reproduced from Finnegan *et al*. (2014), with permission from Elsevier.

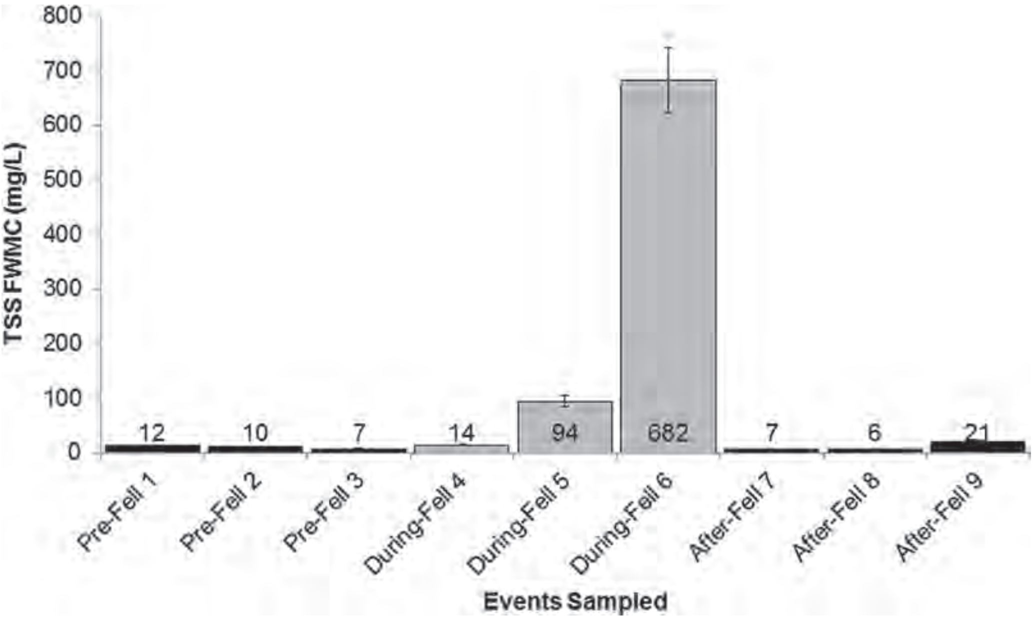

Figure 2.9. Flow-weighted mean concentrations (FWMC) of suspended sediment, pre-felling, during and after felling at the River Ow site. TSS, total suspended solids.

TSS concentrations. Harvesting stopped during heavy rainfall. A similar pattern was observed for phosphorus concentrations.

Taking the data from all study sites together, HYDROFOR showed that clearfelling increased the amount of sediment and nutrients released from a forest, and that the environmental impact of this depends on the size and location of the felled area and on the soil type, drainage characteristics and topography of the felled area. In all three HYDROFOR felling study sites, the highest releases of nutrients and sediment were measured near the end of felling, when 100% of the area had been clearfelled. No potential catchment felling thresholds for water quality or ecological impact could be derived because of the small number of sites investigated. Further research is required to address this.

Management practices, such as silt traps, carefully chosen felling sequences and management of extraction routes, did not prevent the release of nutrients from the sites, with one site in the west of Ireland releasing double the mass of highly mobile SRP over a 1-year period after clearfelling had finished compared with a similar catchment where clearfelling had not taken place.

The differences between the Glennamong and Ow studies indicate that existing guidelines have value particularly in relation to sediment attenuation. At the Glennamong site – where guidelines were generally adhered to – there was negligible impact on the receiving stream, whereas at the River Ow sites – where guidelines were not fully adhered to – large amounts of sediment and nutrients were measured in the receiving stream.

An important consideration is the size of the felled area of forest compared with the total area of catchment contributing to the streams that pass through it. In many areas, the plantation forest does not extend all the way to the top of the catchment boundary ridges and the intervening area is typically moorland and generates runoff during storms. If the clearfelled area is small compared with the entire catchment, the potential is greater for dilution, by relatively unaffected water from these areas, of any sediment or nutrient inputs to the stream from forest operations during storms. This reduces the overall peak concentrations downstream. The HYDROFOR team studied the change in coupe size in time from 2007 to the present and of projected coupe sizes up to the year 2050. Nationally, average coupe sizes declined from approximately 18 ha in 2007 to less than 10 ha in 2015, and are projected to remain at about 10 ha or increase slowly from then on. The trend was consistent for all Irish River Basin Districts except the Neagh-Bann. Thus, for the foreseeable future, large coupe sizes are not expected in most Irish forests.

2.2.2 Riparian buffer zones – potential to mitigate nutrient inputs to surface waters

Riparian buffer zones are intended to resist the passage of overland flows, slowing them down so that their particulate load is deposited in the buffer zone. In addition, more of the flow volume has time to infiltrate into the ground, leaving its particulate load behind on the surface and having more contact time with the subsoil to allow for the degradation of dissolved contaminants. Naturally, no individual streams or channels should be allowed to cut through, and effectively bypass, a buffer zone. Riparian buffer zones can be created in a number of ways:

1. by leaving an intact strip of forest adjacent to the stream and clearfelling the main coupe of trees behind it. This is appropriate for sheltered sites and can be planned at the time of clearfelling, or
2. by harvesting the trees from a strip beside the stream a number of years prior to clearfelling the main coupe and allowing the area to revegetate, either naturally or artificially. While requiring prior planning some years before clearfelling, this promotes biodiversity and allows more sunlight reach the stream.

The effectiveness of a riparian buffer zone was investigated in a 2.5 ha study site at Altaconey in County Mayo, where in May 2006, prior to the commencement of the HYDROFOR study, a 300 m strip of forest along the side of a stream was clearfelled to create a substantial buffer zone in which nutrient concentrations in soil water were measured. The residue forest cuttings (‘brash mats’) were placed on the ground to prevent soil damage by the machinery during clearfelling, and were left in situ on completion of clearfelling. In April 2007, 1 year after clearfelling, the riparian buffer was replanted with native broadleaved tree species. In February 2011, a forest upslope from, and draining into, the riparian buffer was clearfelled. In August 2011, a survey was carried out to determine the percentage survival and increase in height of the surviving saplings. Subsurface (to a depth of 100 cm below the ground surface) and surface water samples were collected throughout the entire site and upstream and downstream of the buffer before, during and after clearfelling of the forest area in February 2011.

Most of the water quality data indicated relatively uniform concentration of most contaminants, and no significant changes in the acidity of the surface and subsurface water along the buffer were detected. However, the concentrations of phosphorus, a nutrient linked to eutrophication, were highest under the brash mat in the riparian buffer, but also were much lower in other areas of the site (Figure 2.10). This indicated that the decomposing brash mats in the riparian buffer

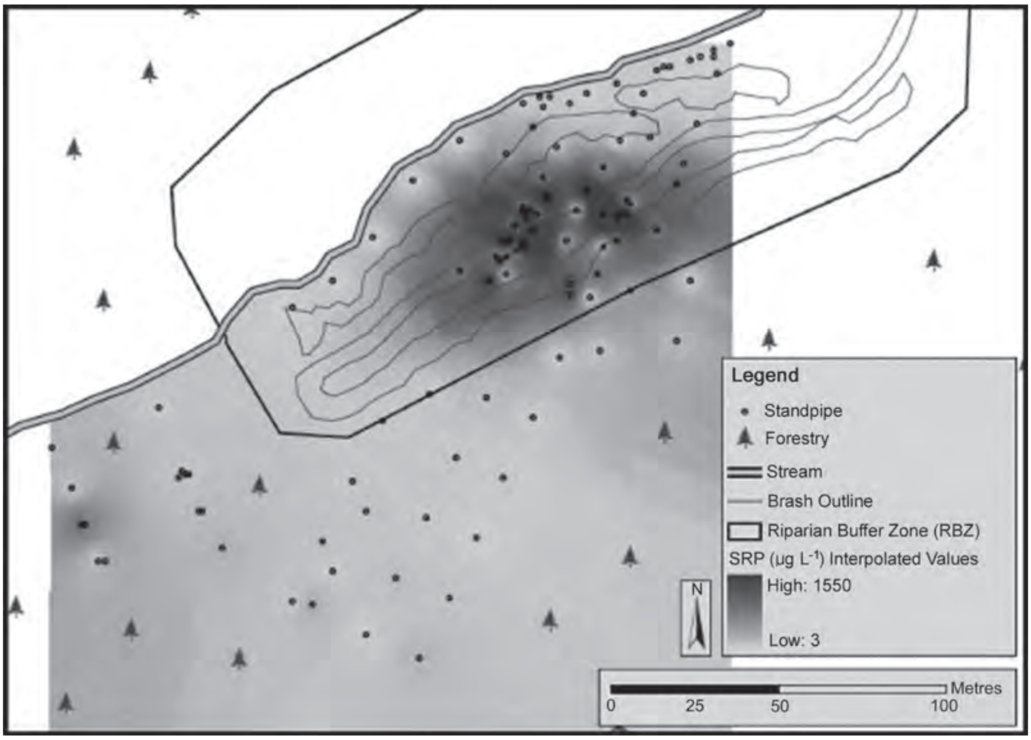

Figure 2.10. Average soluble reactive phosphorus (SRP) concentration from 20 cm, 50 cm and 100 cm depths below the ground surface measured over a 12-month period (April 2010 – April 2011) and expressed as µg/L. Reproduced from Finnegan *et al.* (2012), with permission from Elsevier.

released phosphorus into the underlying soil, which meant that, over time, this phosphorus may percolate to the wider environment. Based on the experimental measurements of SRP in subsurface water (at 20, 50 and 100 cm below the surface), there was no leaching of SRP from the upslope felling.

Water quality measurements in a stream running parallel to the clearfelled site indicated that neither the forestry activities nor the brash mat caused pollution of the receiving downstream waters. This was mainly attributable to a layer of sand, positioned right beside the river, which trapped any of the phosphorus released from the brash mat and underlying peat, from the water which percolated through it. Desorption–adsorption isotherms of phosphorus adsorption by weight (mg/g dry material) showed that the peat directly underneath the brash mat appeared to be at phosphorus saturation and had little remaining adsorption capacity. However, the phosphorus adsorption capacity of the mineral-rich peat 1 m from the stream was much higher than the peat layers higher up the buffer.

Overall, the effectiveness of the riparian buffer zone at this study site was compromised by the presence of degrading brash material on its surface. This suggests that there is a need to keep brash mats away from watercourses. There was good phosphorus retention at the river edge at this particular site, but this was only due to the sand layer present. The surface flow of sediment was low and sometimes below the limits of detection, so the qualitative efficacy of the riparian buffer zone in trapping sediment was difficult to quantify. To hasten the regrowth of woody vegetation, the riparian buffer was replanted with a variety of native broadleaved tree species. Rowan saplings thrived best and over half of rowan, oak and birch saplings survived. In contrast, willow and alder did not thrive and while holly did somewhat better, less than half its saplings survived. Thus, for best revegetation, care must be taken in the choice of species replanted.

2.3 Inputs of Sediment and Phosphorus During Replanting Operations

Planting or replanting of felled forest is an activity that also has the potential to cause the release of sediment and nutrients to local streams because it involves disturbing the ground surface and its protective layer of vegetation, leaving the surface vulnerable to the erosive action of rain and overland flows (Reynolds *et al* 1995; Nieminen, 2003). After a portion of a forest is felled and the logs removed, the discarded branches and brash are usually left on site to decay until the site is replanted. However, before replanting, windrowing of this brash material is undertaken, which is the most common method of site preparation prior to replanting. Windrowing involves gathering the brash into ridges in long narrow strips, called windrows. The timing of windrowing in relation to the preceding felling is critical to its impacts, as if it is carried out more than 1 year after felling, the needles on the discarded branches will have begun to decay and windrowing will spread them over the site.

The effects of windrowing were investigated at three river sites in the Wicklow Mountains: Annalecka, Oakwood and Kilcoagh. In Annalecka, 10 ha of a 168 ha catchment was windrowed over 18 months after felling and a buffer zone was maintained between the windrowing and the local stream. At Oakwood, just over 1 ha of a 48 ha catchment was windrowed over 18 months after felling. At Kilcoagh, 22 ha of a 129 ha catchment was windrowed more than 1 year after felling. The study focused on high temporal resolution hydrochemical measurements during storms as this is when most of the sediment and nutrients are mobilised. Sediment concentrations in storms during windrowing were over five times those in storms prior to windrowing and, while declining after windrowing, remained at approximately twice the pre-windrowing concentrations for up to 1 year afterwards (Figure 2.11). The sediment concentrations were comparable to those measured during felling, e.g. at the Ow sites. Within the windrowing period, sediment concentrations increased with the amount of area windrowed.

Phosphorus concentrations, in contrast to the results seen for the clearfelling operations, were elevated even prior to windrowing (except at Kilcoagh), due to the post-felling decay of the brash (Figure 2.12) and, while they increased during windrowing, the increase was smaller relative to that for sediment. Nevertheless, windrowing has the potential to increase sediment and phosphorus concentrations in receiving streams to levels close to those during felling. Particulate phosphorus bound to sediment was the main source of increased phosphorus concentrations. These increases may have occurred as a result of the mobilisation of loose sediment underneath windrows and an increase in ground disturbance caused by the movement of brash and soil when gathering brash into rows. It is likely that overland flow transported most of this to the study streams.

