Managing the Impacts of Forest Clearfelling on Stream Environments

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FOREWORD

Forest practice in Ireland has undergone considerable change during the past decade, reflecting new considerations in sustainable forest management and the environmental interactions of forests. This is at a time when the forest industry is of growing importance to national and local economies, as a source of employment and income generation.

The Forest Service has recently published a series of guidelines to ensure that forest operations take place in the context of sustainable forest management and in harmony with the environment. COFORD-funded research provided much of the scientific knowledge on which these guidelines are based. This present report augments the guidelines and brings together the latest knowledge on the interaction between clearfelling and stream ecosystems. Clear recommendations for good forest practice are presented. Implementation of the recommendations will further contribute to Ireland's sustainable forest management effort.

We acknowledge the time and input of a large number of stakeholders in both supporting the initial research and in reviewing and commenting on this report. Such commitment by forest owners and the wider industry is indicative of the sector's commitment to conducting forestry operations in a manner that is fully compatible with the environment.

Dr Eugene Hendrick
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1. INTRODUCTION

Increasing emphasis on the concept of Sustainable Forest Management (SFM) in the forest industry is having a significant impact on routine management practices in forestry operations such as clearfelling. This is particularly pertinent in view of the need for certification of timber products, which will be required through independent verification of the sustainability of the industry and the reduction/elimination of negative impacts on the environment.

Although the land now becoming available for forestry is of improved quality and located at lower altitudes, the majority of Irish plantation forests have historically been planted in upland areas and many Irish rivers either rise in or receive drainage from plantation forestry areas. This has led to concerns about the possible impacts that these forests may have on aquatic systems.

After the adoption of a set of criteria and accompanying indicators for the sustainable development of forests at the Ministerial Conference on the Protection of Forests in Lisbon in 1998, Ireland responded by initiating the development of a National Forestry Standard. This has included the development of a Code of Best Forest Practice and associated guidelines. Indicators for the standard are not only based on best international practice, but also, and perhaps even more relevant, on results from objective scientific research conducted within Ireland.

The development of a National Forest Standard makes it important to disseminate the findings of COFORD-funded research to a wider audience, with different interests in and connections to the forest industry, as well as to apply the results to the day-to-day management of forestry operations. Recommendations generated from research findings need to be implemented in order to eliminate/minimise adverse impacts of forestry activities and thus ultimately contribute to SFM.

It is in this context that this report has been written. It provides information about the potential impacts of clearfelling[1] on freshwater stream systems and on the main issues that are involved, based on objective scientific research. It also highlights the importance of protecting streams, and recommends practices that can be used to reduce and minimise the impacts of clearfelling operations on stream environments (Plates 1, 2 and 3).

Although this report has been reviewed in a consultation process by representative groups linked to environmental issues and the forest industry (see list in Appendix I), its main contributors are stream ecologists. It is hoped that this report will prove useful in relation to routine clearfelling practices and the reduction/elimination of environmental impacts, and that it will also raise awareness and appreciation of the value of aquatic resources and emphasise the importance of protecting the diversity of life within streams. Chapter 2, on stream ecology, is therefore written as a 'scene-setter' with an overview of different aspects of the stream environment and some background information about the study of stream ecology. This chapter also focuses on how the study of organisms and their surrounding environment can be used to identify changes and impacts caused by land-use activities. Chapters 3 and 4 deal with more practical aspects of the potential impacts of clearfelling on stream systems, with recommendations for minimising such impacts.

Recommendations made to date cannot specify exact limits, quantities or methodology for all situations. The extent to which some of the listed recommendations are put into practice ultimately depends on the subjective decision-making by forest managers at each individual clearfell site. Furthermore, objective models, decision-making keys, classifications and/or site sensitivity analyses to be used as decision-making tools are not yet available. However, this is adequate in most cases, since many decisions depend on the (often unique) knowledge of forest managers about site-specific factors and the individual clearfelling operation itself. Complementary to the site-specific knowledge of forest managers, the ultimate goal is also to develop practical and objective tools to aid in the decision-making process during individual clearfelling operations to ensure the protection of aquatic resources, without unduly limiting the efficient management of the operations. (For example, classification systems for the design and maintenance of riparian buffer strips, site-sensitivity classifications with regard to erosion risk and/or fisheries, models to determine the optimum extraction system in any location and keys to quantify the range of acceptable windthrow or woody debris)[2].

Finally, a glossary of some terms used in stream ecology and clearfelling is provided at the back of this report, and terms contained in it are indicated in *italics* in the main text where they occur for the first time.

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[1] Clearfelling should be viewed here as the final stage in the forestry crop cycle, where an entire standing crop of trees is removed from an area or harvested (also called clear-cutting, clearfell logging, clearcut logging). Although it does not include the harvesting practice of thinning, many recommendations listed in this handbook can also be applied during thinning operations near watercourses.

[2] Development of these objective tools for decision-making at each individual clearfell site requires more specific research into the various factors affected by clearfelling in different areas and under a wide range of conditions.

PLATE 1: A GENERAL VIEW OF INCHAMAY FOREST.

PLATE 2: A CLEARFELLED AREA IN MUNSTER.

PLATE 3: A FORESTED STREAM (CARRYAGUILLA FOREST, PRE-FELLING).

2. STREAM ECOLOGY

Water environments vary from open oceans and inter-tidal marine systems to freshwater lakes, streams and rivers. What distinguishes streams and rivers from other *aquatic* systems is their uni-directional flow of water. This means that upstream sections of streams and rivers influence downstream sections, giving running water systems unique characteristics in both their structure and functioning.

Streams and rivers are important components of the landscape in a number of ways. For example, they provide corridors through the landscape; are important *habitats* for fish and other kinds of living organisms; they give aesthetic enjoyment and recreational opportunities; they act as important navigational routes for people and goods; and they provide an important source of domestic, industrial and agricultural water and sometimes *food*.

Water is a renewable resource and cycles in the biosphere within the hydrological cycle. Water enters the atmosphere through evaporation from the oceans and transpiration from *terrestrial* plants. It is moved by the winds and condenses to rain or snow, picking up chemical substances produced in the air or released to it by human activities and other organisms as it does so. As rain or snow falls on land surfaces, the underlying rocks, soils and vegetation further change the chemical composition of the water, before it drains directly or through the ground to streams and rivers[3]. The composition of running waters is also determined by the uses made of the surrounding landscape or *catchment* from which it drains. There is an important interplay between the stream channel and the surrounding landscape, whereby the river catchment must be seen as the natural unit of the landscape, combining physical, chemical and biological features (*biotic* factors) of both the *terrestrial* and aquatic *ecosystems*. Because of the close links between both terrestrial and aquatic components in a catchment, land-use activity in a catchment inevitably has some effect, either direct or indirect, on the quality of the water in and reaching streams and rivers. Management of streams and rivers must therefore be at a landscape scale, rather than solely concentrated on the stream channel itself.

The characteristics of the surrounding landscape not only influence the chemical composition and quality of the aquatic system but also control the physical features of the system and the nature of the energy inputs to the system, which in turn determine the variety of living organisms that live in a stream environment. Living organisms in a stream can alternately influence water chemistry, physical features and energy cycles within the system and thus influence the character of downstream *reaches*.

Thus, not only are there large scale links between the stream and its surrounding landscape or catchment, but there are also dynamic links on a smaller scale between water chemistry, physical and biological features both on the bankside and within the stream, which together make up the entire stream environment. Any human activity which influences any of the links has the potential to set in motion a ‘chain-reaction’, whereby several components in the system might be affected and the functioning of the system can be temporarily or permanently disturbed.

2.1 WHAT IS STREAM ECOLOGY?

Stream *ecology* is the study of the interactions between the organisms and their physical and chemical stream environment. Catchment characteristics such as geology, land-use, slope, soil, hydrology and vegetation ultimately play an essential role at a larger scale in determining the stream environment. However, at a smaller scale, the environment in which organisms live is essentially determined by water chemistry, local physical features (both on the bankside and in the stream) and energy inputs to the stream. To survive, living organisms must be able to cope with the particular set of environmental factors present, which show natural variation in both space and time. In order to study the animals and plants living in streams and rivers, it is important to also study and understand the nature of their environment.

[3] In this context use is made of the Forestry and Fisheries guidelines definition of streams and rivers as running watercourses that show upon an Ordnance Survey 6" map.

2.1.1 The stream environment

Water chemistry

As mentioned above, the nature of the stream water is affected by interplay of several factors in the catchment. The general chemical composition of the water consists of groups of dissolved substances such as major *ions* of 'salts' (e.g. sodium, calcium, chloride, hydrogen), atmospheric gases (e.g. oxygen, carbon dioxide, ammonia), key nutrients (e.g. phosphates and *nitrates*), trace ions (e.g. iron, copper), *suspended solids* (from terrestrial sources, such as soil particles) and *dissolved* or *particulate organic matter* in different stages of decomposition (e.g. leaf litter or fine particles). Some of the chemicals are not required in great amounts by living organisms and may even be toxic if present in large quantities (e.g. copper and iron). Other chemical substances, such as nutrient ions, have a relatively high requirement by certain organisms and their concentration plays a key role in the character of a stream environment.

It is impractical to measure all individual substances in a water sample, but several measurements, listed in Table 1, are considered to be of importance in the understanding of the stream as a living environment for organisms.

Stream water chemistry will vary with time - over days or sometimes even over minutes. Natural variation in water chemistry over time is strongly related to changes in water levels associated with rainfall events and seasons. During flood events, concentrations of most ions are generally reduced, because of the increased water volume and since water reaching the stream has had only a very short contact time with the underlying geology and soil. Hydrogen ions (which tend to be leached out of the soil) and suspended solids, on the other hand, tend to increase during flood flows.