Differences in the pattern of sediment and phosphorus concentrations recorded at Kilcoagh suggest that the distance of the windrowing excavator from the stream is also important. As the excavator moved further away from the stream, sediment and phosphorus concentrations recorded in the stream channel decreased. However, other factors such as overland flow paths, and the location and connectivity of drainage ditches to the first order stream channel are also important. At

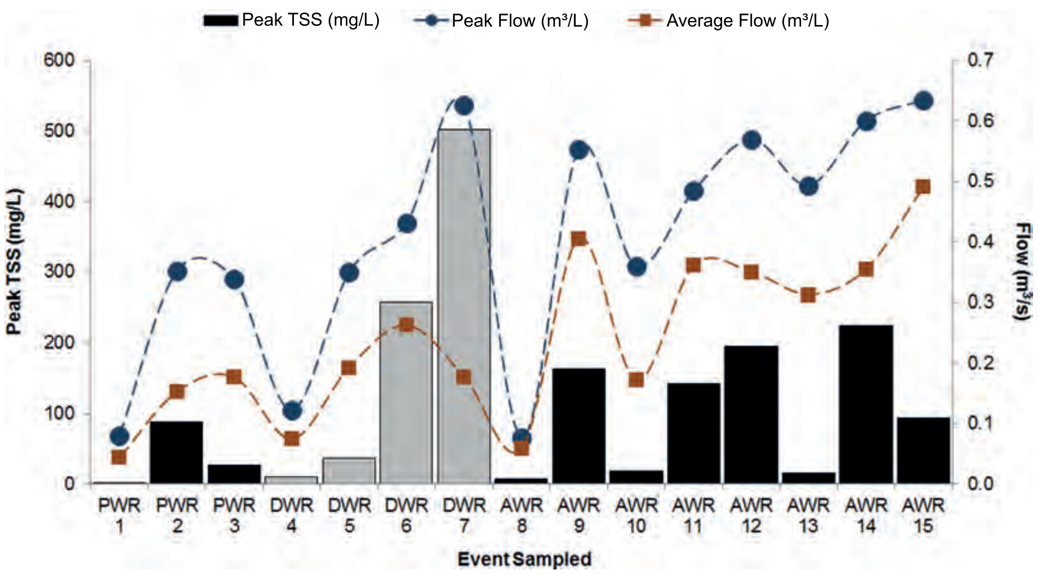

Figure 2.11. Peak suspended sediment before, during and after windrowing at Annalecka site. TSS, total suspended solids; PWR, pre-windrowing; DWR, during windrowing; AWR, after windrowing.

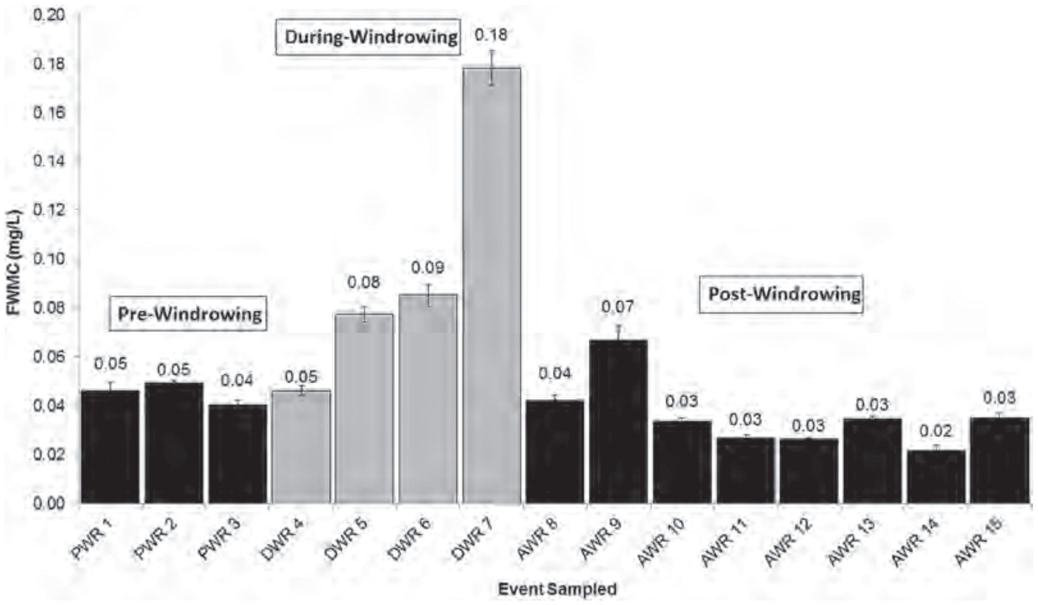

Figure 2.12. Flow-weighted mean concentrations (FWMC) of phosphorus pre-windrowing, during and after windrowing at Annalecka. PWR, pre-windrowing; DWR, during windrowing; AWR, after windrowing. Reproduced from Clarke *et al*. (2015), with permission from Elsevier.

Oakwood, sediment and phosphorus concentrations did not increase to the same extent during windrowing due to the presence of the vegetated strip. This suggests that a buffer area of vegetation would be an effective means of preventing most of the impacts associated with windrowing once drainage channels force water to flow across the buffer and do not discharge directly into the stream.

2.3.1 Assessment of sediment traps in mitigating sediment inputs from windrowing

It is clear that forest operations that disturb vegetation or soil can cause high concentrations of sediment and nutrients in local streams and that buffer zones can help reduce these amounts. However, if these are absent or if they do not prevent all sediment from reaching the stream, then some 'in-stream' measures are required. Thus, the project considered in-stream measures for reducing the downstream input of sediment and phosphorus, and so constructed and studied the effectiveness of silt traps at the Kilcoagh study site in County Wicklow. These have the effect of increasing the water depth at a specific place, which reduces its velocity and thus its ability to transport sediment. The sediment is deposited on the bed of the channel upstream of the trap. The same principle is involved in 'gravel traps' in larger rivers; however, in typical forested streams in Ireland with steep slopes and limited in-channel storage, their design and operation is challenging.

HYDROFOR designed and constructed two sediment traps in sequence in the stream leading from the Kilcoagh study area. These were effectively shallow weirs with one or more slots cut into the horizontal profile. The first weir had a single wide slot and the second had a number of narrow slots (Figure 2.13).

Flows, sediment and nutrient concentrations were measured in the channel upstream of the first trap and downstream of the second trap for a series of storms before, during and after windrowing operations. Over the entire sampling period, of approximately 2 years, the combination trapped 133 kg of sediment, with 30 kg being trapped by the first weir and over 103 kg trapped by the second. As might be expected, the sediment trapped by the first weir was coarser (20% >4 mm) than that trapped by the second (3% >4 mm) (Figure 2.14). More organic matter (38%) was trapped by the second trap than the first (15%). An important result is that the trapping efficiency was greater (58%) during windrowing, when it is most needed, than during the pre-windrowing (34%) or post-windrowing periods (15%). This is likely due to the larger particle sizes mobilised from soils recently disturbed by windrowing. The traps are easy and cheap to construct with simple materials and the study shows the benefits of a sequence of traps in a stream rather than a single trap.

To assist in the design of silt trap sequences, a computer model was developed, based on the HEC-RAS river simulation programme. The small physical dimensions of the streams, high bed-slopes, water velocities and short calculation time-steps are at the limits of the capability of this model. However, it succeeded in modelling the measured flows and sediment loads well. Thus, this is a tool that can be used to predict the performance of any proposed sequence of traps and weir profiles.

The full technical report which includes more detail on the results, including statistical analysis, is available at http://erc.epa.ie/safer/reports.

Figure 2.13. Downstream silt trap (within blue box) at Kilcoagh site (photograph: John Clarke, UCD).

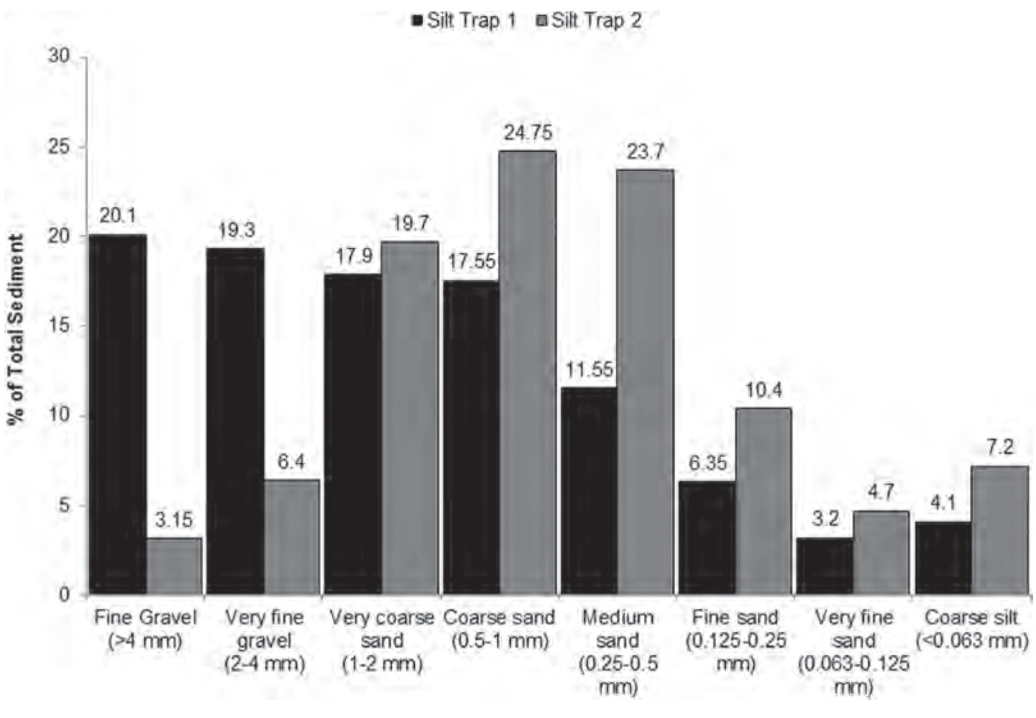

Figure 2.14. Different-sized particles deposited in each silt trap as a percentage of the total sediment.

3 Lake Studies

The locations of the HYDROFOR project lake study sites are shown in Figure 3.1.

The effect of conifer plantation forestry on lentic systems is much less frequently studied than the effect on river systems (Laird and Cumming, 2001; Northcote and Hartman, 2004), although lakes within forested catchments typically show a similar pattern of elevated concentrations of plant nutrients, major ions, humic substances and higher sediment inputs (Rask *et al*., 1998; Carignan and Steedman, 2000; Carignan *et al*., 2000; Steedman, 2000; Watmough *et al*., 2003; Feller, 2005; Kreutzweiser *et al*., 2008). Elevated concentrations of these substances can persist for a long time in lakes (depending on lake size and turnover) and may lead to widespread and pervasive changes to lake ecosystems, in comparison with their impact in streams which may be reduced by overriding factors such as hydraulic disturbance and riparian shading. Dissolved and particulate substances also tend to accumulate in lakes, which act as nutrient sinks (Søndergaard *et al*., 2003). Lakes may thus provide a more integrated assessment of catchment chemical influxes associated with forestry operations compared with streams.

Figure 3.1. Locations of HYDROFOR project lake study sites.

The HYDROFOR investigations are the first to consider the potential impacts of conifer forest and forestry operations on small upland lakes in Ireland. These lakes support a characteristic and sometimes unique suite of invertebrate species and are thus extremely important from a biodiversity perspective (Baars *et al*., 2014).

The objectives of the HYDROFOR investigations on the small upland lakes were to determine the effect of conifer forests on lake hydrochemistry, to determine whether or not hydrochemical change depended on the nature of forestry operations (mature forests vs part-catchment clearfelling) and to assess the nature and magnitude of any impacts on the invertebrate communities and fish populations.

3.1 Inputs from Conifer Forests to Small Upland Lakes: Implications for Hydrochemistry

Water samples were analysed bimonthly from 26 lakes for a suite of chemical determinands over a period of 12 months, beginning in March 2009. Thirteen lakes had catchments of unplanted blanket bog, seven lakes had catchments dominated by closed-canopy conifer forests with no clearfelling and six lakes were in catchments containing closed-canopy conifer forests with recently clearfelled areas. The 12 lakes in the south and mid-west were underlain by sandstone geology, whereas the 14 lakes in the west were underlain by granite geology. Typical lakes in the three land uses are shown in Figures 3.2 to 3.4.

Lakes within forested catchments across both geologies had elevated concentrations of phosphorus, nitrogen, dissolved organic carbon (DOC), aluminium, manganese and iron, with the highest concentrations of each recorded from lakes with forest clearfelling compared with the lakes in unplanted blanket bog (Table 3.1). The elevated levels of metals such as iron and manganese in the lakes in forested catchments are likely to be organically complexed and thus unlikely to have

Figure 3.2. Example of a blanket bog lake (photograph: Tom Drinan, UCC).

Figure 3.3. Lake with closed-canopy conifer forest in its catchment (photograph: Tom Drinan, UCC).

Figure 3.4. Lake with clearfelling in the catchment (photograph: Tom Drinan, UCC).

a direct, toxic effect on aquatic biota. Iron levels were generally below that reported to cause acute or chronic toxicity in zooplankton and benthic invertebrates (Vuori, 1995). Indirect effects of high iron concentrations include complex interactions with substances such as humic acids, DOC and plant nutrients, and precipitation onto benthic and organic surfaces (Vuori, 1995). High iron concentrations can also lead to 'browning' of waters, decreasing light penetration, and reducing primary and secondary production (Kritzberg and Ekström, 2012). Dissolved oxygen (DO) was also significantly lower in the forested lakes than in lakes in unplanted blanket bog, particularly the lakes in clearfelled catchments. However, DO levels recorded in lakes within forested catchments were not below the lower statutory threshold level for Irish lakes (S.I. 272 of 2009) and the biological impact of any forest-associated reduced oxygen is uncertain. Rather, DO levels likely reflect a general increase in decomposition activity, rather than act as a direct biological driver in themselves. Analysis of runoff from a recently clearfelled site located in a neighbouring blanket peat catchment (within 50 km of the lake study sites), revealed high biological and chemical oxygen demands, consistent with at least part of the elevated concentrations of DOC emanating from clearfelled sites having higher biochemical lability. The nutrient status of most, but not all, lakes surrounded by forestry operations was higher than unplanted blanket bog lakes.

3.2 Invertebrate Communities of Small Upland Lakes: Potential Impact from Forest Inputs

The 26 lakes studied were also sampled for Chydoridae (Cladocera) and benthic macroinvertebrate communities (Hemiptera, Coleoptera and Odonata) over a 12-month period 2009–2010. These taxa were chosen because their environmental tolerances and responses to hydrochemical disturbances are relatively well known and reported in the literature.

The Chydoridae (Branchiopoda, Anomopoda) are a speciose group of cladocerans ('water fleas') that primarily inhabit the littoral zone of lakes. In lentic habitats, aquatic Coleoptera, Hemiptera and Odonata are the most widely used indicators, as they are usually the most speciose taxonomic groups, their ecology and national distributions are well documented, and they are found in a wide variety of habitats (Savage, 1982; Foster *et al*., 1992; Sahlén and Ekestubbe, 2001; Bilton *et al*., 2006). The majority of species from these taxa are also predators and the number of species is reported to be an important indicator of environmental quality for a given site (Davis *et al*., 1987). All three groups also tend to respond in a predictable manner to lake physico-chemical environmental variation (Macan 1954; Nilsson *et al*., 1994; D'Amico *et al*., 2004). Chydorids are known to be important contributors to secondary

Table 3.1. Mean values/concentrations (± SE) of hydrochemical determinands measured in the lakes in each catchment land use (blanket bog, mature forest and clearfelling) across both geologies (sandstone and granite)

Hydrochemical parameter	Units	Sandstone						Granite					
		Blanket bog		Mature forest		Clearfelling		Blanket bog		Mature forest		Clearfelling	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Elevation	m.a.s	309.17	40.08	374.00	4.93	199.33	49.31	88.14	5.23	184.00	30.93	82.00	3.51
Mean depth	m	1.92	0.17	1.90	0.17	2.13	0.39	2.26	0.22	2.50	0.18	2.33	0.58
Size	ha	1.31	0.22	1.39	0.37	3.11	1.23	1.51	0.47	2.34	0.78	1.97	0.48
pH		5.14	0.17	4.69	0.26	4.89	0.35	5.57	0.21	5.05	0.30	5.04	0.21
Conductivity	µS/cm	36.49	1.38	44.65	4.69	63.10	4.15	72.13	1.78	77.72	9.17	72.28	5.56
Temperature	°C	9.91	0.14	10.38	0.07	10.56	0.12	10.84	0.18	11.26	0.12	11.02	0.10
Oxygen	mg/L	10.89	0.14	10.23	0.36	9.00	0.45	11.14	0.08	10.48	0.10	9.87	0.45
Colour	mg/L Pt. Co.	115.50	8.45	146.94	43.82	278.61	13.86	88.90	14.75	180.71	44.04	327.50	109.80
Chlorophyll	mg/L	5.77	1.42	9.55	4.56	17.77	7.37	3.67	0.46	4.23	1.07	6.63	0.38
TDOC	mg/L	8.21	0.95	10.11	2.49	19.29	0.58	7.18	0.59	11.83	2.27	17.22	4.83
TP	mg/L P	0.01	0.00	0.02	0.01	0.04	0.01	0.01	0.00	0.01	0.00	0.05	0.04
SRP	mg/L P	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01
TN	mg/L N	0.50	0.03	0.49	0.08	0.78	0.05	0.48	0.04	0.59	0.08	0.81	0.24
TON	mg/L N	0.03	0.01	0.01	0.00	0.02	0.01	0.02	0.01	0.02	0.00	0.03	0.01
Ammonia	mg/L N	0.02	0.00	0.03	0.01	0.04	0.01	0.03	0.00	0.03	0.01	0.10	0.06
Sulphate	mg/L SO_4	1.96	0.09	2.01	0.10	2.44	0.08	2.94	0.11	3.17	0.23	2.51	0.07
Aluminium	µg/L Al	44.25	8.27	59.13	14.87	176.54	51.02	27.79	4.90	132.41	29.93	90.06	33.21
Calcium	mg/L Ca	0.92	0.16	0.50	0.28	1.62	0.46	1.19	0.12	1.23	0.47	1.59	0.53
Sodium	mg/L Na	4.13	0.15	5.13	0.70	7.01	0.15	9.40	0.23	10.04	0.96	9.32	1.07
Chloride	mg/L Cl	6.72	0.28	7.92	0.90	11.56	0.47	17.27	0.39	17.39	1.92	16.17	1.51
Potassium	mg/L K	0.25	0.02	0.12	0.01	0.31	0.01	0.33	0.02	0.19	0.02	0.39	0.11
Magnesium	mg/L Mg	0.58	0.02	0.60	0.08	0.97	0.07	1.21	0.03	1.09	0.10	1.13	0.04
Manganese	µg/L Mn	20.36	7.23	27.21	15.61	139.98	67.13	26.78	4.45	45.61	14.81	66.18	21.49
Iron	µg/L Fe	159.44	52.86	226.44	104.21	945.11	171.45	321.71	118.13	477.29	111.53	1202.17	514.33

m.a.s., metres above sea level; SE, standard deviation; TDOC, total dissolved organic carbon; TN, total nitrogen; TON, total oxidised nitrogen.

production in small lakes and can also provide prey for many species of fish (Frey, 1995; Parke *et al*., 2009). Importantly, as chydorid communities respond in a predictable manner to acidification and nutrient enrichment, they can also be used as biological indicators in lakes (Hofmann, 1996; Walseng and Karlsen, 2001; de Eyto *et al*., 2002; Bos and Cumming, 2003). Chydorids have also been previously used to assess the impact of forestry operations on lakes in Canada (Bredesen *et al*., 2002).

Both invertebrate groups showed changes consistent with forestry-driven changes to water chemistry, with species characteristic of nutrient-poor waters (including some nationally rare species) being replaced, in lakes with forested catchments, with species characteristic of nutrient-enriched waters. There was no evidence that invertebrate groups were responding to changes in pH. Forestry-mediated changes in community composition were most marked for lakes subject to clearfelling within their catchments.

The chydorid communities of the lakes in the forested catchments, especially clearfell lakes, were associated with elevated DOC, iron, aluminium, TP, total nitrogen (TN), ammonia, SRP and chlorophyll a concentrations. Conversely, the communities in blanket bog lakes were associated with higher dissolved oxygen concentrations. Abundances of certain species [e.g. *Alonopsis elongata* and *Chydorus sphaericus* (Figure 3.5)] varied significantly between lakes of differing catchment land use (Figure 3.6). *A. elongata* was significantly more abundant in the blanket bog lakes in comparison to the lakes with closed-canopy plantation and clearfell lakes. Conversely, *C. sphaericus* was significantly more abundant in the lakes in forested catchments, including clearfell.

Changes in lake trophy are well known to influence chydorid communities, with *C. sphaericus* known to respond well to eutrophication (Hofmann, 1996; Vijverberg and Boersma, 1997; Brodersen *et al*., 1998; Bos and Cumming, 2003), often better than *A. elongata* (de Eyto and Irvine, 2001). In this study, the beneficial response of *C. sphaericus* and other smaller bodied chydorids to the altered trophic state caused by plantation forestry surrounding the lakes is most likely ascribed to the increased availability of smaller food particles, which smaller bodied cladocerans are known to feed on more efficiently than larger species (Geller and Müller, 1981). The *Chydoris* response may also relate to the increased autochthonous production from the supply of nutrients,

Figure 3.5. *Chydorus sphaericus* (photograph: Elvira de Eyto, Marine Institute).

and the allochthonous supply of organic matter to the lakes from the conifer plantation. The higher abundance of *A. elongata* in non-forested, higher altitude lakes with low plant nutrient availability suggests that this species may have a more limited chemical tolerance in comparison to other chydorid species, especially for lower dissolved oxygen concentrations.

In a similar pattern to that seen with the chydorids, the macroinvertebrate predators showed marked shifts in community composition in response to forest-mediated changes in hydrochemistry. Coleoptera and Hemiptera assemblages from lakes within forested catchments, particularly clearfell-affected lakes, were associated with elevated concentrations of DOC, total monomeric aluminium, TP, iron, TN, chlorophyll a, ammonia, SRP and reduced dissolved oxygen levels. The communities of Odonata changed more between geologies than with land use. For Coleoptera and Hemiptera, though not Odonata, higher-richness abundances were associated with lakes on sandstone geology (Figure 3.7). The species richness and species quality scores of the three predatory macroinvertebrate groups showed a positive response to forestry-mediated nutrient enrichment, consistent with trophic enrichment of the habitat. The increase in Species Quality Score (SQS) for the Coleoptera and Hemiptera in lakes in forested catchments was attributable to the increased species

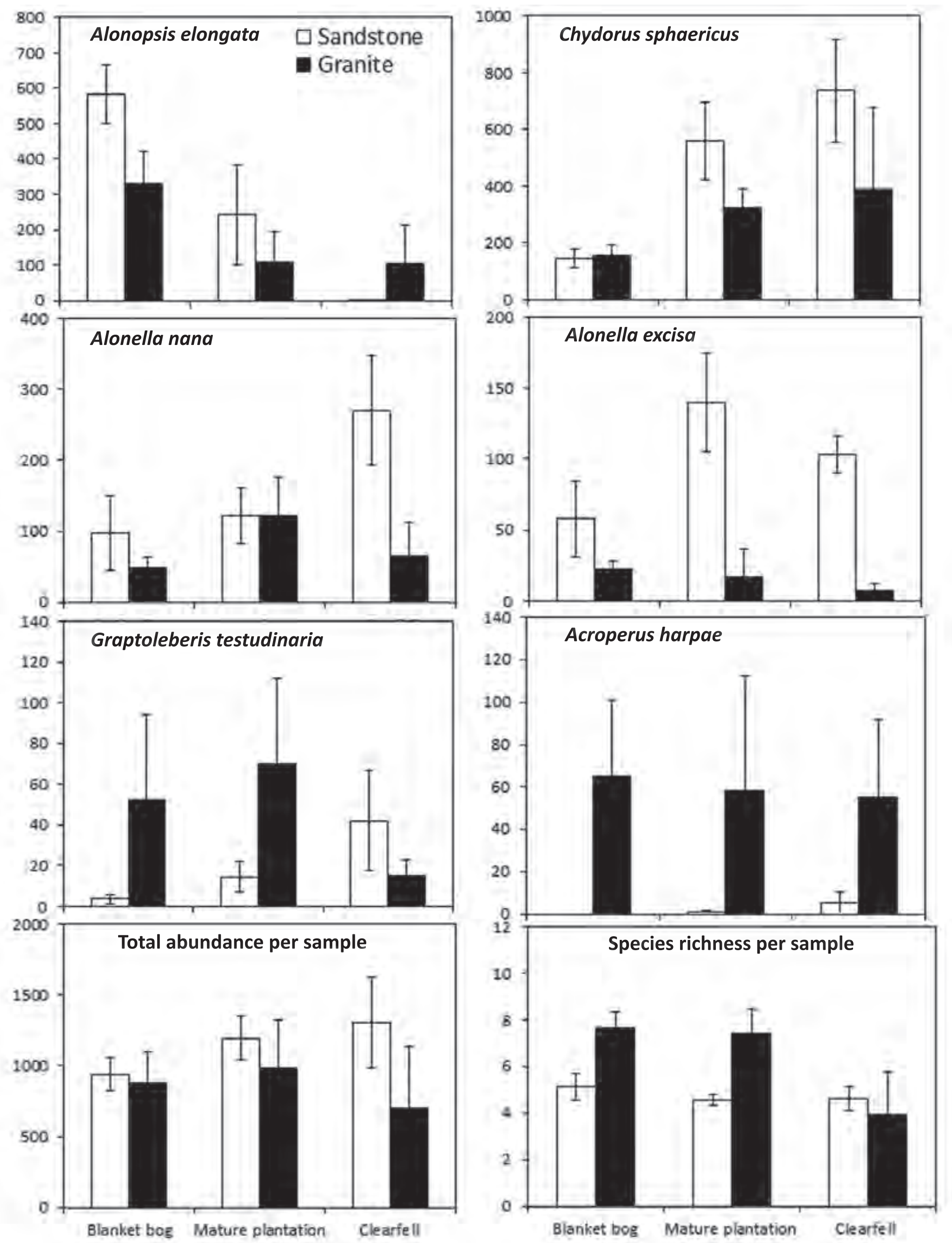

Figure 3.6. Mean abundances (± SE) of selected chydorid species, species richness and mean chydorid abundance in the blanket bog, mature plantation and clearfell lakes across both geologies (sandstone and granite). Columns on each graph are mean values (± SE) for each catchment land use calculated over the 12-month sampling period. The number of lakes in each classification were as follows: SB = 6, GB = 7, SM = 3, GM = 4, SC = 3 and GC = 3, where S = sandstone, G = granite, B = blanket bog, M = closed-canopy plantation and C = clearfell. Reproduced from Drinan *et al*. (2014), with permission from Springer.