Water chemistry also varies naturally at different locations along a watercourse - from the headwaters to the mouth of a stream or river system. Moving downstream, nutrients, *pH*, *conductivity*, *alkalinity* and *hardness* tend to generally increase as the water 'picks up' salts and ions from the increasingly larger surrounding catchment area. At a location where a tributary or a groundwater source with very different chemistry joins a stream or river, water chemistry can change quite suddenly from one section to the next.

Physical features

As well as water chemistry, several physical characteristics, both in the stream and on the stream bank, play an important role in structuring the environment for living organisms.

(a) In-stream features

The major in-stream features include *substrate*, flow, depth and temperature. Substrate is the material on the bottom of streams and rivers which provides living space for a variety of functions, such as movement, shelter, resting, reproduction, as rooting or attachment surface and provides a surface on which food collects. The physical nature of the substrate has been recognised to be one of the most important biological properties of a stream. Substrate can be inorganic (sand, stones) or organic (e.g. woody debris, leaf litter) in nature and its size can range from bedrock and boulders to clay and from fallen trees to small organic *detritus*.

Substrate, flow and depth vary naturally at different locations within a stream or river. This variation takes place on different scales, from the scale of a small patch or point on the streambed, to within a stream section or reach, and on a longitudinal scale from the headwaters to the mouth of the river.

The size and type of substrate, including the spaces between the substrate particles, as well as flow and depth, all vary within small areas of streambed, creating sets of individually different environmental conditions or *microhabitats* for different organisms. The different microhabitats form a 'mosaic' of different living conditions on the streambed, which is an important factor in determining the variety, abundance and distribution of organisms in a particular stream section. Figure 1 shows the range of microhabitats [10].

Variation in flow within a stream section or reach will lead to patterns of erosion and deposition and creates microhabitats based on stream flow, i.e. *riffles*, *glides* and *pools*. Riffles (or white water sections) are relatively shallow sections of a stream or river with relatively rapid (> 50 cm/s) current and a turbulent surface broken by gravel, rubble or boulders. Slower, relatively shallow stream sections with water velocities of 10 to 20 cm/s and little or no surface turbulence are glides, whilst portions of a stream with

TABLE 1: SOME MAJOR CHEMICAL MEASUREMENTS OF RUNNING WATER AND THEIR SIGNIFICANCE FOR THE BIOLOGY OF THE SYSTEM.

Measurement	*Definition*	*Significance for living organisms*
PH	A measure of the acidic or basic character of a solution (at a given temperature); calculated from the concentration of hydrogen ions	Underlying geology or buffering is important. Incorrect range may be toxic to certain organisms and affect reproduction. pH also influences other chemical reactions in the stream. Streams of low pH tend to be less diverse in species than those of high pH.
Alkalinity	The concentration of carbonate ions - a measure of the buffering or acid neutralising capacity of water (its resistance to pH change)	Waters with high alkalinity are generally less sensitive to acidification. Biological communities living in these waters are less vulnerable to acidification.
Hardness	The concentration of calcium and magnesium ions	Organisms are relatively insensitive to hardness, but high hardness levels reduce toxic effects of some metals such as copper and zinc in waters. Certain organisms also require high levels of calcium.
Conductivity	Measure of the amount of dissolved ions and determines the ability of water to conduct an electric current	Organisms are relatively insensitive to conductivity, but it can be an important indicator of water quality.
Concentration of individual major ions	Measure of, for example, concentration of sodium or chloride ions	Generally only required in small quantities by living organisms, but are indicators of the influence of land-use, geology and atmospheric processes (involving soils and air pollution).
Concentration of nitrogen compounds	Measurement of (dissolved) nitrogen-containing compounds, such as nitrates or ammonia	Nitrate is an essential nutrient for plant growth generally found in small quantities in unpolluted, 'natural' surface water, but may attain high levels in some groundwater. In excessive amounts it is undesirable for public health and can cause excessive algal growth and toxicity. Ammonia can be toxic to some aquatic insects and fish even at low levels.
Concentration of phosphorus compounds	Measurement of (dissolved) phosphorus containing compounds, such as (ortho) phosphates	Phosphorus is an essential nutrient for plant growth. In large quantities it can lead to nutrient enrichment (eutrophication) and excessive algal growth with associated changes in water chemistry and biology in a system.
Dissolved oxygen concentration	The amount of oxygen dissolved in water	Critical to the biology in a stream and to the breakdown of organic material. Generally present in sufficient amounts in fast flowing waters, unless disturbed by management activities. Sufficient dissolved oxygen in salmonid spawning gravel beds is essential.
Amount of suspended solids	Inorganic or organic materials carried or held in suspension in water	In high concentrations they can interfere with photosynthesis of aquatic plant life, affect fish and insect life and form deposits on the bed of rivers and lakes.

reduced current velocity and finer *sediment*, often with deeper water (> 25 cm) than surrounding areas and with a smooth surface are called pools.

Variation in substrate, flow and depth from the headwaters to the mouth is mainly caused by variation in slope and volume of water. In headwaters, generally on steep slopes, rapid, turbulent flow predominates, resulting in the removal of smaller particles and the presence of bedrock materials and boulders or large stones. As the catchment area is smaller, there is generally less volume of water in the channel and the stream is relatively shallow. Moving downstream, the slope generally decreases and the river becomes wider and deeper, and instead of erosion and turbulence, slower flow and *sedimentation* predominate, resulting in the settling out of smaller substrate particles.

Natural variation in substrate, flow and depth over time is mainly caused by changes in current velocity associated with the normal variation in rainfall. However, heavy rainfall periods of high *discharge* and flood events cause the movement and redistribution of substrate particles. The strength of the current determines the size of the particle that can be moved: the larger the particle, for example a boulder, the less it tends to move, whilst small particles will be carried in the current after a relatively minor increase in discharge.

Temperature affects oxygen availability (warmer water holds less oxygen than colder water) and several biological processes in the water environment, such as growth and egg development. Even small fluctuations in temperature can cause stress for organisms in a stream. Although temperature is mainly determined by climate, season and altitude, physical features on the stream bank, such as *canopy cover* and amount of undercutting of the bank, also play an important role in controlling the temperature conditions in a stream.

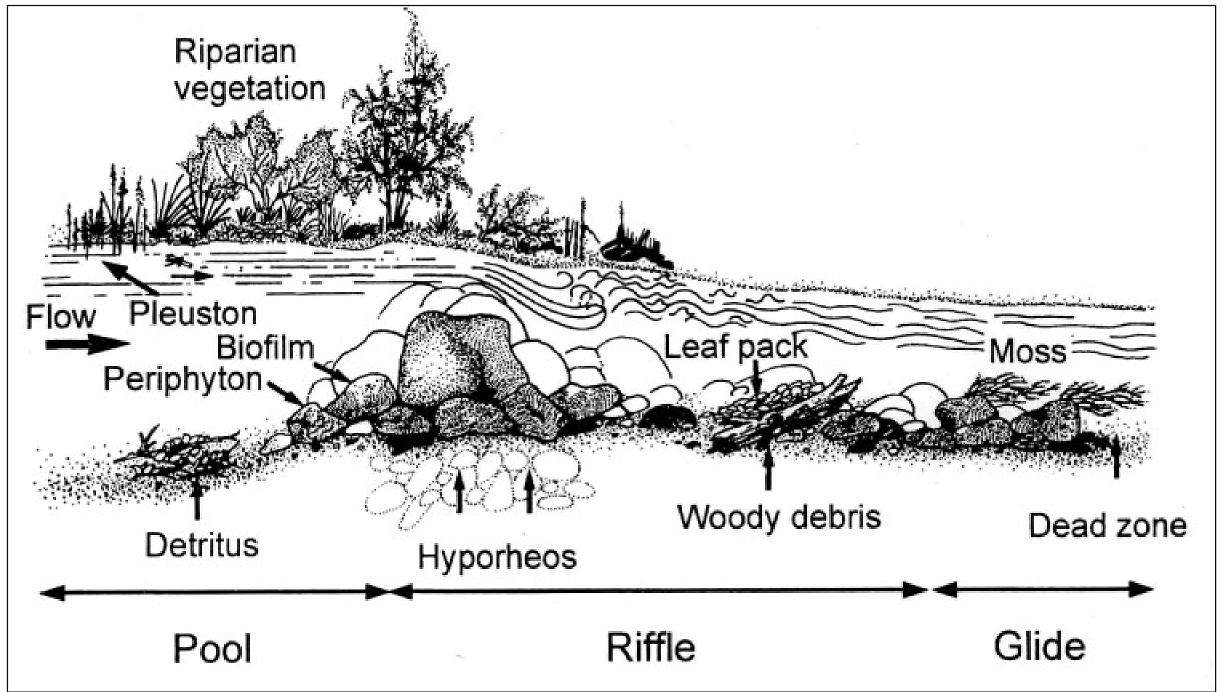

FIGURE 1: VARIOUS MICROHABITATS COMMONLY FOUND IN A STREAM OR RIVER (FROM GILLER AND MALMQVIST 1998).

(b) Riparian (stream bank) features

The main physical feature on the stream bank that influences the stream environment is the riparian zone. The *riparian zone* is a boundary area between the stream channel and the surrounding terrestrial landscape and includes all the bankside vegetation (refer also to the Forestry and Water Quality Guidelines).