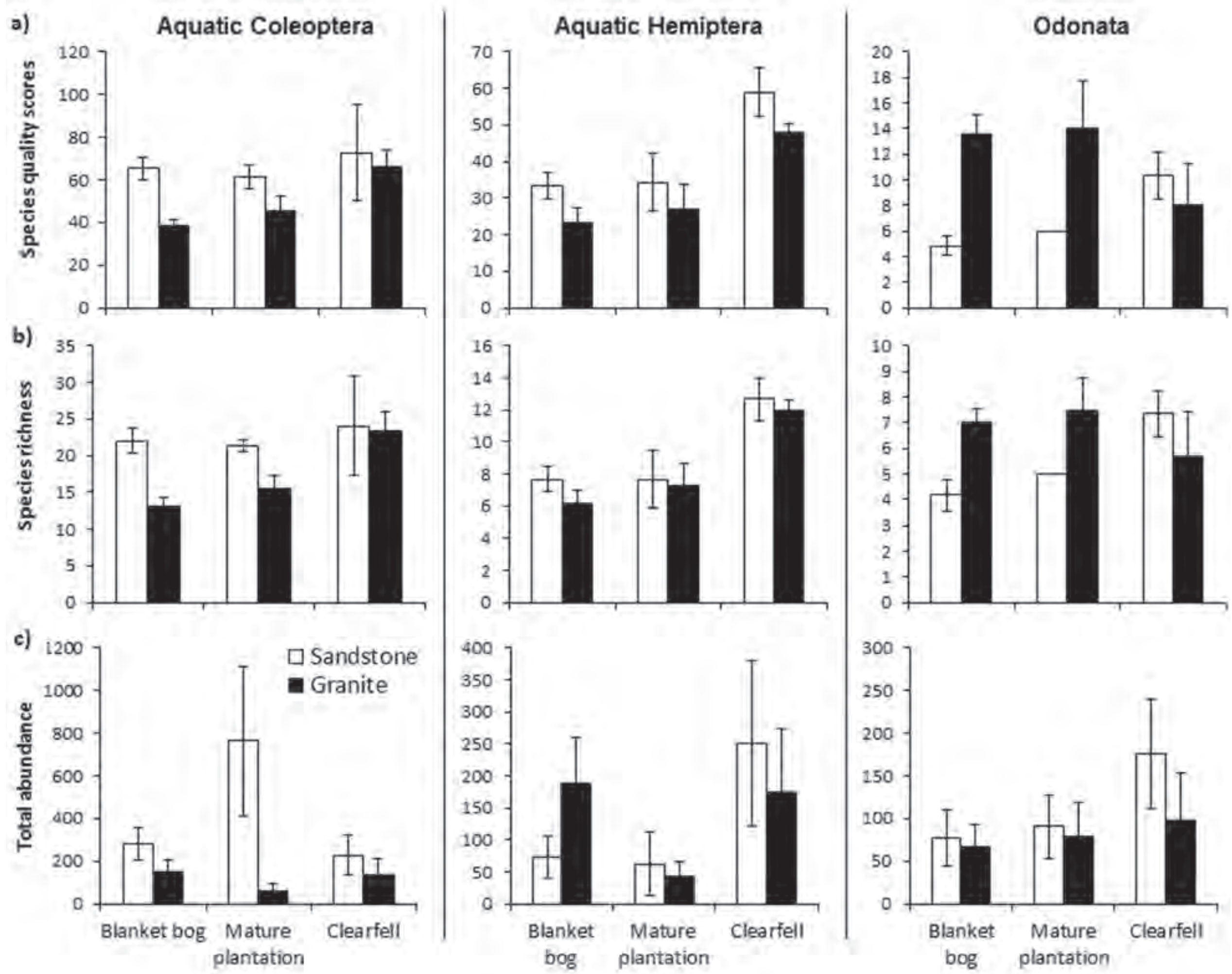

Figure 3.7. Comparison of mean (a) SQS, (b) species richness, and (c) total abundance for all three macroinvertebrate groups between the blanket bog, mature plantation and clearfell lakes across both geologies (sandstone and granite). Species Quality Scores (SQS) were calculated using the number of hectads (10 × 10 km square) of the Irish National Grid in which each individual species of aquatic Coleoptera, Hemiptera and Odonata have been recorded since 1950. Columns on each graph are mean values (± SE) for each catchment land use calculated over the duration of the sampling period. The number of lakes in each classification were as follows: SB = 6, GB = 7, SM = 3, GM = 4, SC = 3 and GC = 3. Reproduced from Drinan *et al*. (2013), with permission from Elsevier.

richness of these lakes, rather than an increase in rare high-scoring taxa.

3.3 Brown Trout in Upland Lakes: Population Characteristics and Effects from Forest Inputs

Compared with the larger number of studies on invertebrate and plant communities, there are relatively few studies investigating impacts of forest practices on fish populations or communities, particularly in small lakes (Jutila *et al*., 1998; Rask *et al*., 1998; Northcote *et al*., 2004), despite the more commercial importance of this group of animals. Many of these studies have focused on the effect of acidification, as low pH levels and elevated levels of labile monomeric aluminium are known to impoverish fish communities (Driscoll *et al*., 1980) and the early life stages of fish, including salmonids, are highly sensitive to acidification (Kelly-Quinn *et al*., 1993; Sayer *et al*., 1993). The distribution and density of brown trout (*Salmo trutta*; Figure 3.8) have been shown to be negatively impacted by forest-associated acidification (Stoner *et al*., 1984; Rees and Ribbens, 1995; Kelly-Quinn *et al*., 1996b).

The objective in this study was to investigate relationships between lake hydrochemical conditions and

Figure 3.8. Brown trout (*Salmo trutta*) fry (photograph: Jan Robert Baars, UCD).

brown trout population biology in two non-randomly selected lakes in blanket bog catchments with no forest, two with medium (approximately 30–40%) and two with high (approximately 80–95%) forest cover in their catchment. Fish were sampled in early June and September 2010 following Inland Fisheries Ireland protocols, using multi-mesh gill nets set in benthic, littoral and pelagic habitats, to give a whole-lake estimate for relative trout abundance, expressed as catch-per-unit-effort (CPUE). Growth rate (observed mean and maximum potential instantaneous daily growth rate) was estimated for each year class. Estimates were also made of (a) the maximum potential ration size for a fish of a given weight at the specified lake temperature, (b) the maintenance ration which is the calculated ration required for maintaining metabolism of a trout of the measured weight at the temperature experienced over the study period and (c) the calculated actual daily ration consumption needed to produce the observed fish growth, at the given lake temperature. The hydrochemical characteristics of each lake were also determined.

In agreement with previous results from the study on the 26 lakes, there were higher concentrations of plant nutrients, DOC and heavy metals in the lakes in forested catchments, but no change to pH. Whereas there was no consistent trend in brown trout density between land uses, highest densities were recorded in lakes within forested catchments (Figure 3.9). Trout populations in lakes within forested catchments were dominated by younger fish, primarily 1+ (1-year-old) and 2+ (2-year-old) individuals with some 0+ (young of the year) trout present, compared with control lakes, which were largely dominated by 2+ and 3+ (3-year-old) individuals (Figure 3.10).

Older age classes of trout had larger body sizes in lakes with high catchment plantation forest cover, indicating higher empirical growth rates, likely due to trophic enrichment. Brown trout-specific growth models that incorporated the potential confounding influence of different temperature regimes, showed no consistent relationship between growth and forest cover over the summer study period, however. Food consumption models indicated that trout in all sites were energetically challenged during the summer when sampling took place. Discrepancies between the observed body size and estimated growth of trout in lakes may potentially be due to (a) a significant amount of growth occurring outside of the summer study period and/or (b) unusually

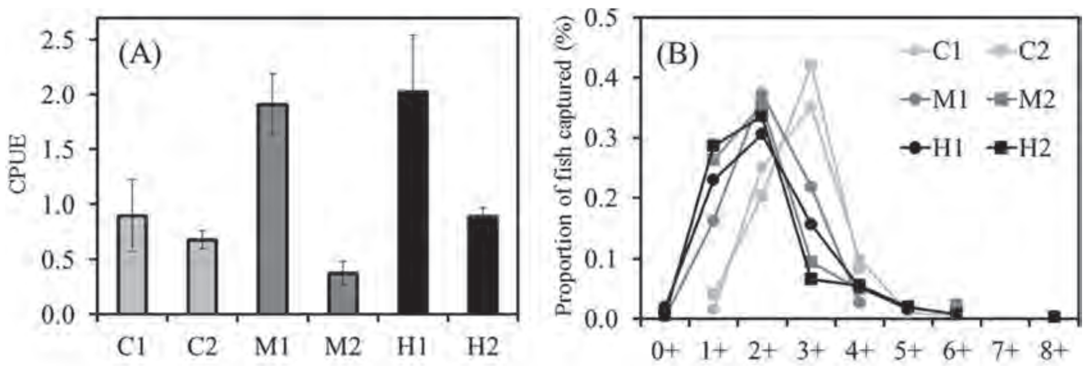

Figure 3.9. Comparison of (a) mean (± SE) CPUE of total trout over the two sampling dates and (b) the age structure of the brown trout populations in each of the six study lakes in western Ireland, expressed as a proportion of the total number of brown trout captured in each lake. C1 and C2, controls; M1 and M2, medium (approx. 30–40%) catchment forest cover; H1 and H2, high (approx. 80–95%) catchment forest cover. Reproduced from Graham *et al*. (2014), with permission from Elsevier.

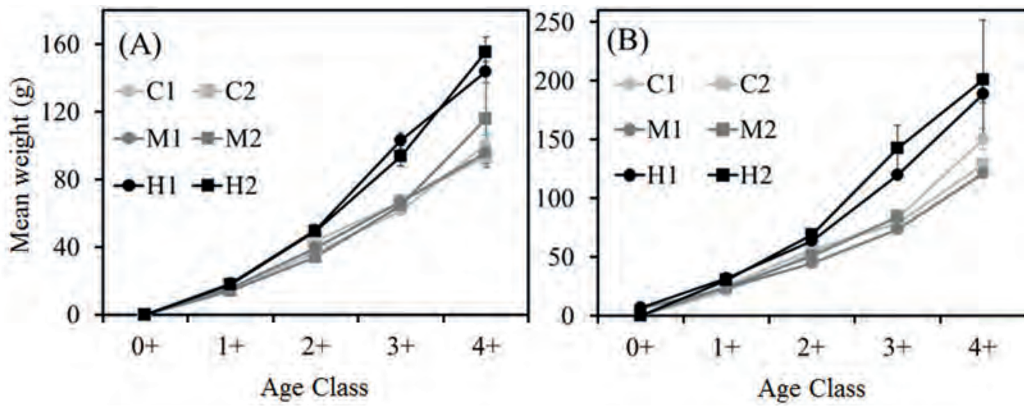

Figure 3.10. The mean size of 0+ to 4+ year classes of trout in each of the six study lakes in western Ireland in (a) June and (b) September. C1 and C2, controls; M1 and M2, medium (approx. 30–40%) catchment forest cover; H1 and H2, high (approx. 80–95%) catchment forest cover. Reproduced from Graham *et al*. (2014), with permission from Elsevier.

elevated temperature regimes during the study period, particularly in the forested sites.

Overall, the observed impact of forestry operations on brown trout populations in forested blanket bog lakes in western Ireland was consistent with moderate nutrient enrichment, leading to enhanced growth, recruitment and size of trout, rather than any negative effect such as that due to acidification or heavy metal toxicity. Species with higher conservation value such as Atlantic salmon (*Salmo salar*) and Arctic char (*Salvelinus alpinus*), both of which also occur in many western lakes, may be more sensitive to the effect of forest-mediated changes to hydrochemistry.

4 General Conclusions and Recommendations

HYDROFOR has demonstrated the dynamic nature of conifer forest–water interactions in predominantly upland catchments and shown the need to consider the potential effects on water quality through the life cycle of the forest. The research highlighted that, while there was evidence for some recovery in pH in streams in forested catchments, the analyses indicated that higher episodic acidity/greater alkalinity loss is still associated with streams draining catchments with closed canopy forest, despite significant reductions in atmospheric acid deposition. Furthermore, for the first time, a forest effect was detected in streams draining ORS. Impact on aquatic macroinvertebrates was shown to be seasonal with loss of acid-sensitive taxa in the winter/spring, presumably due to more frequent storm flow. Recovery occurred during the summer months. Impact, albeit seasonal, is likely to challenge the resilience of upland systems and may, in the longer term, affect aquatic biodiversity, especially if the projected increase in rainfall during the winter months occurs as a result of climate change. The downstream extent of impact is likely to be limited to a few kilometres and, therefore, in an Irish context, it is unlikely to affect status rating at the first WFD monitoring site. Nevertheless, the implications for catchment biodiversity must be considered. As previously highlighted, up to 29% of catchment macroinvertebrate diversity is unique to headwaters, i.e. typically within 2.5 km from the river source. Furthermore, the results relating to longitudinal extent of impact were based on just two forested streams. Further sampling is recommended to confirm this for other systems, especially in catchments where peaty soils dominate the adjoining land for a long length of the stream channel.

Organic acidity (in the form of DOC) was shown to be the key driver of the episodic acidity and was higher in streams draining forested catchments. It is unclear why this is occurring and may relate to reductions in inputs of sulphate, increased soil temperatures and changes in rainfall patterns. Nevertheless, it represents elevated loss of carbon (i.e. a negative effect on carbon balance) from peat soils and should be further investigated. It is highly recommended that a number of the HYDROFOR sites be selected for the long-term monitoring of DOC composition and dynamics in forested and moorland streams. Based on the 32 sites examined, it is not possible to propose a threshold for catchment forest cover. This is due to lack of suitable sites within the lower end of the forest cover gradient (e.g. only one forested site with < 20% catchment forest cover and four sites with 20–30% forest cover), which precluded identification by this project of a safe threshold for catchment forest cover. Impact on hydrochemistry and aquatic macroinvertebrates was shown in catchments with both low and high forest cover, relating to elevated DOC concentrations and lower pH. These research findings, in combination with the potential for sediment and nutrient losses during harvesting and preparation for replanting (discussed below) and biodiversity concerns, support a recommendation for the cessation of conifer afforestation on peat soils (especially blanket and raised peat bogs) in acid-sensitive (< 15 mg $CaCO_3$/L – see acid sensitivity protocols in DAFM, 2015b) headwater catchments. In relation to reforestation of sites in such catchments, there are serious concerns with respect to the aforementioned impacts. In some cases, deforestation may raise operational concerns with respect to conifer regeneration and invasive species (e.g. rhododendron), which may colonise cleared sites. Peatland restoration measures that might minimise these problems should be trialled. Where replanting is considered, the design should be hydrologically informed and demonstrate empirically on a site-specific basis that it can mitigate impacts on water quality and aquatic biodiversity through the forest management cycle, as highlighted in this report.

A considerable amount of forest planted in the 1960s and 1970s is now at the felling stage. HYDROFOR has shown that clearfelling and windrowing prior to replanting can generate substantial sediment and nutrient loads in streams leading from the areas concerned. The amounts are influenced by site-specific characteristics, such as depth of peat or the slope of a site, and other potential confounding factors, such as the time of year felling occurs (e.g. low vegetation cover in winter), weather conditions at the time of felling and area of clearfell relative to catchment area. Cognisance should be taken of these factors when drafting a harvesting or replanting plan. Sediment loading was observed to increase as windrowing progressed. Preventing deep rutting, through the use of brash mats, may prove challenging as the purpose of windrowing is to lift all remaining brash materials post felling into rows using an excavator to provide space for the replanting of new trees. According to good practice, windrowing should be carried out by the machine as it reverses away from the site, lifting brash as it goes. In general, a conscious effort by the operator to minimally disturb the ground when felling and extracting timber and when scraping and gathering brash would also be beneficial and in compliance with best practice guidelines. There is a need for instruction of machinery operators in this regard, with onsite supervision and real-time quality control of operations during harvesting and windrowing.

The use of riparian buffer zones and vegetated areas with drains blocked to allow flow through the vegetation may be effective at preventing elevated sediment in receiving watercourses. However, the potential for phosphorus retention is low on peaty soils and particularly steep catchments, and may be dependent on the occurrence of mineral material in the riparian zone, as illustrated in the study on the buffer zone at Altaconey in County Mayo. That study recommended that brash mats should be kept away from watercourses and that a full-site characterisation be conducted prior to creating buffer zones, particularly in ecologically sensitive areas. In instances where there is no mineral layer present at a watercourse edge, leaching of nutrients from decomposing brash mats will occur unabated. Management options for the creation of buffer zones prior to the commencement of felling operations may include thinning in areas adjoining watercourses (where windfirmness allows) in order to encourage the development of thicker ground vegetation cover in advance of the eventual clearfell of the proposed riparian zone. Where riparian buffer zones are being cleared of trees, machine passage should not take place along the watercourse. Where this is unavoidable for operational reasons, brash mats should be used, but only in concert with an existing mineral barrier, as was the case in Altaconey. Where clearfelling occurs in the riparian zone, it should be undertaken in a manner that minimises the use of machinery, e.g. motor manual felling and extraction using iron horses or similar light extraction machines. Further investigation needs to be conducted on alternative management options, such as the use of structures and media capable of trapping nutrients and sediment.

Preventing sediment from entering watercourses is likely to prevent very large increases in phosphorus concentrations. Windrowing changes the location and timing of phosphorus loadings. The operation of windrowing causes large immediate short-term releases although subsequent phosphorus concentrations may, in some cases, be as low or lower than pre-windrowing levels and are mainly localised to the vicinity of the windrows. Thus, if measures such as buffer zones and/or silt traps can be employed to properly manage the higher immediate short-term releases, then windrowing may ultimately lead to lower subsequent longer term releases. It is important that such measures be planned and implemented in advance of machinery entering the site to windrow. Ideally, movement across the site by machinery should be minimised, and confined as much as possible to the brash mats as it works its way off the site. No machinery should enter watercourses or riparian zones. The preference between riparian buffer zones and silt traps will depend on an inspection of the drainage routes into the channel, so some understanding of the site drainage must be obtained for planning purposes. Riparian buffer zones are more effective when the topography is smooth and overland flow more distributed, but are less effective in more complex topography where there are many individual drains leading to the stream, which allow some water to bypass the buffer zone. Silt traps can be effective at trapping sediment that has entered a channel (see Figure 2.13).

Silt traps should be installed in drainage channels and ditches in steep forested catchments where riparian buffer zones have not been established and where forest operations are planned. These will aid reducing overall sediment inputs to downstream waters. During forest operations such as windrowing, the traps were more effective and are therefore more important during these times. The installation of these traps before felling with the intention of leaving them in place for 1 or 2 years post windrowing may be the best approach, as long as their installation and removal are properly managed and no large sediment and nutrient inputs occur. Installation should preferably be in the smaller local drainage channels leading to major streams. No alternation or disturbance of the major natural stream channels should be undertaken. Placing silt traps as close as possible to sediment sources is preferable to further downstream where flows and channel dimensions are greater.

The design and location of the silt trap structures is important and a combination of two silt traps can be more effective at trapping a range of particle sizes.

Typically, forest operations such as windrowing are short in duration (4–5 weeks depending on the plantation size) and the installation of silt traps for only this period may not be justified considering potential impacts that might arise during their installation and removal. The installation of silt traps before tree harvesting and their removal when sufficient vegetation cover has been re-established (2+ years post windrowing) is a better approach, providing the traps are maintained correctly. HEC-RAS can be used to model flow and sediment transport in small river reaches less than 30 m in length with catchment areas less than 30 ha. A mixed flow regime should be selected if both subcritical and supercritical flows are possible in the channel. When calibrating a small stream channel with high temporal resolution data, lowering the computation interval and increasing the number of cross sections are important. Care must be taken in selecting the distance between modelled cross sections.

When using the sediment transport model, it is recommended that a sediment load series is not inputted directly through the upstream boundary condition. However, a workaround can be used. Running HEC-RAS using US customary units instead of metric units is also recommended as potential conversion issues were highlighted. Manual conversion back to metric units for reporting is recommended instead. This issue may be resolved in future versions of HEC-RAS.

HYDROFOR completed the first series of investigations on potential impacts of conifer forests and forestry operations on small peatland lakes in Ireland. The finding from these lake studies showed that nutrient enrichment and increases in DOC and heavy metal concentrations were the main issues associated with afforestation/felling in their catchments. Associated changes in the structure of the chydorid communities and to some of the macroinvertebrate groups can occur. The traditional mitigation measure of drain-blocking, whilst potentially reducing the supply of particulates and fine sediment, is unlikely to prevent soluble materials (nitrogen, phosphorus and carbon) from leaving catchments. ‘Buffer zones’ bordering plantations in these peat soil blanket bog catchments are unlikely to sequester nutrients to any great extent, particularly if forest drains bisect them. Restricting the area felled around a lake during any one year may reduce the supply of soluble materials flowing into the lake from the plantation. Whether this reduces the net quantities in the lake will depend on the degree to which lakes retain nutrients over time.

Felling should be undertaken with maximum sensitivity in the catchment of these lakes, contingent on site conditions. Further research is urgently needed to determine the exact source of plantation runoff and the mechanisms that generate it. Should much of the soluble plant nutrients and labile DOC be found to emanate from felling residue, whole tree harvesting should be considered where feasible. Furthermore, the practice of minimising soil disturbance using brash mats may need to be revised as this measure may actually increase the input of soluble nutrients to lakes, through enhanced decomposition of clearfell reside within the brash mats. Novel methods of intercepting runoff from felled sites, before they enter lakes, should also be explored, due to the likely ineffectiveness of buffer zones in blanket bog catchments. Blanket peat extended to the littoral of all study lakes, with very little mineral sub-soil being exposed. The planting of broadleaved trees on the blanket peat, similarly, is unlikely to prove effective as the trees are unlikely to grow well in the poorly-drained, acid peat soil. In the absence of any cost-effective mitigation measures in these blanket bog catchments, the replanting of conifers, within the (limited) catchments of small upland lakes should be avoided, if economically feasible, for particularly sensitive sites.

A considerable body of hydrochemical, hydrological and biological data from research on forest–water interactions in Ireland has been brought together for the first time by the HYDROFOR team, some of which covers sites that have been examined at various points in time, e.g. the PEnrich study. It is highly recommended that a selection of forested and non-forested sites be chosen for long-term monitoring similar to what has been undertaken in the UK with the acid-waters network.

4.1 Policy Recommendations

The project outputs (reports and peer-reviewed publications) will inform the development of forestry policy and guidelines, as well as the implementation of the WFD.

- Sediment release to water courses during felling and replanting may be reduced by careful onsite management of felling and windrowing operations, installation of silt traps and greater application and oversight of best practice guidelines.
- A combination of several sediment traps may be more effective at trapping a range of sediment particle sizes than single isolated traps.

- Retention of phosphorus requires attention as it is more challenging on peat soils and will depend on the occurrence of mineral content in riparian soils or the installation of mineral barriers.
- Based on the suite of impacts from planting to harvesting, including elevated DOC nutrient and sediment release and aquatic biodiversity concerns, cessation of afforestation on peat soils in acid-sensitive headwater catchments is recommended by the project team. In relation to reforestation of sites in such catchments, there are serious concerns with respect to the aforementioned impacts. Where replanting is considered, the design should be hydrologically informed and demonstrate empirically on a site-specific basis that it can mitigate impacts on water quality and aquatic biodiversity through the forest management cycle, as highlighted in this report. A number of mitigation measures (aquatic buffer zones and sediment traps) were investigated in this study, and the research evidence highlighted their ability to reduce some pollutant inputs. Their effectiveness is likely to be site specific and other measures, not investigated in this project, e.g. reduced catchment tree cover, minimising drainage and soil disturbance, may reduce impact, but these remain to be validated by further research.

4.2 Recommendations for Further Research

- Establish long-term monitoring sites to track changes in hydrology, hydrochemistry and aquatic ecology in forested catchments into the future.
- Characterise the chemical composition of DOC, its source and the processes leading to its current release from peaty soils in order to improve understanding of forest–water interactions and impacts on freshwater biology.
- Determine the sources, pathways and processes releasing soluble nitrogen, phosphorus and sediment from felled sites to water courses.
- Further develop and evaluate mitigation measures and management approaches to reducing nutrient and sediment inputs to streams from forestry operations.
- Characterise changes in stream hydrology, hydrochemistry, ecology and associated management issues (e.g. measures to promote bog restoration, and to control conifer regeneration and colonisation by invasive species) in felled catchments that will not be replanted, or in catchments within which forests will be converted from the clearfell system to less intensive CCF systems based on, for example, Scots pine, birch, rowan, etc., or to alternative non-forest land uses. Establish a forest-cover threshold at which reforestation on peat soils in acid-sensitive catchments can be considered.
- Determine the factors and conditions which facilitate ecological recovery of impacted watercourses.

This report concludes with three appendices. Appendix 1 lists the HYDROFOR project's peer-reviewed journal articles, doctoral theses, presentations and other public dissemination activities. Appendix 2 describes the end-of-project workshop the HYDROFOR researchers hosted in April 2014 to communicate their key findings to an audience of 135 delegates representing 44 organisations active in influencing forest and water policy in Ireland and abroad. The two-way exchange of knowledge on that day in April and the many subsequent correspondences that followed have served an important role in the manner in which HYDROFOR's researchers made final interpretations of their findings. Finally, Appendix 3 is a description of and guide to accessing and utilising the HYDROFOR project database.

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Glossary

Afforestation	The conversion of land to a forest.
Alkalinity	Measure of the acid neutralising capacity of a water sample.
Base flow	Flow conditions during periods of dry weather. The stream flow comes from deep subsurface *flow* and/or delayed shallow sub-surface *flow.*
Catchment	Drainage basin of a river or lake.
Chydoridae	A group of small waterfleas.
Coleoptera	A group of insects commonly known as beetles.
Ephemeroptera	A group of aquatic insects commonly known as mayflies.
Episodic acidity	Increases in acidity/decreases in pH that occur during periods of high flow in streams draining acid-sensitive geology.
Macroinvertebrate	Aquatic invertebrate that is visible to the naked eye.
Odonata	A group of insects that contains dragonflies and damselflies.
pH	A measure of the molar concentration of hydrogen ions in a solution and so a measure of the acidity or basicity of a water sample, expressed on a scale of 1 to 14.
Riparian buffer zone	An area of land bounding a water body that is in place to intercept pollutants from various land use activities.
Silt trap	An area or structure in which contaminated water containing suspended sediment is slowed down to facilitate deposition of the sediment.
Storm flow	Elevated flow conditions during periods of high or prolonged precipitation.
Windrowing	Arranging the brash mats (tree branches and woody debris left after felling) into piles to facilitate replanting of trees.