As well as influencing temperature and light levels (through shading), the bankside vegetation supplies leaf litter, which is an important source of food for stream organisms. In small streams the *riparian vegetation* is usually the largest source of organic material and hence a critical source of detritus for aquatic food webs. Additionally, the riparian zone can play an important part in preventing bankside erosion and sediment input, since plant and tree roots stabilise and protect stream banks. Vegetation and other channel bank characteristics control the shape, width and depth of the stream channel, thereby influencing the variety of habitats available for fish and stream *invertebrates*. It also is the source of woody debris which can enhance the habitat of stream systems by creating more microhabitats, deeper pools, providing additional substrate and resources (Plate 4).

Another important function of streambank vegetation is that it acts as a filter or sink for run-off water carrying high levels of soil or sediment from the surrounding catchment. The filtering action of the roots and canopy of riparian vegetation also plays a role in preventing nutrients and ions (e.g. phosphate) from directly entering the stream, and modifies the chemical composition of rain- and soil water before it reaches the stream. The riparian zone bordering streams thus serves as a *buffer* between the stream and the surrounding catchment. Considerable emphasis has therefore been placed on the protection or revegetation of riparian zones in order to protect streams from land-use and management activities in the catchment and to enhance the *diversity* of life in streams.

PLATE 4: NATURAL WOODY DEBRIS ACCUMULATIONS IN A STREAM.

Energy inputs

As for all living systems, a continual input of energy is required for a stream ecosystem to function and to sustain itself. There are two sources of energy to streams and rivers. The first is *autochthonous*, in the form of primary production, where *organic matter* is produced, by *algae* and higher plants, within the system through the use of sunlight by a process called *photosynthesis*. The second source of energy is organic matter produced elsewhere, and hence called *allochthonous*, and imported into the stream reach both from the surrounding terrestrial ecosystem (like *dissolved organic matter* in groundwater, nutrients and organic matter in soil particles, leaves, wood, twigs) and from upstream (dead plants, breakdown products and organic matter dissolved in the stream water).

The contribution of both autochthonous and allochthonous energy sources varies at different locations of a stream as well as in time. For example, upland streams, where dense tree cover occurs close to the stream bank, have a generally low level of autochthonous energy production, because of shading and hence little photosynthesis. However, such environments might have a relatively high input of allochthonous energy since organic matter, such as twigs and leaves, fall from the riparian zone into the stream. Wider, lowland rivers or streams where there is little riparian vegetation to provide shade generally have higher levels of photosynthesis and autochthonous energy production. Although there is still an input of allochthonous energy from upstream reaches and flood plains, the contribution of allochthonous energy from the surrounding terrestrial ecosystem is smaller. Variation in the relative contribution of authochthonous and allochthonous energy sources occurs seasonally and is related to temperature, shading, availability of nutrients for plant growth and *retention time* of food particles in the stream.

The relative contribution of the type of energy source dominating in a stream at a particular point in time plays an important role in determining the variety of living organisms present. For example, where the major source of energy is autochthonous, there is a relatively large proportion of algae and/or plants present, which in turn leads to an increase in types of animals which graze on algal and plant matter. Plants not only provide food, but also offer shelter, a refuge from flow and a substrate for certain species of animals. Plants thus increase the number of microhabitats in the stream, thereby potentially increasing the number of species present. However, balance is required as too much plant growth resulting from excess nutrients can be detrimental to the system. Where the major source of energy is allochthonous there may be few algae and plants. However, organic matter, such as leaves, twigs, woody debris and small particles, all have particular types of organisms feeding on them and collections of allochthonous organic matter can form intricate habitat structures for fish (e.g. woody debris dams) and stream insects (e.g. leaf packs). The nature of the allochthonous material is important (e.g. species of tree providing the litter) as certain types of litter, such as alder, hazel and beech, are more nutritious and more readily utilisable by *macroinvertebrates* than others (such as conifer needles).

Rivers in different catchment types

Forested catchments will differ from non-forested catchments in a number of different ways, for instance resulting in different species compositions and densities of aquatic organisms. When discussing catchments, a clear distinction must be made between forested (native/exotic), agricultural or mixed catchments. If a catchment land-use has changed, does one compare the aquatic system with one reflecting the previous land-use or with one to which the river or stream might develop? For example, comparison between a conifer (Sitka spruce) plantation, which originated as a moorland, with an old oak plantation will be instructive, but perhaps not valid. In other words, when considering the impact of *clearfelling* on forested catchments and their ecology the reference point is forested catchments. Whether these catchments are composed of exotic species or not is, however, relevant to the likely impact on the river ecology.

2.1.2 Biology

Although rivers and streams are important for a range of animals [9], the main focus here is macroinvertebrates. As discussed before, environmental variation, which occurs both in time and space, is the predominant factor determining the types of plants and animals present, their interaction with one another and with their environment. Before considering how the study of stream ecology can be used to indicate changes in a stream environment (both natural and anthropogenic), a brief overview of the various types of plants and animals found in Irish streams is presented.

The number of species of plants and animals in Irish streams and rivers is relatively small compared to the continent of Europe. Ireland was extensively glaciated during the last ice age and, although recolonisation and immigration occurred naturally and through human introductions, the relative isolation of Ireland from the continent and the limited time of the presence of land-bridges resulted in an overall lower number of species (or *species richness*). However, the relative biological isolation of Ireland created conditions for a unique development of many species, resulting in a distinctive subset of species of notable ecological importance.

Streams and rivers are essential habitats for many species, ranging in size from bacteria to larger animals, such as fish and birds. Birds, fish, some water plants and several flying insects hovering above the water surface are usually noticed from the stream bank, but simply picking up a stone from the streambed reveals a large number of other species, each with its own adaptations and its own role to play in a healthy functioning of the system.

Although microorganisms, such as bacteria and fungi, play an important role in the structure and function of stream ecosystems, particularly in the breakdown of organic matter, our knowledge of the biology of bacteria and fungi in streams and rivers is relatively limited, due to their small size and the difficult techniques required for their identification. Instead focus is placed here on the main groups of higher organisms of which our understanding is more extensive, namely algae, *mosses/liverworts*, vascular plants, (macro)invertebrates, fish, birds and mammals.

PLANTS: Algae, mosses/liverworts and higher plants (or macrophytes)

Algae, mosses and higher plants (*macrophytes*) form an important basis of energy/food production in streams through their photosynthetic capacity. They also play a role in influencing water chemistry (e.g. oxygen, carbon dioxide and nitrate levels) and biotic factors, such as macroinvertebrate and fish *community* structure. The presence of plants can be beneficial for many organisms. They provide an important substrate (both when alive and when decomposing) and increase the availability of microhabitats and food. They also provide a refuge from flow and predators. Higher plants also provide a surface for the deposition of eggs for some aquatic *invertebrates* and form a link between air and water for semi-aquatic insects.

(a) Algae and biofilm

Algae contribute most to the production of autochthonous energy in streams and rivers, particularly in unshaded streams with relatively clear water where nutrients are not limiting. Most algae are microscopic, often forming colonies of visible layers on the substrate. Algae in streams generally grow on stones and rocks, and either form thin crusts or occur in layers several millimetres thick, often slippery to the touch. A dominant group of microscopic algae, called *diatoms*, are considered to be the most important food source for many *herbivores* living on the streambed. There are also algae, called *macroalgae*, which are large and ‘plant-like’ in appearance and occur as filaments, threads or tufts on rocks. Light and nutrient availability, flow rate, amount of sedimentation and the number of organisms present that graze on algae determine the amount of algae present at a site. Filamentous algae and diatoms, together with bacteria, fungi, and amorphous particles become enmeshed in a gelatinous matrix to form a thin coating referred to as biofilm, which occurs on most surfaces in streams and rivers and has an important role in energy flow and nutrient cycling.

(b) Mosses/liverworts

Mosses and liverworts can either be aquatic, semi-aquatic or terrestrial. Aquatic and semi-aquatic members cover large substrate particles, such as large rocks, boulders and bedrock, often in relatively shaded stream sections. Mosses provide important refuges for invertebrates and trap fine particles and many microscopic algae which are a food source for invertebrates.

(c) Higher plants (macrophytes)

Higher plants or *macrophytes* are vascular flowering plants, which can be floating, submersed or emergent (such as water lilies, pond weeds and rushes). Not many macrophytes are encountered in fast-flowing upland streams, since they mainly occur where the flow rate is low, where the substrate is appropriate for rooting and where nutrient and light levels are adequate for growth. In places where macrophyte communities are present (often in eutrophic or enriched systems) they create a three-dimensional habitat with a complex structure and contribute to the stream ecosystem in several ways as described above. They are rarely eaten directly but when dead contribute to the detritus pool.

ANIMALS: Macroinvertebrates, fish, birds and mammals

(a) Macroinvertebrates

Invertebrates are animals without a backbone. Historically, the invertebrates as a group have received major attention in the study of stream and river ecosystems. The larger invertebrates in particular, referred to as macroinvertebrates (greater than approximately 0.5 mm in size), form the link between algae, microorganisms and leaf litter, which serve as their major food sources, and the fish and birds, for which they are prey. They are the most diverse group of organisms and play a crucial role in the functioning of running water habitats. Macroinvertebrates are large enough to be observed with the unaided eye and are abundant enough to be readily collected (e.g. by hand-picking from stones and aquatic vegetation, through *kick sampling* or *surber sampling*). Owing to regular and systematic water quality recording of many Irish streams and rivers in the last twenty years, the distribution and ecology of the more common stream macroinvertebrates are reasonably well known. Invertebrates less than 0.5 mm in size generally live below the surface and are termed *meiofauna*. This group has received much less attention than the macroinvertebrates, as their small size and the difficulty in identifying them pose problems in their study. Here the focus will be on macroinvertebrates, which can be divided into the insect and non-insect groups.