Abbreviations

ANC	Acid neutralising capacity
AWIC	Acid Water Indicator Community (index)
AWICsp	Acid Water Indicator species
CCF	Continuous cover forestry
CPUE	Catch-per-unit-effort
DAFM	Department of Agriculture, Food and the Marine
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DTM	Digital Terrain Model
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
FEPS	Forest Environmental Protection Scheme
GIS	Geographic information system
HF	High forest cover
HYDROFOR	Assessment of the Impacts of Forest Operations on the Ecological Quality of Water
LF	Low forest cover
NUIG	National University of Ireland, Galway
ORS	Old Red Sandstone
POM	Programme of Measures
RBZ	Riparian Buffer Zone
SE	Standard error
S.I.	Statutory Instrument
SQS	Species Quality Score
SRP	Soluble reactive phosphorus
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
UCC	University College Cork
UCD	University College Dublin
UKTAG	United Kingdom Technical Advisory Group
WFD	Water Framework Directive

Appendix 1 Outputs

HYDROFOR journal articles

Authors	Year	Title	Journal
Drinan, T., Nelson, B., Tickner, M., O'Donnell, G.O., Harrison, S.S.C., O'Halloran, J.	2011	First discovery of larvae of the Downy Emerald Cordulia aenea (L.) in Ireland and the species' use of lakes in treeless blanket bog in Connemara, Co. Galway	*Journal of the British Dragonfly Society* 27: 1–12
Feeley, H.B., Kerrigan, C., Fanning, P., Hannigan, E., Kelly-Quinn, M.	2011	Longitudinal extent of acidification effects of plantation forest on benthic macroinvertebrate communities in soft water streams: evidence for localised impact and temporal ecological recovery	*Hydrobiologia* 671: 217–226
Feeley, H.B., Woods, M., Baars. J., Kelly-Quinn, M.	2012	Refining a kick sampling strategy for the bioassessment of benthic macroinvertebrates in headwater streams	*Hydrobiologia* 683: 53–68
Feeley, H.B., Davis, S., Bruen, M., Blacklocke, S., Kelly-Quinn, M.	2012	The impact of a catastrophic storm event on benthic macroinvertebrate communities in upland headwater streams and potential implications for ecological diversity and assessment of ecological status	*Journal of Limnology* 71: 73–82
Finnegan, J., Regan, J.T., de Eyto, E., Ryder, L., Tiernan, D., Healy, M.G.	2012	Nutrient dynamics in a peatland forest riparian buffer zone and implications for the establishment of planted saplings	*Ecological Engineering* 47: 155–164
Drinan, T.J., Foster, G.N., Nelson, B.H., O'Halloran J., Harrison, S.S.	2013	Macroinvertebrate assemblages of peatland lakes: assessment of conservation value with respect to anthropogenic land-cover change	*Biological Conservation* 158: 175–187
Drinan, T.J., Graham, C.T., O'Halloran, J., Harrison, S.S.C.	2013	The impact of catchment conifer plantation forestry on the hydrochemistry of peatland lakes	*Science of the Total Environment* 443: 608–620
Drinan, T.J., Graham, C.T., O'Halloran, J., Harrison, S.S.C.	2013	The impact of conifer plantation forestry on the Chydoridae (Cladocera) communities of peatland lakes	*Hydrobiologia* 700: 203–219
Drinan, T.J., O'Halloran J., Harrison, S.S.C	2013	Variation in the physico-chemical and biological characteristics between upland and lowland (Atlantic) blanket bog lakes in western Ireland	*Biology and Environment: Proceedings of the Royal Irish Academy* 113B: 67–91
Feeley, H.B., Bruen, M., Blacklocke, S., Kelly-Quinn, M.	2013	A regional examination of episodic acidification response to reduced acidic deposition and the influence of plantation forests in Irish headwater streams	*Science of the Total Environment* 443: 173–183
Feeley, H.B., Kelly-Quinn, M.	2014	Re-examining the effects of episodic acidity on macroinvertebrates in small conifer-forested streams in Ireland and empirical evidence for biological recovery	*Biology and Environment: Proceedings of the Royal Irish Academy* 114B: 1–14
Finnegan, J., Regan, J.T., O'Connor, M., Wilson, P., Healy, M.G.	2014	Implications of applied best management practice for peatland forest harvesting	*Ecological Engineering* 63: 12–26
Finnegan, J., Regan, J.T., Fenton, O., Lanigan, G.J., Brennan, R.B., Healy, M.G.	2014	The short-term effects of management changes on water table position and nutrients in shallow groundwater in a harvested peatland forest	*Journal of Environmental Management* 142: 46–52
Graham C.T., Drinan T.J., Harrison S.S.C., O'Halloran J.	2014	Relationship between plantation forest and brown trout growth, energetics and population structure in peatland lakes in western Ireland	*Forest Ecology and Management* 321: 71–80
Clarke, J., Kelly-Quinn, M., Blacklocke, S., Bruen, M.	2015	The effect of forest windrowing on physico-chemical water quality in Ireland	*Science of the Total Environment* 514: 155–169
Feeley, H.B., Kelly-Quinn, M.	2015	The nymphal diet of the stonefly *Protonemura meyeri* (Pictet) (Plecoptera: Nemouridae) in four episodically acidic headwater streams in Ireland	*Irish Naturalist's Journal* 34: 104–109.

HYDROFOR oral presentations

Lead author(s)	Date	Title	Forum
Sean Blacklocke	February 2009	Development of regression models to predict forestry impacts on aquatic ecology and effectiveness of mitigation measures: the HYDROFOR strategy	Environmental Sciences Association of Ireland's ENVIRON 2009 Annual Conference, Waterford, Ireland
Sean Blacklocke (self-funded)	October 2009	Tapping old knowledge trees and growing new ones: the HYDROFOR Project strategy for developing predictive models of forest and water interactions in Ireland	International Water Association's 13th International Specialized Conference on Diffuse Pollution and Sustainable Basin Management, Seoul, South Korea
Hugh Feeley	February 2010	A preliminary assessment of the longitudinal extent of impact on macroinvertebrate communities in coniferous forestry catchments in Ireland	20th Irish Environmental Researchers' Colloquium (ENVIRON 2010), Limerick, Ireland
Hugh Feeley	August 2010	A preliminary assessment of the longitudinal extent of impact on macroinvertebrate communities in coniferous forestry catchments in Ireland	31st Congress of the International Society of Limnology (SIL), Cape Town, South Africa
Sean Blacklocke (self-funded)	September 2010	An assessment of spatial statistical techniques to inform the development of empirical models for the prediction of forestry practice impacts on surface waters in Ireland	14th International Water Association Diffuse Pollution Specialist Group Conference (DIPCON 2010), Quebec, Canada
Sean Blacklocke (self-funded)	September 2010	Diffuse versus point source control: river basin phosphorous accounting (September).	Presentation to the Workshop on Phosphorous Management in the Water Cycle, International Water Association World Water Congress and Exhibition, Montreal, Canada
Joanne Finnegan	April 2011	Assessment of impacts of forest operations on the environment	ESAI Colloquium, University College Cork, Ireland
Joanne Finnegan	April 2011	Assessment of impacts of forest operations on the environment	Postgraduate Research Open Day, National University of Ireland, Galway, Ireland
Sean Blacklocke (self-funded)	August 2011	Development of empirical models to predict the effects of common forestry operations on Irish surface water quality	Meeting of the Jönköping County Administrators, Jönköping, Sweden
Sean Blacklocke	September 2011	Defining spatial relationships between forestry operations and surface water quality in Ireland	15th International Water Association Diffuse Pollution Specialist Group Conference (DIPCON 2011) Rotorua, New Zealand
Joanne Finnegan	September 2011	Assessment of impacts of forest operations on the environment	12th International Conference on Environmental Science and Technology (CEST 2011) Rhodes Island, Dodecanese, Greece
Sean Blacklocke	December 2011	An overview of the HYDROFOR Project	Coillte Headquarters, Newtownmountkennedy, Ireland
Hugh Feeley	December 2011	Forestry and surface water acidification in 21st century Ireland: changing chemical trends and ecological status?	UCD School of Biology and Environmental Science, University College Dublin, Ireland
Hugh Feeley	March 2012	The changing chemical trends and ecological status of forested streams in Ireland: a reassessment of surface water acidification and future considerations	ENVIRON 2012, Newman Building, University College Dublin, Ireland
Hugh Feeley	March 2012	The effects of changing climate on surface water acidification in headwater streams in Ireland	Annual Meeting of Irish Freshwater Biologists 2012, Joly Lecture Theatre, Hamilton Building, Trinity College Dublin, Ireland
John Clarke Hugh Feeley Joanne Finnegan Simon Harrison	May 2012	Forestry and water interactions	International Water Association First World Congress on Water, Climate and Energy: Forestry and Water Interactions Workshop, Dublin, Ireland
Joanne Finnegan	June 2012	Use of brash mats for clearfelling of forestry on peat: an Irish perspective	The International Peat Congress, Stockholm, Sweden

HYDROFOR oral presentations (continued)

Lead author(s)	Date	Title	Forum
Conor Graham	August 2012	Effect of plantation forestry on brown trout growth, energetics and community structure in peatland lakes in the west of Ireland	Second International Conference on Biodiversity in Forest Ecosystems and Landscapes, IUFRO, University College Cork, Ireland
Sean Blacklocke	October 2012	An overview of the HYDROFOR Project	Eastern River Basin District Project Workshop on Forestry Measures, Glen of the Downs, Ireland
Sean Blacklocke	March 2013	Optimising forestry and catchment management in Wicklow	Eastern River Basin District Project Workshop on Protected Areas, Dublin, Ireland
Hugh Feeley	April 2015	HYDROFOR: forest and water interaction – managing forests in acid sensitive catchments	Forestry and Fisheries – Where Next? Conference, Rheged Centre, Penrith, England

HYDROFOR posters, articles and PhD theses

Lead Author	Date	Output and Title	Forum
Tom Drinan	January 2010	Conference Poster – Effects of conifer afforestation on peatland lake ecosystems	Symposium on the Role of Littoral Processes in Lake Ecology, Hegne, Germany
Sean Blacklocke	March 2010	Conference Poster – HYDROFOR: project to assess forest and surface water interactions: first early findings	Coillte Workshop on the Value of Forest Monitoring Networks: Their Role in a Changing Environment, Delgany, Ireland
Hugh Feeley	May 2010	Workshop Poster – Assessing the ecological effects of forestry operations and potential mitigation measures in riverine systems in sensitive regions of Ireland	Joensuu Forestry Networking Week 2010: Forest–Water Interactions in Europe, Joensuu, Finland
Joanne Finnegan	May 2010	Workshop Poster – Assessment of impacts of forest operations on the ecological quality of water	Joensuu Forestry Networking Week 2010: Forest–Water Interactions in Europe, Joensuu, Finland
Joanne Finnegan	September 2011	Article – Best forestry oral presentation: assessment of impacts of forest operations on the environment	*Environews*, ESAI, Summer 2011 issue no. 22
Joanne Finnegan	September 2011	Article – Research in focus: change	*Research Matters*, NUIG, Autumn 2011 Issue
Hugh Feeley	July 2012	PhD Thesis – The impact of mature conifer forest plantations on the hydrochemical and ecological quality of headwater streams in Ireland, with particular reference to episodic acidification	University College Dublin
Tom Drinan	September 2012	PhD Thesis – The impact of conifer plantation forestry on the ecology of peatland lakes	University College Cork
Joanne Finnegan	December 2012	PhD Thesis – Assessment of the impact of forestry on peatlands on the environment	National University of Ireland, Galway
John Clarke	September 2015	PhD Thesis – Measuring, evaluating and modelling physico-chemical water quality during forest operations	University College Dublin

Appendix 2 Workshop

The HYDROFOR Project held its End-of-Project Workshop in April 2014 with the co-operation of an estimated 135 delegates representing 44 organisations and another 13 independent professionals. The project's fact sheet and publication list were distributed to every attendee, as was its web address where all project outputs to date were posted.

Delegates spent most of the day engaging with nine presenters, who included representatives of the Steering Committee, the EPA, Coillte and the HYDROFOR team of principal investigators and PhD student researchers. After lunch, a series of five parallel break-out sessions, led by appointed unaffiliated delegates, were conducted so that the workshop's five main topics of interest could be discussed between delegates in some detail, with input from researchers only being contributed when solicited. The five pre-designated groups of approximately 20 delegates each discussed the following topics:

- mature conifer forest effects on water quality and aquatic ecology of acid-sensitive rivers;
- clearfelling effects on peatland rivers;
- composition of riparian buffer zones to mitigate clearfelling effects;
- windrowing effects on river water quality;
- effects of forestry on small peatland lakes.

Five lists of items for further consideration by the project were generated and recorded by the five focus groups of delegates. The five groups also each reported back a list of potential remedial actions to address the issues raised in the researchers' presentations. Each group was balanced by affiliation and led by a group rapporteur assigned based on alphabetic ordering of surnames in the group. The project team had the benefit of taking this wealth of knowledge into account when deriving the project's final conclusions and recommendations. The workshop programme is shown in detail in Table A2.1.

Table A2.1. Agenda for the HYDROFOR End-of-Project Workshop programme entitled "Workshop on Understanding Water Quality and Aquatic Ecology in Forested Catchments in Ireland". Chairman: Professor Emeritus Ted Farrell, UCD

Time	Talk	Speaker(s)
09:00–09:05	HYDROFOR Project and Workshop Introduction	Professor Emeritus Ted Farrell, UCD
09:05–09:25	Forest and Water Interactions	Dr Tom Nisbet, Forest Research UK
09:25–10:05	Forest and Water Interactions Policy in Ireland	Dr Alice Wemaere, EPA
10:05–10:35	Mature Conifer Forest Impacts on the Water Quality and Aquatic Ecology of Acid-Sensitive Rivers	Dr Hugh Feeley, UCD (now at Cardiff University); Dr Mary Kelly-Quinn, UCD
10:35–11:05	*Coffee Break*	
11:05–12:05	Clearfelling Impacts on Peatland Rivers	Dr Mark Healy, NUIG; Mr John Clarke, UCD; Professor Michael Bruen, UCD
12:05–12:30	Assessment of a Riparian Buffer Strip to Mitigate Clearfelling Impacts on a Peatland River	Dr Joanne Finnegan, NUIG (now at RPS Consulting Engineers)
12:30–13:30	*Lunch (provided)*	
13:30–14:00	Windrowing Impacts on River Water Quality	Mr John Clarke, UCD; Professor Michael Bruen, UCD
14:00–14:45	Effects of Forestry on Small Peatland Lakes	Dr Simon Harrison, UCC
14:45–15:30	Mitigation Measures to Address River and Lake Impacts from Mature Forests and Forestry Operations	Dr Philip O'Dea, Coillte
15:30–15:40	Introduction of Discussion Group Exercise	
15:40–16:10	*Working Coffee Break: Five Concurrent Discussions*	
16:10–17:00	Discussion Group Reports	Moderator: Professor Steve Ormerod, Cardiff University

Appendix 3 Database

Metadata for each of the worksheets in the HYDROFOR Database and a screenshot of the Integrated Interactions Data worksheet are shown. Co-ordinates for sample sites are not included in the dataset because a companion directory of geographic information system (GIS) shape files is available with the spreadsheet-based database. In the main component of the database, the Integrated Interactions Data worksheet, data from two independent projects (HYDROFOR and FORWAT) are organised by columns of common parameters.