Non-insect groups:

The major non-insect groups are flatworms, leeches, worms, water mites, snails, mussels, crayfish and freshwater amphipods (‘scuds’ or ‘shrimps’) (Figure 2).

The flatworms and leeches are fairly well known, of which there are ten and fourteen freshwater species respectively, not all occurring in running waters. A majority of stream-living flatworms prefer water of relatively lower temperatures and are most abundant in upland streams. Most leeches are predators of other invertebrates and some are parasites of fish, birds and mammals. As streams and rivers become more enriched with nutrients, some leech species become more abundant.

Worms feed on small particles that are sedimented on the streambed, and may be very abundant where there are high amounts of decomposing organic material and where oxygen levels are low. Worms, such as Tubificidae, are well known indicators of polluted rivers.

Snails are widely distributed in streams and rivers and different species vary in their preferred living environment. Irish freshwaters hold 33 species of snails, but not all occur in running waters. Freshwater limpets and some smaller spiral-shelled snails occur on hard rocks in streams, whilst others are found on sandy sediments of streams and on vegetation. Although some feed on detritus, most snails graze on algae.

Freshwater mussels feed mainly on small, suspended food particles which they filter from the water column. Whilst large mussels, such as duck- and swan mussels are mainly found in larger, slow-flowing rivers, small pea-mussels and the pearl mussel, *Margaritifera margaritifera* (Figure 2a), occur in faster flowing streams and rivers. The latter species is declining across Europe due to lower water quality, increased siltation and decreased availability of salmonid hosts for their parasitic larvae. This species is of high conservation concern and is listed as endangered in Ireland [25, 34].

Although crayfish (Figure 2c) do not occur in large numbers, their effect on the ecology of a system can be significant. Most species are not selective in their food, although they have been shown to have an important role in processing allochthonous plant litter and in feeding on macrophytes. The white-clawed freshwater crayfish is widespread in hard-water Irish lowland rivers and is also listed as endangered.

Freshwater ‘shrimps’ are quite widespread and can occur in very large numbers in upland streams, when there is plenty of food and a stable substrate. The species *Gammarus duebeni* is native to Ireland (Figure 2b), but there are also a few introduced species. They play an important role in decomposition processes and in the diet of salmonid fish, when they are carried downstream by *drift*.

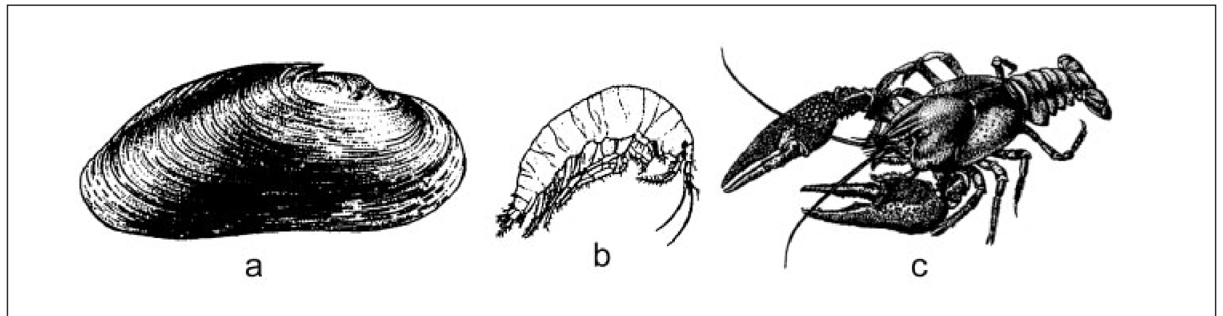

FIGURE 2: EXAMPLES OF NON-INSECT MACROINVERTEBRATES IN STREAMS: A) A FRESHWATER PEARL MUSSEL; B) A FRESHWATER SHRIMP; C) A CRAYFISH (FROM GILLER AND MALMQVIST 1998).

Insect groups:

Insects are widespread in freshwater environments, particularly in running waters. In most cases the larval stages of these insects are aquatic and rely on the river to complete their life cycle, whilst the adults are terrestrial. The major sub-groups in running waters are mayflies, stoneflies, caddisflies, true flies, beetles and waterbugs. Stream insect groups are often represented by many species, which vary in their microhabitats, mode of life and feeding.

Mayflies (Ephemeroptera) graze mainly on algae on the surfaces of stones, where they are exposed to predators and the fast flowing current, or feed on fine detritus (Figure 3a). Some types of mayfly occur in drift and are an important source of food for young salmonid fish. Since different mayfly species vary in their tolerance to low oxygen conditions and are generally sensitive to acid conditions, therefore, they are useful indicators of *pollution* and acidification.

Stoneflies (Plecoptera) are characteristic inhabitants of cold, clear, running water and have a high oxygen demand (Figure 3b). They are very sensitive to organic pollution, but are more tolerant of acid conditions (and are also used as indicators of low pH). Many stoneflies feed on detritus, but there are also many predatory species, which feed on smaller invertebrates.

Caddisflies (Trichoptera) are one of the most diverse insect groups and show a large variation in adaptive features and feeding, which allow them to occupy a wide range of aquatic habitats and microhabitats. Caddisflies are divided into case-building (Figure 3c) and case-less, or free-living (Figure 3d), groups. They are able to spin silk which is used for the building of cases or the spinning of nets (in the case of some free-living groups). Cased caddisflies feed on a wide variety of food, although their method of obtaining food may be highly specialised, whilst the case-less flies are mainly either active predators or spin nets to trap their food (small animals or particles) from the water column. The cases, of broad ranging forms, are built from pure silk, sand grains, twigs and plant materials or a combination of them. Since different caddisfly species are so specifically adapted to their environmental conditions, the occurrence of a particular species can be a useful reflection of water quality and other habitat characteristics.

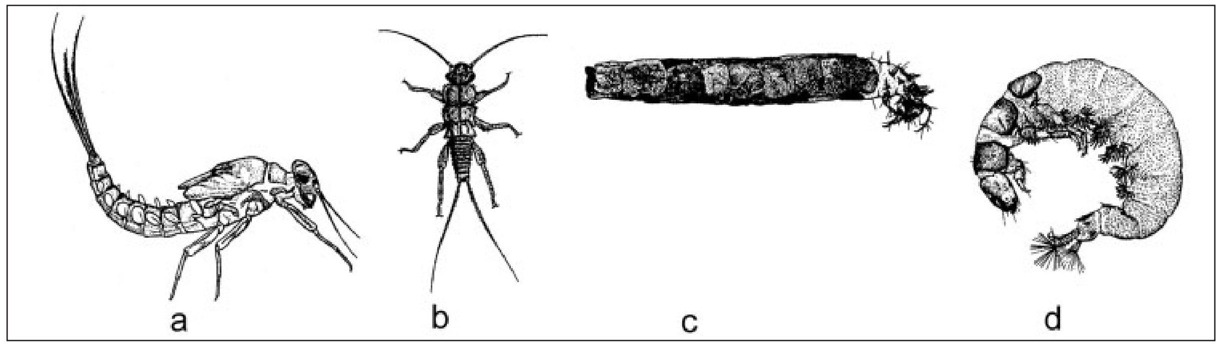

FIGURE 3: EXAMPLES OF COMMON INSECT GROUPS IN STREAMS AND RIVERS (NOTE THEY OCCUR AS LARVAE IN THESE FRESHWATER HABITATS): A) MAYFLY; B) STONEFLY; C) CASED CADDISFLY; D) NET-SPINNING CADDISFLY (FROM GILLER AND MALMQVIST 1998).

The insect groups mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera) are collectively referred to as EPT taxa. The number of species of *EPT taxa* present and their abundance are important indicators of the quality of the aquatic environment.

True flies (Diptera) are a very diverse group of insects but in relation to running waters, blackflies, midges and craneflies are the most important families. Blackfly (Simuliidae) larvae (Figure 4a) attach to the substrate and filter small particles from the water using fan-like structures. Blackfly larvae can occur in huge numbers on surfaces of stones and rocks, sometimes more than 100 per cm^2, and they are an important food source for predatory insects and birds. The midges (Chironomidae) (Figure 4b) are perhaps the most diverse group. Although they are the most widely distributed and often the most abundant group of insects in freshwater habitats, they are relatively difficult to identify. Most midge species feed on small particles which they collect from the surrounding substrate, but there are also species feeding on algae, higher plants, leaf litter and wood, and one particular family is mainly predatory. Some midges build tubes which can be found in clumps on stones and rocks and on muddy bottoms and plant leaves. Midges are an important food source for predators. Craneflies (Tipulidae) are less well known and they play an important role in the decomposition of organic material. Some species, however, are predators or feed on moss and higher plants.

Aquatic beetles (Coleoptera) (Figure 4c) and waterbugs (Hemiptera) (Figure 4d) usually live in water throughout both their larval and adult life stages. Most waterbugs, and quite a number of beetles, occur in slow-flowing waters or in pools, whilst riffle beetles occur in faster flowing streams. The riffle beetles are relatively small in size and most species feed on fine detritus, which they scrape from the substrate. A few riffle beetles feed on wood.