Each data cell in the Integrated Interactions Data worksheet has a corresponding cell to its right indicating its source, coded as follows:

Data Reference	Source of Data
UCDSB	Sean Blacklocke, Michael Bruen, Mary Kelly-Quinn at University College Dublin
UCDJC	John Clarke, Michael Bruen, Mary Kelly-Quinn at University College Dublin
UCDHF	Hugh Feeley, Mary Kelly-Quinn, Michael Bruen at University College Dublin
UCCTD	Tom Drinan, Simon Harrison, John O'Halloran at University College Cork
UCCCG	Conor Graham, Simon Harrison, John O'Halloran at University College Cork
NUIGJF	Joanne Finnegan, John Regan, Mark Healy at National University of Ireland, Galway
ME	Met Éireann
C	Coillte
EPA	Environmental Protection Agency
UCDMKQ	Mary Kelly-Quinn at University College Dublin

Cells with –999 indicate that data for the relevant parameter are either not available or have not been added.

Cells with –888 indicate that data are not relevant to the corresponding parameter.

HYDROFOR Project database metadata

Integrated Interactions Data

Sample/measurement date: In yyyy/mm/dd format. 00 for dd means day of month unknown.

Sample/measurement time: In military time.

Sample/measurement site name: Name given to site by original researchers.

Sample/measurement site ID: Code assigned to site in HYDROFOR database.

Sample/measurement ID: Comprised of site ID, date and sample number.

Sample/measurement target: Target for all data is surface water.

Sample/measurement type: Includes automatic monitoring/sampling and grab sampling. Automatic monitoring/sampling was done with automatic samplers and, in some cases, automatic flow meters. Grab sampling done by either hand dipping bottles or by passive sampling with devices constructed to capture and store rising stream waters.

Project/dataset name: Name of project or study in which core data (i.e. water quality data) originated. Projects include HYDROFOR and FORWAT.

Work package ID: Identification code for project work package in which core data were originated.

Affecting forestry management measure(s): Non-comprehensive list of pollution abatement measures employed at the site and time at which samples were taken. Measures noted are thought to be those not necessarily applied at all sites and at all times.

Forestry operation(s) potentially affecting sample/measurement: Forestry operations such as clearfelling and windrowing that are known to generate water pollution. Data are from researchers' observations and communications with Coillte.

Status of forestry operation(s) potentially affecting sample/measurement (before, ongoing, after): The status of the forestry operations such as clearfelling and windrowing that are known to generate water pollution. Status is either before (b), ongoing (o) or after (a). Data are from researchers' observations and communications with Coillte.

Surface waterbody type: River (i.e. natural first-order stream or greater), drain (i.e. man-made conduit) or lake (of any size). Data interpreted by HYDROFOR researchers from the EPA's WFD GIS dataset.

Surface waterbody name (rivers, lakes): Data interpreted by HYDROFOR researchers from the EPA's WFD GIS dataset.

Surface waterbody order (rivers): Data interpreted by HYDROFOR researchers from the EPA's WFD GIS dataset.

% Subcatchment in forested blocks (%): HYDROFOR-based project data were generated by digitising GIS polygons of forested blocks from current Google Earth satellite photographs. Ireland's 20-metre resolution Digital Terrain Model (DTM) was made available to HYDROFOR researchers from the EPA. The model was used in conjunction with ArcView 10 to create subcatchment delineations created with the ArcHYDRO tool. These polygons were projected as WGS1984 kml files in Google Earth so that the subcatchment delineation would project onto the Google Earth maps. Forest cover was identified in Google Earth by its distinct dark colour in the photographs, and blocks of forested areas were digitised as polygons and saved as kml files. Kml files of forest blocks were converted to shape files in ArcView and areas were calculated and summed across subcatchments. Percentage area in forested blocks was determined by dividing forested area within the subcatchment by total subcatchment area and multiplying by 100. FORWAT project data were taken from estimates in the Forest Service's FIPS 07 database. Further details on how those data were calculated are unavailable.

Subcatchment mean slope, **subcatchment mean slope of forested blocks**, and **subcatchment mean slope of non-forested blocks (degrees):** Ireland's 20-metre resolution DTM was made available to HYDROFOR researchers from the EPA. The model was used in conjunction with ArcView 10 to calculate the average slopes in degrees of each delineated subcatchment. Average slopes were also calculated for each delineated forested block polygon (see % Subcatchment in forested blocks (%)) and the average slope of all forested blocks in each subcatchment was calculated as follows:

fbts = ((fb1a/fbta) × fb1s) + ((fb2a/fbta) × fb2s) + ...((fbna/fbta) × fbns)

where:

fbts = average slope of all forested blocks in subcatchment

fb1a = area of forested block 1

fbta = total area of all forested blocks in subcatchment

fb1s = average slope of forested block 1

fb2a = area of forested block 2

fb2s = average slope of forested block 2

fbna = area of forested block n

fbns = average slope of forested block n

The average slope of non-forested areas in each subcatchment was calculated as follows:

nfbts = (fbts – pscfb(fbts))/(1 – pscfb)

where:

nfbts = average slope of all non-forested blocks in subcatchment

fbts = average slope of all forested blocks in subcatchment

pscfb = percent of subcatchment in forested blocks

Surface waterbody primary geology: The Teagasc national geology GIS dataset was made available by the EPA and used to determine the primary geology type underlying the surface waterbodies or streambeds.

Surface waterbody primary soil: The Teagasc national soils GIS dataset was made available by the EPA and used to determine the primary soil type underlying the surface waterbodies or streambeds.

Subcatchment primary geology: The Teagasc national geology GIS dataset was made available by the EPA and used to determine the primary geology underlying the subcatchment draining to the sample location (i.e. pour point or discharge node).

Subcatchment primary soil: The Teagasc national soils GIS dataset was made available by the EPA and used to determine the primary soil type underlying the subcatchment draining to the sample location (i.e. pour point or discharge node).

Nearest rainfall station name: Met Éireann data for rainfall stations throughout Ireland were obtained by the HYDROFOR project and names (in code form) for those stations are indicated. Data from the Coillte-operated weather station at the FutMon site (UCDFM) were analysed and recorded the same as the data from Met Éireann sites.

Nearest rainfall station type: Met Éireann data for the three types of weather stations throughout Ireland were obtained by the HYDROFOR project: rainfall station (R), climatological stations (R, T) and synoptic stations (R, T, W). Since all three types include rainfall data, the Met Éireann station nearest to the water quality sampling site, and for which relevant data were available, was identified and the type of that station indicated.

Linear distance between surface waterbody sample site and nearest rainfall station (km): The Met Éireann station nearest to the water quality sampling site, and for which relevant data were available, was identified and the linear distance between the surface waterbody sample site and its associated rainfall station was recorded.

Total rainfall – preceding 2 days (mm): Rainfall data from the Met Éireann station nearest to the water quality sampling site for the 2 days prior to the date on which the sample was taken are indicated. For instance, if the sample was taken at 13:00 on 31 March, total rainfall accumulated during the period from 00:00 to 23:59 on 29 March and 00:00 to 23:59 on 30 March is recorded.

Total rainfall – preceding 7 days (mm): Rainfall data from the Met Éireann station nearest to the water quality sampling site for the 7 days prior to the date on which the sample was taken are indicated. For instance, if the sample was taken at 13:00 on 31 March, total rainfall accumulated during the period from 00:00 on 24 March to 23:59 on 30 March is recorded.

Total rainfall – preceding 30 days (mm): Rainfall data from the Met Éireann station nearest to the water quality sampling site for the 30 days prior to the date on which the sample was taken are indicated. For instance, if the sample was taken at 13:00 on 31 March, total rainfall accumulated during the period from 00:00 on 1 March to 23:59 on 30 March is recorded.

Nearest temperature station name: Met Éireann temperature data from stations throughout Ireland were obtained by the HYDROFOR project and names (in code form) for those stations are indicated. Data from the Coillte-operated weather station at the FutMon site (UCDFM) were analysed and recorded in the same way as the data from Met Éireann sites.

Nearest temperature station type: Met Éireann data for the three types of weather stations throughout Ireland were obtained by the HYDROFOR project: rainfall station (R), climatological stations (R, T) and synoptic stations (R, T, W). Since all three types can include temperature data, the Met Éireann station nearest to the water quality sampling site, and for which relevant data were available, was identified and the type of that station indicated.

Linear distance between surface waterbody sample site and nearest temperature station (km): The Met Éireann station nearest to the water quality sampling site, and for which relevant data were available, was identified and the linear distance between the surface waterbody sample site and its associated temperature station were recorded.

Mean temperature – sample day (°C): Temperature data from the Met Éireann station nearest to the water quality sampling site for the date on which the sample was taken were averaged and recorded. For instance, if the sample was taken at 13:00 on 31 March, the average temperature during the period from 00:00 to 23:59 on 31 March is recorded.

High temperature – sample day (°C): Temperature data from the Met Éireann station nearest to the water quality sampling site for the date on which the sample was taken were assessed and the highest temperature during the period from 00:00 to 23:59 on that date was recorded.

Low temperature – sample day (°C): Temperature data from the Met Éireann station nearest to the water quality sampling site for the date on which the sample was taken were assessed and the lowest temperature during the period from 00:00 to 23:59 on that date was recorded.

Mean temperature – preceding 2 days (°C): Temperature recordings from the Met Éireann station nearest to the water quality sampling site for the 2 days prior to the date on which the sample was taken were averaged and that 2-day average is indicated. For instance, if the sample was taken at 13:00 on 31 March, the average temperature across the period from 00:00 on 29 March to 23:59 on 30 March is indicated.

Mean temperature – preceding 7 days (°C): Temperature recordings from the Met Éireann station nearest to the water quality sampling site for the 7 days prior to the date on which the sample was taken were averaged and that 7-day average is indicated. For instance, if the sample was taken at 13:00 on 31 March, the average temperature across the period from 00:00 on 24 March to 23:59 on 30 March is indicated.

Mean temperature – preceding 30 days (°C): Temperature recordings from the Met Éireann station nearest to the water quality sampling site for the 30 days prior to the date on which the sample was taken were averaged and that 30-day average is indicated. For instance, if the sample was taken at 13:00 on 31 March, the average temperature across the period from 00:00 on 1 March to 23:59 on 30 March is indicated.

Nearest wind station name: Met Éireann data for wind stations throughout Ireland were obtained by the HYDROFOR project and names for those stations (synoptic only) are indicated. Data from the Coillte-operated weather station at the FutMon site (UCDFM) were analysed and recorded the same as the data from Met Éireann sites.

Nearest wind station type: Met Éireann data for the three types of weather stations throughout Ireland were obtained by the HYDROFOR project: rainfall station (R), climatological stations (R, T) and synoptic stations (R, T, W). All Met Éireann wind data are from synoptic stations.

Linear distance between surface waterbody sample site and nearest wind station (km): The Met Éireann station nearest to the water quality sampling site, and for which relevant data were available, was identified and the linear distance between the surface waterbody sample site and its associated wind station was recorded.

Mean wind speed – sample day (knots): Wind speed data from the Met Éireann station nearest to the water quality sampling site for the date on which the sample was taken were averaged and recorded. For instance, if the sample was taken at 13:00 on 31 March, the average wind speed during the period from 00:00 to 23:59 on 31 March is recorded.

Mean wind speed – preceding 2 days (knots): Wind speed recordings from the Met Éireann station nearest to the water quality sampling site for the 2 days prior to the date on which the sample was taken were averaged and that 2-day average is indicated. For instance, if the sample was taken at 13:00 on 31 March, the average temperature across the period from 00:00 on 29 March to 23:59 on 30 March is indicated.

Mean wind speed – preceding 7 days (knots): Wind speed recordings from the Met Éireann station nearest to the water quality sampling site for the 7 days prior to the date on which the sample was taken were averaged and that 7-day average is indicated. For instance, if the sample was taken at 13:00 on 31 March, the average wind speed across the period from 00:00 on 24 March to 23:59 on 30 March is indicated.

Mean wind speed – preceding 30 days (knots): Wind speed recordings from the Met Éireann station nearest to the water quality sampling site for the 30 days prior to the date on which the sample was taken were averaged and that 30-day average is indicated. For instance, if the sample was taken at 13:00 on 31 March, the average temperature across the period from 00:00 on 1 March to 23:59 on 30 March is indicated.

Prevailing wind direction – sample day: Wind direction data from the Met Éireann station nearest to the water quality sampling site for the date on which the sample was taken were assessed and the prevailing direction was recorded (i.e. the wind direction category appearing in the recordings most frequently). Met Éireann numerical wind direction readings in degrees from were categorised by the HYDROFOR researchers as follows:

N	349–11
NNE	12–33
NE	34–56
ENE	57–78
E	79–101
ESE	102–123
SE	124–146
SSE	147–168
S	169–191
SSW	192–213
SW	214–236
WSW	237–258
W	259–281
WNW	282–303
NW	304–326
NNW	327–348

Prevailing wind direction – preceding 2 days: Wind direction recordings from the Met Éireann station nearest to the water quality sampling site for the 2 days prior to the date on which the sample was taken were categorised (see Prevailing Wind Direction) and the distribution of wind directions recordings was graphed. The prevailing wind direction for this period was then judged based on the graphical representation.