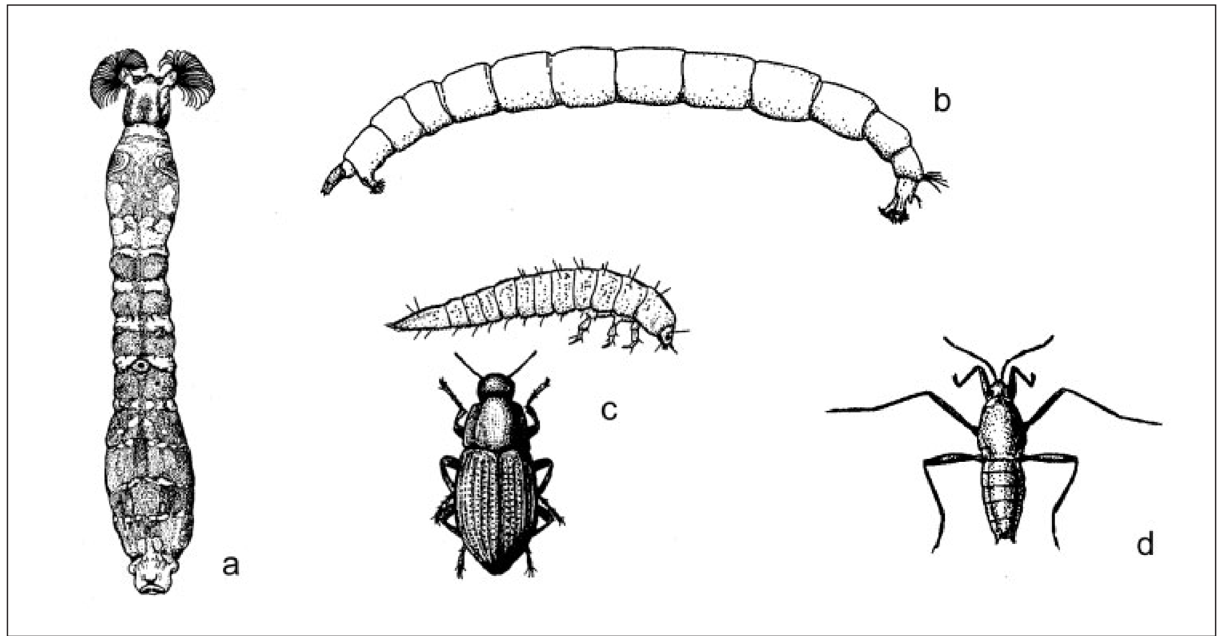

FIGURE 4: FURTHER EXAMPLES OF COMMON INSECT GROUPS. (NOTE THE LATTER TWO OCCUR AS BOTH NYMPHS/LARVAE AND AS ADULTS IN FRESHWATERS): A) BLACKFLY, B) CHIRONOMID MIDGE; C) WATER BEETLE (ADULT AND LARVA); D) WATER BUG (FROM GILLER AND MALMQVIST 1998).

(b) Fish

Fish are undoubtedly the best-known organisms in streams and rivers. Because of their size, ease of identification, economic importance (both in relation to commercial fishery and recreation/tourism) and conservation status, fish are well studied and the waters they inhabit are well monitored. Ireland's freshwater fish fauna consists of 34 species, but in most Irish fast-flowing streams and rivers, trout, salmon, eel and stickleback are predominant. Mullet and flounder also occur in the most downstream sections. Lampreys, which are primitive jawless fish-like animals, also have been found in Irish streams and are protected under the EU Habitats Directive [34]. *Salmonids* (both trout and salmon) feed and spawn in most streams. Salmonids feed on a wide range of macroinvertebrates on the streambed or drifting in the water column. Salmonids require clean, fast-flowing, well oxygenated water and physical structures in their habitat and the availability of gravel beds are important factors in their survival and success. Populations of salmonid fish can decline through habitat destruction, over-fishing, the presence of migration barriers such as dams, and *pollution of surface waters*.

(c) Birds and mammals

Few species of birds and mammals associated with streams and rivers actually live in the water [20], but they are found in riparian habitats along rivers and use streams and rivers for feeding. Dippers are birds which are exclusively riverine and rely on the river for food, nesting etc. They play an important role in the ecology of Irish streams and rivers and are able to swim underwater to prey on macroinvertebrates. Studies have shown that a pair of dippers breeding with young on a stretch of river consume up to 11 kg (dry weight) of stream macroinvertebrates each year [28]. Important mammals in the ecology of streams are otters, which are native aquatics, and mink, which escaped from fur-farms during the 1960s. Otters feed mainly on eels and salmonids, but also feed on amphibians, birds and crayfish when available. Otters are territorial and live in underground holts, mostly in riparian zones with deciduous trees and good cover. Whilst otters feed almost entirely on aquatic prey, mink are more terrestrial and have a less specialised diet.

2.2 HOW CAN STUDIES OF STREAM ECOLOGY INDICATE CHANGES IN THE STREAM ENVIRONMENT?

Studying the interactions of different stream organisms and their environment under conditions undisturbed by human activity can unravel the structure and functioning of the stream ecosystem under 'natural' conditions. This knowledge can be used to help distinguish natural changes in aquatic systems from those caused by human activities. The idea that certain species can be used to indicate certain types of environmental conditions is now well established. The presence of an 'indicator species' indicates that the habitat is suitable and, because some of the environmental requirements are known for many species, their presence indicates something about the nature of the environment in which they are found. This not only applies to single species, but also to the total assemblage of populations of different species living in an environment: the *community*.

2.2.1 Animals in the stream as indicators of change

Macroinvertebrates are probably the most useful indicators of change in aquatic systems:

- The structure and diversity of macroinvertebrate assemblages can be related directly to water quality measures (e.g. EPA Q-values).
- As macroinvertebrate communities integrate conditions over time, they can be used to detect the impact of most changes in water chemistry which otherwise, without continuous sampling, can be missed.
- There are many different species, which allow for a range of responses to the nature and degree of change to their environment.
- Their limited movement over relatively short distances also makes them well suited to determine the spatial extent of a change or disturbance.
- Much of their importance as indicators also comes from their position in the *food web* between micro-organisms/algae/plants on which they feed on the one hand, and fish, their predators on the other.

Certain species, belonging to the EPT taxa, are very sensitive to pollution of surface waters and their presence generally is associated with clean well-oxygenated waters of good quality, low organic pollution and low levels of suspended solids. On the other hand, the occurrence of large numbers of certain species of worms and fly larvae indicates water low in oxygen and of increased organic pollution.

The importance of salmonid fish as indicators of the general health of a system has also long been recognised. Since their environmental requirements are relatively stringent, salmonids are very sensitive to changes and disturbance in their habitat. Populations of salmonid fish generally decline under conditions of poor quality water and destruction of habitat and spawning sites.

Other groups, such as algae, can also be used as indicators of changes in stream environments.

Well-balanced monitoring programmes should involve physical, chemical and biological measurements, each complementary to one another, to detect changes caused by human activities and to distinguish them from natural changes.

D.M. Rosenberg at the University of Manitoba summarised the importance of biological monitoring of stream and river systems as follows: "Chemical measurements are like taking snapshots of the ecosystem, whereas biological measurements are like making a videotape" (Bulletin of the Entomological Society Canada 1998. 30(4): 144-152).

2.2.2 Types of changes

Natural changes occur in water chemistry, physical habitat features and energy inputs, which in turn cause natural variation in biology. Table 2 gives a summary of different scales of natural variation in time and across locations (i.e. spatial variation) which influence the types of organisms present and their distribution in a stream habitat.

Different land-uses, such as agriculture, forestry, mining, industry and other management activities in the surrounding catchment, can lead to direct pollution of surface waters, to acidification, *eutrophication* and other impacts on stream systems. Like natural changes, changes caused by human activity (or human disturbance) also vary in time and in space and occur at different scales. In order to understand the effects of a human activity on a stream system and to manage a stream system effectively, it is important to distinguish effects operating on different scales and also at different locations on a stream or river network.

In impact studies and environmental monitoring programmes, including those associated with forestry, it is also important to distinguish natural changes in time and space from those caused by human activity. Natural changes can, to some extent, be controlled for by selecting a reference sampling station (usually upstream of the activity) or by selecting sites of paired catchments as well as at least one sampling station adjacent to and one downstream of the management activity or source of disturbance in question. Changes in chemistry, physical habitat and biology at the reference sampling station are assumed to reflect natural variation. Changes in chemistry, physical habitat and biology at sampling stations adjacent to or downstream of the management activity before and after the disturbance event can subsequently be compared to those found at the reference (again before and after the event) and from this the impact of a particular activity can be assessed.

Seasonal variation can be distinguished by investigating changes over time at the reference station (prior to commencement of a management activity) to determine what the natural seasonal patterns are. Changes in the relationship between reference and treatment stations in chemistry, physical habitat and biology after commencement of the activity can be used to assess the impact of a particular activity.

TABLE 2: FACTORS OF NATURAL VARIATION IN STREAMS AND RIVERS BOTH IN TIME AND SPACE (I.E. ACROSS LOCATIONS) AND ON DIFFERENT SCALES (ADAPTED FROM GILLER AND MALMQVIST, 1998).

Scale	*Space*	*Time*	*Tendency to change*
Small scale	*Within-stream section or reach:* variation in flow, substrate, particle size, organic matter (food) retention, vegetation	*Daily/short-term variation:* temperature, oxygen, flow (related to current and substrate), chemistry (related to increased flow, sediment, reduced pH), flood disturbances	Highest
Medium scale	*Longitudinal distance (from source to mouth):* variation in temperature, oxygen, water chemistry, flow, substrate and energy inputs	*Seasonal changes:* temperature, climate, water chemistry, discharge and flow, energy inputs, flood disturbances	High
Large scale	*Differences between streams:* water chemistry, particularly pH (related to geology/soil type)	*Amongst years and decades:* climatic variation	Medium to Low
Very large scale	*Biogeographical:* catchment area, river length, history of development of landscape	*Past history:* development of river and development of vegetation and other factors in the surrounding landscape, large climatic changes	Lowest

2.2.3 Possible effects of changes in a stream environment

Long- or short-term effects

As mentioned before, changes in a stream environment caused by human activity, like natural changes, vary in time and space, and occur at different scales. The impact of change depends on the intensity of the management activity (or disturbance) and the timing, frequency, magnitude and duration of the activity or disturbance. However, several features of the river system itself also determine whether a change takes place in the stream system and whether it is of long- or short-term duration.

Firstly the *resistance* of a stream system to disturbance determines the magnitude of change necessary to cause an impact and how long it takes before an impact occurs. Once a change takes place following a disturbance, the duration of change depends on the *resilience* of animal and plant communities. A high resilience indicates a rapid recovery to pre-disturbance conditions and the effects are therefore generally short-term.

In relation to a flood disturbance, which generally is viewed as a natural disturbance, the overall pattern amongst plant and animal communities in streams and rivers is of generally low resistance (i.e. the system tends to change quickly after a flood). However, the resilience is generally high and rapid recovery occurs after all but the most catastrophic flood events.

Running water systems also appear to show high resilience to many disturbances caused by human activity, for example organic pollution and even application of insecticides. It is only when the magnitude of the change or the frequency of occurrence of a disturbance is great that the stream community is greatly affected for long periods of time and recovery takes place only very slowly. Such recovery requires the environmental conditions to return to the pre-disturbance situation.

Local or downstream effects (effects on a longitudinal scale)

The uni-directional flow of running waters means that substances introduced from a land-use activity into a stream or river can be carried downstream for long distances. The longitudinal impact of disturbance events depends on the frequency, magnitude, nature and duration of the disturbance. However, several features of the river itself determine whether a local change in a stream environment also has an impact in downstream sections. If the change is brought about by the introduction of, for example, suspended solids, the slope and flow of the stream are important in determining how far downstream the materials are carried and where they settle out. Physical features in the stream, such as woody debris dams and pools, also play an important role in trapping suspended solids or other materials. Biological features, such as algal growth, can influence how far nutrients are carried downstream after introduction into the system, since they are capable of ‘mopping-up’ large amounts from the water column.

Cumulative effects

As catchment size increases from the headwaters to the mouth of a stream system, a greater volume of water runs through the channel. This leads to greater dilution, which decreases the magnitude of change resulting from upstream activities. When the influence of a particular land-use activity in a particular area of the catchment is assessed, the impact is not always significant or alarming. However, several individual activities or disturbances in various stream reaches or tributaries can, over time, produce significant cumulative detrimental effects in the whole stream or river system.

Cumulative impacts are often ignored when considering individual land-use activities. However, if a whole catchment is affected by cumulative effects the effects are much more detrimental and there is less chance of recovery to pre-disturbance conditions (or at least recovery takes much longer). Assessment of cumulative impacts requires a landscape approach and large-scale analysis. It is therefore important that management at a particular site will take into account earlier and possibly future management activities in the whole landscape or catchment unit. Stream and river systems are so closely linked to the landscape and to downstream systems that a 'whole-catchment' approach to assessing effects of land-use changes is widely recommended.

2.3 FURTHER READING

Books

- Fitter, R. and Manuel, R. 1986. *Field Guide to Freshwater Life of Britain and Western Europe*. Published by Collins, London. 369 pp.
- Giller, P.S. and Malmqvist, B. 1998. *The Biology of Streams and Rivers*. Published by Oxford University Press, Oxford, New York. 296 pp.
- Giller, P.S. (Ed). 1998. *Studies in Irish Limnology*. Marine Institute, Dublin. 256 pp.
- Petts, G. and Calow, P. 1996. *River Biota - Diversity and Dynamics*. Published by Blackwell Science Ltd., Oxford. 257 pp.
- Reynolds, J.D. 1998. *Ireland's Freshwaters*. Produced for Societas Internationalis Limnologiae (SIL) International Association for Theoretical and Applied Limnology XXVII Congress, Dublin. Marine Institute, Dublin. 130 pp.

Articles

- Beschta, R.L. and Platts, W.S. 1986. Morphological features of small streams: Significance and function. *Water Resources Bulletin*, Volume 22, No. 3, p 369-379.
- Gregory, S.V., Swanson, F.J., McKee, W.A. and Cummins, K.W. 1991. An ecosystem perspective of riparian zones - focus on links between land and water. *BioScience* Vol 41. No. 8, p 540-551.

3. THE POTENTIAL IMPACTS OF CLEARFELLING ON THE STREAM ENVIRONMENT AND RECOMMENDATIONS TO MINIMISE THEM

The previous chapter focussed on how studies in stream ecology can identify impacts of land-use activities that take place in the catchment. One such land-use is plantation forestry, which is expanding rapidly in Ireland. A plantation forest is a biological crop subject to several management activities between site preparation/planting and harvesting. Forestry and the associated management activities can impact on the environment in different ways at nearly all stages of the forest crop cycle (Figure 5).

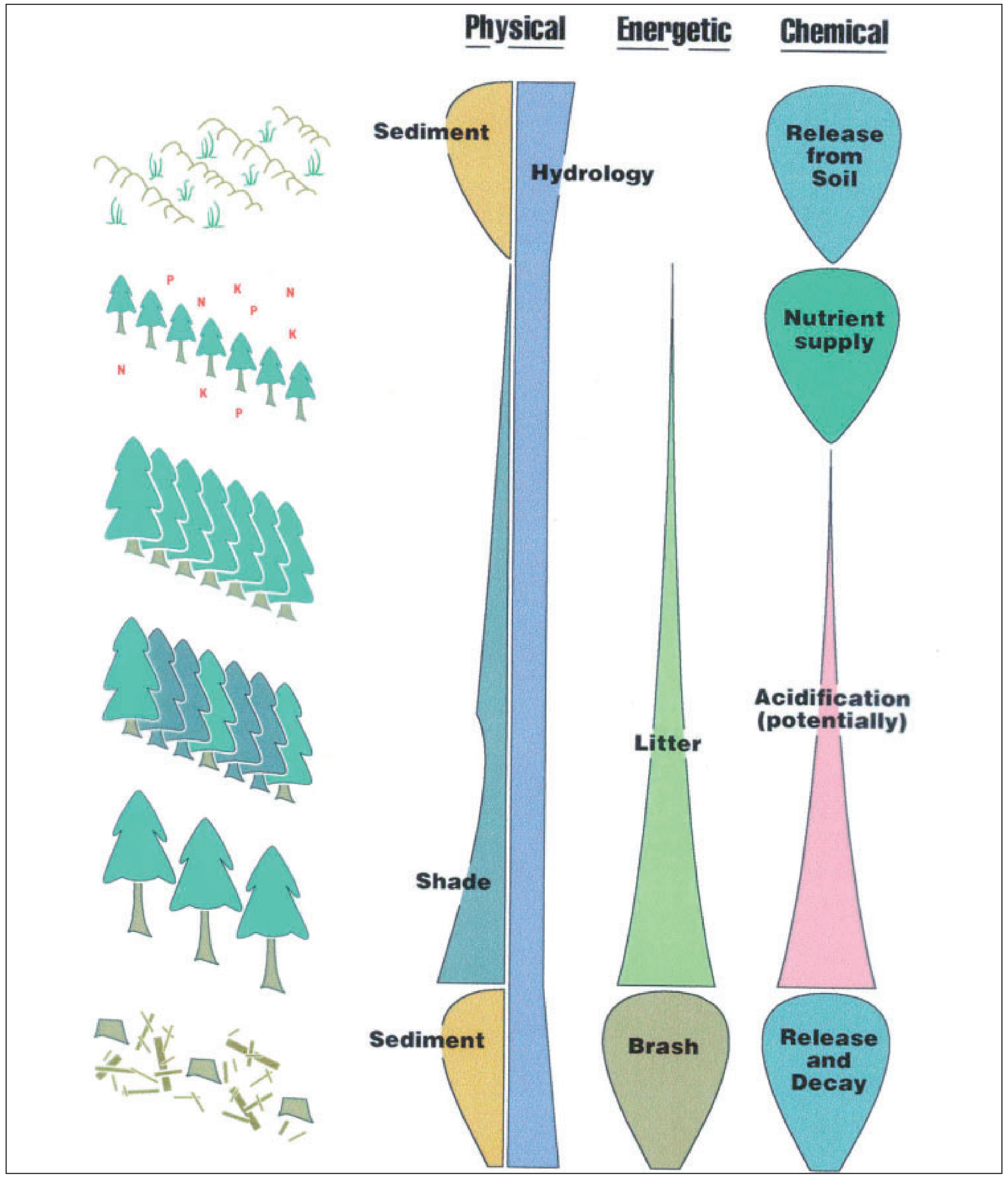

FIGURE 5: A SCHEMATIC DIAGRAM TO ILLUSTRATE THE NATURE OF CHANGES THAT CAN TAKE PLACE TO VARIOUS ASPECTS OF THE ECOLOGY AND HABITAT OF FRESHWATER SYSTEMS IN RELATION TO THE FOREST CYCLE (DRAWN AND CONCEIVED BY DR COLIN SMITH).

The final stage of the plantation forest crop cycle is the clearfelling phase. Running water environments can be affected by clearfelling operations through changes such as loss of bankside vegetation, dramatic changes in the hydrological regime, changes in incident sunlight, increases in soil inputs/suspended solids, physical stream disturbance by machinery, release of nutrients, and inputs of excessive quantities of large woody debris. These changes in the stream environment can in turn cause changes in the quality of the water and in the biology of the stream (Plates 5 a and b).