Prevailing wind direction – preceding 7 days: Wind direction recordings from the Met Éireann station nearest to the water quality sampling site for the 7 days prior to the date on which the sample was taken were categorised (see Prevailing Wind Direction) and the distribution of wind direction recordings was graphed. The prevailing wind direction for this period was then judged based on the graphical representation.

Prevailing wind direction – preceding 30 days: Wind direction recordings from the Met Éireann station nearest to the water quality sampling site for the 30 days prior to the date on which the sample was taken were categorised (see Prevailing Wind Direction) and the distribution of wind direction recordings was graphed. The prevailing wind direction for this period was then judged based on the graphical representation.

Surface water flow (m^3/s): Flow values were recorded by automatic flow meters at weirs installed by the HYDROFOR project team at rates of one reading per minute to readings of one reading per fifteen minutes. The flow rates that coincided with the time each sample was taken are indicated.

Surface water flow category (low, base, mid, flood): FORWAT project researchers determined flow/flood levels for FORWAT sites during each sampling visit via an unknown method, and those observations were put into four categories: low, base, mid and flood.

Surface water temperature (°C): In situ temperatures were recorded for some samples and are indicated.

Surface water pH, alkalinity (mg/L calcium carbonate equivalents), total hardness (mg/L calcium carbonate equivalents), soluble reactive phosphorus (mg/L), total phosphorus (mg/L), total oxidised nitrogen (mg/L), ammonium nitrate (mg/L), nitrate (mg/L), nitrite (mg/L), dissolved organic carbon (mg/L), aluminium (µg/L), total monomeric aluminium (µg/L), inorganic monomeric aluminium (µg/L), sodium (mg/L), potassium (mg/L), magnesium (mg/L), calcium (mg/L), chloride (mg/L), sulphate (mg/L), total suspended solids (mg/L), silicate (mg/L), conductivity (µs/cm), turbidity (NTU), colour (mg/L Pt. Co.), chlorophyll a (µg/L), dissolved oxygen (mg/L), dissolved oxygen (% saturation), manganese (mg/L), iron (mg/L), biochemical oxygen demand (mg/L), chemical oxygen demand (mg/L) and **total nitrogen (mg/L):** These water quality parameter results were generated by the Aquatic Services Centre at University College Dublin and at other laboratories in Ireland according to the temporally accurate version of *Standard Methods for the Examination of Water and Wastewater*, published jointly by the American Public Health Association, the American Water Works Association, and the Water Environment Federation.

Riparian Buffer Data – NUIGJF

Intended Concentration (mg/L), Concentration of Phosphorus as Phosphate (mg/L), Sample Weight (g), Equivalent Dry Weight (g), Soluble Reactive Phosphorus (µg/L), Sorbed Phosphorus (mg), and Sorbed Phosphorus (mg/g): Values for these parameters are given for a series of sites sampled by Joanne Finnegan, PhD under the direction of Mark Healy, PhD at National University of Ireland, Galway.

Biological Data – UCCTD, UCDCG

These data are comprised of counts of invertebrates at various lakes sites in Ireland. The data were collected by Tom Drinan, PhD and Conor Graham, PhD under the direction of Simon Harrison, PhD at University College Cork.

Integrated Invertebrates Data – UCDHF, UCDTD

Invertebrates count data generated from sampling various river and lake sites throughout Ireland comprise this dataset. Sampling and taxonomy work was done by Hugh Feeley, PhD under the direction of Mary Kelly-Quinn, PhD of University College Dublin and Tom Drinan, PhD under the direction of Simon Harrison, PhD of University College Cork.

Clearfell Data – Coillte

This dataset was obtained by the HYDROFOR project from Coillte. It lists the area in hectares of Coillte conifer stands in each of the EPA-designated subcatchments in Ireland (EU_CD) put up for purchase and subsequent clearfelling (from Coillte sales proposal data) for each of the years 2007 through to 2013. Projected sales proposal data are similarly provided for each of the years 2014 through to 2050.

Figure A3.1 shows a screenshot of the Database's Integrated Interactions Data worksheet.

	A	B	C	D	E	O	P	Q	R	S	T	U	V
1	Sample/Measurement Date	Sample/Measurement Time	Sample/Measurement Site Name	Sample/Measurement Site I.D.	Sample/Measurement I.D.	Data Ref.	Surface Waterbody Type	Data Ref.	Surface Waterbody Name (rivers, lakes)	Data Ref.	Surface Waterbody Order (rivers)	Data Ref.	% Subcatchment in Forested Blocks (%)
329	20100326	-999	Mayo 04 Pour Point	MM04PP	MM04PP-20100326-01	-888	river	EPA	-999	-999	2	EPA	54.1
330	20100326	-999	Mayo 05 Pour Point	MM05PP	MM05PP-20100326-01	-888	river	EPA	-999	-999	2	EPA	[illegible]
331	20100326	-999	Mayo 06 Pour Point	MM06PP	MM06PP-20100326-01	-888	river	EPA	-999	-999	2	EPA	93.1
332	20100326	-999	Mayo 07 Pour Point	MM07PP	MM07PP-20100326-01	-888	river	EPA	-999	-999	2	EPA	79.2
333	20100326	-999	Mayo 08 Pour Point	MM08PP	MM08PP-20100326-01	-888	river	EPA	-999	-999	3	EPA	[illegible]
334	20100326	-999	Mayo 09 Pour Point	MM09PP	MM09PP-20100326-01	-888	river	EPA	-999	-999	2	EPA	95.8
335	20100326	-999	Mayo 10 Pour Point	MM10PP	MM10PP-20100326-01	-888	river	EPA	-999	-999	3	EPA	18.1
336	20100326	-999	Mayo 11 Pour Point	MM11PP	MM11PP-20100326-01	-888	river	EPA	-999	-999	2	EPA	24.3
337	20100326	-999	Mayo 12 Pour Point	MM12PP	MM12PP-20100326-01	-888	river	EPA	-999	-999	2	EPA	[illegible]
338	20100326	-999	Kerry 01 Pour Point	KM01PP	KM01PP-20100326-01	-888	river	EPA	-999	-999	2	EPA	68.4
339	20100326	-999	Kerry 02 Pour Point	KM02PP	KM02PP-20100326-01	-888	river	EPA	-999	-999	2	EPA	[illegible]
340	20100326	-999	Kerry 03 Pour Point	KM03PP	KM03PP-20100326-01	-888	river	EPA	-999	-999	2	EPA	55.1
341	20100326	-999	Kerry 04 Pour Point	KM04PP	KM04PP-20100326-01	-888	river	EPA	-999	-999	2	EPA	90.
342	20100326	-999	Kerry 05 Pour Point	KM05PP	KM05PP-20100326-01	-888	river	EPA	-999	-999	2	EPA	26.2
343	20100326	-999	Kerry 06 Pour Point	KM06PP	KM06PP-20100326-01	-888	river	EPA	-999	-999	2	EPA	88.6
344	20100326	-999	Kerry 07 Pour Point	KM07PP	KM07PP-20100326-01	-888	river	EPA	-999	-999	2	EPA	99.0
345	20100326	-999	Kerry 08 Pour Point	KM08PP	KM08PP-20100326-01	-888	river	EPA	-999	-999	2	EPA	89.
346	20100326	-999	Kerry 09 Pour Point	KM09PP	KM09PP-20100326-01	-888	river	EPA	-999	-999	2	EPA	[illegible]
347	20100326	-999	Kerry 10 Pour Point	KM10PP	KM10PP-20100326-01	-888	river	EPA	-999	-999	1	EPA	[illegible]
348	20100326	-999	Kerry 11 Pour Point	KM11PP	KM11PP-20100326-01	-888	river	EPA	-999	-999	3	EPA	38.1
349	20100326	-999	Kerry 12 Pour Point	KM12PP	KM12PP-20100326-01	-888	river	EPA	-999	-999	1	EPA	[illegible]
350	20100326	-999	Kerry 13 Pour Point	KM13PP	KM13PP-20100326-01	-888	river	EPA	-999	-999	2	EPA	58.5
351	20100330	-999	Wicklow 01 Pour Point	WM01PP	WM01PP-20100330-01	-888	river	EPA	-999	-999	2	EPA	48.
352	20100330	-999	Wicklow 02 Pour Point	WM02PP	WM02PP-20100330-01	-888	river	EPA	-999	-999	3	EPA	[illegible]
353	20100330	-999	Wicklow 03 Pour Point	WM03PP	WM03PP-20100330-01	-888	river	EPA	-999	-999	3	EPA	[illegible]
354	20100330	-999	Wicklow 07 Pour Point	WM07PP	WM07PP-20100330-01	-888	river	EPA	-999	-999	1	EPA	29.
355	20100330	-999	Wicklow 08 Pour Point	WM08PP	WM08PP-20100330-01	-888	river	EPA	-999	-999	2	EPA	51.
356	20100330	-999	Wicklow 09 Pour Point	WM09PP	WM09PP-20100330-01	-888	river	EPA	-999	-999	2	EPA	68.7
357	20100423	-999	Wicklow 01 Pour Point	WM01PP	WM01PP-20100423-01	-888	river	EPA	-999	-999	2	EPA	48.
358	20100423	-999	Wicklow 02 Pour Point	WM02PP	WM02PP-20100423-01	-888	river	EPA	-999	-999	3	EPA	[illegible]
359	20100423	-999	Wicklow 03 Pour Point	WM03PP	WM03PP-20100423-01	-888	river	EPA	-999	-999	3	EPA	[illegible]
360	20100423	-999	Wicklow 07 Pour Point	WM07PP	WM07PP-20100423-01	-888	river	EPA	-999	-999	1	EPA	29.
361	20100423	-999	Wicklow 08 Pour Point	WM08PP	WM08PP-20100423-01	-888	river	EPA	-999	-999	2	EPA	51.
362	20100423	-999	Wicklow 09 Pour Point	WM09PP	WM09PP-20100423-01	-888	river	EPA	-999	-999	2	EPA	68.7

Figure A3.1. HYDROFOR Project Database: Integrated Interactions Data worksheet.

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL
Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: *Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú
Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:
- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha)*;
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil
- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhíriú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Uisce
- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaol
- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil *(m.sh. tuairisciú tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn
- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil
- Taighde comhshaoil a chistiú chun brúnna a shainaithint, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta
- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch
- Monatóireacht a dhéanamh ar leibhéil radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha.
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta.
- Sainseirbhísí cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas
- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol *(m.sh. Timpeall an Tí, léarscáileanna radóin)*.
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta
- Feasacht chomhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil
Tá an ghníomhaíocht á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:
- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- An Oifig um Cosaint Raideolaíoch
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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HYDROFOR: Assessment of the Impacts of Forest Operations on the Ecological Quality of Water

Authors: Mary Kelly-Quinn, Michael Bruen, Simon Harrison, Mark Healy, John Clarke, Tom Drinan, Hugh B. Feeley, Joanne Finnegan, Conor Graham, John Regan, Sean Blacklocke

epa Research
Climate - Water - Sustainability
Identifying pressures • Informing policy • Developing solutions

Identifying Pressures

Implementation of the Water Framework Directive (WFD) requires identification and quantification of anthropogenic pressures on water resources and the implementation of Programmes of Measures (POMs) to prevent further deterioration in water quality and achieve least good status for all waters. The 2005 "National Characterisation Report for Ireland" produced during the first WFD management cycle, identified forestry as one of the land-use activities posing potential risk in terms of diffuse pollution due to increased acidification from conifer plantations in acid-sensitive catchments, sedimentation from clear felling, harvesting, new plantations, road construction and erosion on steep catchments, and eutrophication from fertilisation on steep catchments and forest harvesting on peat soils. The Hydrofor project identified windrowing as an additional potential source of sediment and nutrients in streams. The potential for impact depends on the magnitude of the pressure and susceptibility of the pathway as well as the sensitivity of the receptor.

Informing Policy

The Water Framework Directive is the key EU legislation requiring Member States to improve and sustainably manage and protect water resources. The research presented in this report will inform forest policy review, environmental considerations in the development of forestry programmes, the refinement of forest and water quality guidelines, and guidance on best practice in relation to forest operations aimed at reducing pollutant inputs. The latter is especially relevant in the development of measures to protect endangered species such as the pearl mussel. The research also has relevance to water quality monitoring and reporting by the Environmental Protection Agency and overall land-use planning.

Developing Solutions

Solutions to water quality problems must be underpinned by sound knowledge of the sources and drivers of pollution and the pathways that deliver pollutants to water courses. Hydrofor addressed several key information needs by investigating pollutant inputs from forest operations through the entire forest cycle. The key drivers of the episodic acidity were shown to be organic acidity together with base cation dilution. Higher losses of organic acidity from forests planted on peat were highlighted as a concern. Elevated sediment and phosphorus release to water courses was detected during felling, windrowing and replanting. A small number of potential mitigation measures (aquatic buffer zones and sediment traps) to address these problems were investigated in this study and the research evidence highlighted their ability to reduce some pollutant inputs. For example sediment pollution may be reduced by careful onsite management of felling and windrowing operations, installation of silt traps and greater application and oversight of best practice guidelines. Mitigation of phosphorus inputs is more challenging on peat soils and depends on the presence of mineral content in riparian soils or installation of mineral barriers.

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