Possible changes in a stream environment caused by clearfelling are discussed in detail in the following sections and recommendations, which can be used on a day-to-day basis to minimise the impact of clearfelling operations on stream systems, are given for each. The recommendations were in part derived from a detailed COFORD-funded study, conducted in Munster, on the effects of clearfelling on freshwater aquatic ecosystems [21].

PLATE 5: A STREAM AT CLOONTY (FACING UPSTREAM AT THE STUDY SITE) (A) BEFORE AND (B) AFTER FELLING (NOTE THE TREE ACROSS THE STREAM AS A REFERENCE POINT).

3.1 ENERGY INPUTS

3.1.1 Types of energy sources influenced

Clearfelling can affect both autochthonous and allochthonous energy inputs. Clearfelling can cause an increase in incident sunlight into the stream following the removal or thinning of the canopy surrounding the stream. This can lead to increased photosynthesis and autochthonous production, with increased growth of algae (including large quantities of filamentous algae) and/or plants, provided there is no nutrient limitation. Although clearfelling operations initially can increase the input of allochthonous energy inputs, such as leaves and woody debris, into the stream, the felling of trees in the riparian zone may lead to a longer-term overall reduction of energy input from leaves, small woody debris and terrestrial insects (an important food source for fish).

3.1.2 Potential impacts

Increased growth of algae after an increase in light following canopy removal can subsequently increase productivity of macroinvertebrates and fish in the medium-term. However, this increase in production may be offset by a decreased input of leaves and organic material from the riparian zone. The net balance between the increase in autochthonous production and the reduction in allochthonous inputs will depend on the size of the stream and the presence of other factors, such as nutrients and habitat structures. Excessive growth of algae can deleteriously influence the physical habitat and cause decreases in oxygen at night during warm periods.

3.1.3 Scientific findings

Studies elsewhere have shown increases in macroinvertebrates which feed on algae following clearfelling [3, 44], but decreases of up to 30% in densities of macroinvertebrates feeding on leaves and small detritus from the riparian zone [45]. However, the numbers of macroinvertebrates feeding on leaves and small detritus may increase again after forest regrowth [18]. Increases in grazing macroinvertebrate populations have been shown to lead to increased food availability for fish. Increased light levels have also been found to enhance feeding efficiency and general habitat structure for fish [1,2,46].

During the study in the south west of Ireland [21] it was found that although clearfelling caused an increase in canopy openness at sampling stations where a buffer strip was absent, increases in green algae and macroalgae did not always follow. At the majority of sites where no increases in algae occurred after an opening up of the canopy, short-term increases in soil/sediment on the streambed were found. Soil/sediment in the water column can decrease the penetration of sunlight into the water column, and soil/sediment on the streambed can smother algal growth. An increase in algae may therefore have been delayed or prevented, even though the canopy had been opened up. At other sites, nutrients may have been limiting to algal growth. Since a response in algae to an increase in light levels may take longer at some clearfell sites, longer term monitoring is required.

At a few sites where the canopy was fully removed significant increases in relative abundance of the mayfly *Baetis rhodani* were found, which is known to generally prefer sunlit areas. At one site a significant increase in salmonid fish aged 2 years and older was found two years after felling. The presence of a large deep pool at this site would have provided suitable habitat for relatively larger sized fish, even before felling. However, the increase in canopy openness may have resulted in an increase in productivity or greater incident light to increase feeding efficiency. At several sites where the canopy was removed, relative increases in numbers of salmonids were found one year after felling.

3.1.4 Recommendations in relation to energy sources

Depending on the designated use of a stream or river, a change in energy input along a particular stretch, such as an increase in light and algae, is not necessarily undesirable and in fact can enhance a stream ecosystem by providing a greater variety of habitats.

However, both excessive shading and lack of riparian vegetation are in any case undesirable, and overall it is recommended to maintain a riparian buffer strip (see section 4.1) to maintain inputs of organic materials and woody debris from the riparian zone into the stream. Broadleaves (such as alder, hazel and oak) and shrubs are therefore of particular importance.

3.2 NUTRIENTS

3.2.1 Sources

Due to the ability of vegetation, particularly trees, to utilise nutrients from the soil in the surrounding area, nutrient levels are generally relatively low in streams draining from mature forests. However, following clearfelling and removal of vegetation, nutrients such as nitrogen compounds are released and leached into streams via surface or subsurface flow. On the other hand, phosphorus compounds, such as phosphates, are mainly attached to small soil particles and are carried into watercourses if there is sediment input and increased erosion following clearfelling.

3.2.2 Potential impacts

The input of nutrients into surface waters may cause excessive algal and plant growth. This fertilization effect can accelerate eutrophication if the stream empties into a lake or reservoir, leading to excessive production of algae. This in turn results in increased demand for dissolved oxygen through increased microbial decomposition of plant matter and overall oxygen levels are decreased. Similar effects can also be found in the streams and rivers themselves. Large concentrations of nitrate[4], which convert to nitrite , are undesirable for public health and can affect salmonid fish growth (nitrates) or be toxic (nitrites). However, it is worth noting that forestry is a relatively minor contributor to nitrification at the catchment and landscape scale when compared to other land-uses such as agriculture.

3.2.3 Scientific findings

Much more is known about the loss of nitrogen from felled areas than of phosphorus. Several studies in the United States have found increases in both nitrogen and phosphorus export into streams following felling, particularly in association with organic particles [11,23]. Depending on site-specific factors, increases in nutrients in surface waters may not occur immediately following clearfelling and changes can take up to five years to reach detectable levels [39]. In an American study, nitrate concentrations in a logged catchment were 41 to 56 times higher than in a similar undisturbed catchment two years following felling [23]. Nutrient inputs into streams have been typically found to decline following soil stabilisation and regrowth of riparian vegetation [14].

Riparian zones can be effective in preventing an input of nutrients into streams after clearfelling: in one study it was found that a 30 m riparian buffer strip was enough to remove all nitrates coming through groundwater and thus to prevent them from reaching the stream system [31].

During the study in the south west of Ireland [21] increases in nitrates were found in the stream at nine of sixteen clearfell sites within the time frame of the study. Nitrate release occurred at sites both with and without buffer strips, and was apparently related to an interaction between factors such as area felled, bank slope and input of sediment. The presence of a buffer strip of the size specified in the Forestry and Fisheries Guidelines (1992), viz. 10 m, did seem to prevent a release of nitrates at some sites. However, the absence of a buffer strip did not necessarily lead to nitrate releases, since not all unbuffered sites showed increases

[4] If information on critical limits of nitrates and nitrites is required, it is recommended to consult the Environmental Protection Agency for the most up-to-date information.

in nitrates. Longer-term monitoring at sites where no increases in nitrates have been found is required before it can be concluded that no effects have occurred.

3.2.4 Recommendations in relation to reducing inputs of nutrients

(i) Vegetated riparian buffer zones should be maintained to prevent or reduce the input of nutrients. However, more research on the nature and size of buffer strips in their role of preventing nutrient inputs is required (also see section 4.1).

(ii) Soil/sediment inputs into the stream should be kept to a minimum (see recommendations in section 3.4.4), since they can be an important source of phosphates into the stream after clearfelling.

(iii) Drainage channels from felled areas should never be in direct contact with a stream, since they can be a source of nutrient input into the stream.

It may not always be possible to get machines on to a clearfell site to block all drainage channels that empty directly into a stream. Straw bales placed in these drains, to act as filters, may be an option to reduce nutrient input associated with the input of sediment. However, when the bales are removed care must be taken to prevent the release of trapped sediment.

3.3 pH AND OTHER CHEMICAL VARIABLES (CONDUCTIVITY, TOTAL HARDNESS)

3.3.1 Sources

Acidification is one of the most widely researched aspects of the interaction of forestry and river systems. Although acidification has been found to affect many streams, underlying geology, soil type and extent of atmospheric pollution appear to be of paramount importance. For example, little impact has been found in areas of low atmospheric pollution and with a high geological buffering capacity. Upland areas with high rainfall, peaty soils and poor buffering capacity are often most vulnerable to acidification. Coniferous trees exacerbate the effect of acid deposition from polluted atmospheres through their ability to 'scavenge' airborne particles (more efficiently that deciduous vegetation) and in areas of poor buffering capacity this can result in an increase in *pH* and hence stream acidity. There is some evidence that organic acids contribute to acidification when leached from bark and other organic debris.

Inputs of sediment and soil also deliver substances that are dissolved or attached to them, such as ions and/or toxic substances, to the stream environment. Inputs of sediment can also bring about changes in conductivity and *total hardness*. One of the main consequences of increased acidity is the leaching out of aluminium, which in some forms is toxic to aquatic organisms. *Labile monomeric aluminium* is the most important form of aluminium and has been found to be toxic to fish and stream macroinvertebrates.

3.3.2 Potential impacts

A lowering in pH may be toxic to certain organisms (including salmonids) and affect their reproduction. pH also influences other chemical reactions in the stream. The combined effect of reduced pH and aluminium toxicity is detrimental to aquatic organisms.

Organisms are relatively insensitive to conductivity, but changes in conductivity can be an important indicator of water quality.

Total hardness is slow to change, but increased total hardness levels may reduce toxic effects of some metals, such as copper and zinc in salmonid waters.

3.3.3 Scientific findings

In relation to pH and acidification, most studies abroad have indicated that stream pH is generally insensitive to clearfell activities. However, in one study it was found that water quality became less acidic up to two years after clearfelling, after which pH returned to pre-felling levels [30]. Results from a COFORD-funded study carried out by the Forest Ecosystem Research Group (FERG), UCD at Cloosh, Co. Galway, also has shown a consistent and immediate increase in pH of stream water after clearfelling, which was sustained for at least a year (T. Cummins, FERG, UCD, pers comm.).

There is some evidence that clearfelling indirectly affects pH through the introduction of large amounts of bark and other organic debris into the stream system, which can either lower pH (by increasing the concentration of organic acids, as well as increasing carbon dioxide inputs due to respiration) [29] or increase pH (whereby hydrogen ions are converted and bases are generated in the presence of organic matter) [19].

In relation to conductivity, results vary: in one study abroad short-term increases in conductivity were found after felling which were associated with increased sediment levels [22]. Another study found that conductivity increased during high flow in the first two years after an intensive clearfell operation [38]. Other studies have found that clearfelling caused little or no change in conductivity [13,24]. Clearly any activity that will increase the ionic composition of water will increase conductivity, but the effects are more likely to be at the individual ion level rather than conductivity *per se*. There is no evidence from the literature on effects on total hardness due to felling trees.

The study in the south west of Ireland [21] indicated that clearfelling did not have a major effect on pH (*hydrogen ion concentration*), except at a very small tributary running from a clearfell area into a stream. This section received relatively large amounts of organic debris, brash and sediment, causing pH to decrease. Of the hydrochemical parameters considered, conductivity and total hardness were least affected by clearfelling within the time frame of the study. Conductivity increased significantly on only one occasion during increased discharge at a site downstream of a large input of sediment and soil. Changes in total hardness were found at two sites on one occasion, but it was not clear how these changes could have been related to felling.

3.3.4 Recommendations in relation to reducing changes in pH, conductivity and total hardness

Since few effects of clearfelling on these water quality parameters have been found, not many recommendations can be made. However, since pH changes may be associated with the introduction of relatively large amounts of (fine) organic debris, bark and brash, it is recommended to keep the input of these to a minimum (as recommended in the Forestry and Water Quality Guidelines).

3.4 SOIL INPUTS

3.4.1 Source

Potentially, the most significant change to a stream environment due to clearfelling is the input of soil[5], which results in increased suspended solids and sedimentation on the streambed (Plate 6). Soil sediment also transports nutrients, notably phosphates.

Clearfelling can increase soil inputs through a variety of processes: surface erosion from landings, skid trails and other compacted areas; slope failures caused by the removal of vegetation; physical damage to the streambank, such as slippages and bank collapses; and increased surface run-off. If the hydrological regime of a catchment has been upset by clearfelling, an increase in quantity and rate of discharge will increase the eroding potential of the stream. However, the scale of all these depends on the intensity of the operation, the area felled, the topography of the land and weather conditions. The use of a stream crossing point by machinery can also be a significant source of soil input during felling and extraction and will be dealt with in section 3.5.

[5] Soil occurs in many forms ranging from peat to mineral soil. Although different soil types will vary in their susceptibility to erosion, their potential to be transported and to act as pollutants, soil is used here as a general term. Regardless of which soil type predominates at a clearfell site, inputs to aquatic systems should be kept to a minimum.

PLATE 6: SEDIMENTATION IN A STREAM AFTER CLEARFELLING.

3.4.2 Potential impacts

Soil and suspended solids can settle out on the streambed, depending on the discharge, gradient, shape of the stream channel and microhabitat conditions at a particular stream section. Increased sediment can smother the streambed and the organisms living on it. It can also decrease oxygen levels within the gravel bed, which can be detrimental to both macroinvertebrates and salmonid spawning sites. Large increases in the amount of soil delivered to the stream can thus greatly impair, or even eliminate, fish and macroinvertebrate habitat and change the structure of the physical habitat. Many nutrients and other chemicals are attached to fine soil particles, so sediment inputs are often directly related to inputs of these substances as well.

3.4.3 Scientific findings

Suspended solids have been found to increase following clearfelling in most studies undertaken [17,24], particularly if best management practices are not carried out efficiently [15,32]. Large inputs of suspended solids have been found to reduce macroinvertebrate richness, biomass, and change species composition (in one case this was still evident some five years later) [12,35]. Some studies found increases in blackfly larvae, which feed by filtering out small particles in the water column, after increases in sediment following clearfelling. However, another study showed that high concentrations of fine sediment negatively affected filter feeders such as blackfly larvae and certain species of caddisflies by clogging their nets and other filtering devices [15]. Increases in suspended solids have also been shown to lead to considerable increases in invertebrate drift [6], which is a well-known response to stress. Large floods and subsequent removal of the sediment may lead to recovery to pre-clearfelling levels. Increased suspended solids carried in the water column have been shown to be toxic to fish and reduce their feeding efficiency due to poor visibility [2]. More importantly, an increase in fine sediment in gravel spawning beds can significantly decrease reproductive success and increase juvenile mortality through reduced gravel permeability and flow of oxygen [26,32,36].

Studies in south west Ireland found that of all the physico-chemical parameters investigated, suspended solids were the most affected by clearfelling operations [21]. Results showed increases in suspended solids at ten of the sixteen clearfell sites. Some increases were short-term and clearly centred around the duration of the clearfell operation. Where long-term increases were found, they were generally associated with flood events post-felling, whereby soil was washed from the clearfell area into the stream. Increases in sediment and soil on the streambed, which originated from the clearfell operation, have been found at seven out of sixteen sites. Again, most of the increases were short-term, but it is not known to what extent the sediment became trapped within the gravel of the streambed.

These investigations showed that the presence of a buffer strip, even as narrow as 5 m, appeared to be effective in preventing an input of suspended solids into the stream at a number of sites. However, it has also become clear from the study that the presence of a buffer strip alone does not always prevent an input of suspended solids and sediment into the stream, particularly if there is a single direct link between the clearfell area and the stream, such as a run-off channel, a bank collapse or a crossing point for machinery. At one clearfell site, mechanical removal of woody debris from the stream channel caused bank collapse and a substantial input of soil. At another clearfell site, a very large and relatively long-term input of suspended solids was recorded due to the overflow of a sediment trap. Effects of the sediment trap overflow were even observed 2.4 km downstream of the clearfell area, and on one occasion sediment was observed to travel 4 to 5 km from the clearfell area.

Negative impacts on the macroinvertebrate community, such as reduced *taxa richness*, particularly of mayflies, stoneflies and caddisflies, were found at sites that had been subject to relatively large and longer-term inputs of soil and suspended solids. However, rather than being associated with direct run-off, slippages, drainage channels or bank collapses, most of these sites were located downstream of crossing points for machinery where no logs or other materials had been used to cross the stream and where relatively large and long-term inputs of suspended solids, sediment/soil occurred.

Negative impacts on salmonids, such as decreases in abundance and *condition* of 0+ (*young-of-the-year*) fish and one year old fish, were found at those clearfell sites where negative impacts on macroinvertebrates also had been found, and were also predominantly associated with relatively large and longer-term increased levels of suspended solids and *inorganic sediment*.

3.4.4 Recommendations in relation to soil input

It is critical that inputs of soil/suspended solids and sediment from clearfell operations are minimised, since these can have long-term detrimental effects on macroinvertebrates and fish:

(i) Felling plans should include details of soil and sediment management regimes.

(ii) Buffer strips should be maintained along a watercourse to act as barriers or filters against surface movements of sediment (see section 4.1).

(iii) Drainage channels should never form a direct connection between the clearfell area and the stream (i.e. bypassing of buffer strips should not occur in any way). If it is not possible to get machines on to a clearfell site to block all drainage channels which empty directly into a stream, straw bales placed in these drains to act as filters may be an option to reduce the input of sediment. However, care must be taken to prevent the release of trapped sediment when the bales are removed.

(iv) Care should be taken to prevent bank collapses and slippages. Any risk of bank collapse and slippage should be identified and eliminated prior to commencement of clearfelling operations.

(v) Silt traps should be constructed at locations that will intercept run-off to streams (see section 4.2).

(vi) Where sediment traps have been put in place, a regime of checking and emptying them should accompany the felling schedule, to prevent them from overflowing.

(vii) Machinery roads/tracks should be kept away from streams to avoid them becoming a direct route of sediment input. Where tracks have been created on slopes, small offlets should be dug at intervals to prevent water running directly down the slope.

(viii) For catchments sensitive to soil erosion, and particularly those where adequate provision for the control of sediment cannot be made, cable or horse extraction should be considered rather than forwarding, to keep soil disturbance to a minimum.

(ix) Skidding on all but the least erodible sites must be ruled out.

(x) Minimise the potential of soil and sediment movement towards watercourses by avoiding long ground extraction routes on steep slopes.

(xi) Provide and maintain an adequate brash mat for vehicle routes and tracks, to protect soft and delicate forest surface soils from damage. One way to do this is by constraining roadside crops to be felled only subject to confirmation that later extraction will not occur across that land (i.e. the crops further from the road cannot be felled later).

(xii) It is recommended that machinery is not allowed to cross any stream without protecting the stream banks and streambed (see section 3.5 on stream crossing points). The use of temporary bridges is strongly recommended.

(xiii) When mechanically removing woody debris from streams, machinery should be kept as far from the streambank as practical and care should be taken to prevent bank collapses and slippages. If it is not possible to remove woody debris without causing an input of soil/sediment or without entering buffer and exclusion zones with machinery, consideration should be made to leaving the woody debris in place, depending on the size and quantity of the debris (also see section 3.7).

(xiv) Clearfelling during periods of high rainfall will exacerbate the potential for soil erosion and sediment run-off. If possible, clearfelling close to watercourses should be avoided during the winter and suspended during periods of heavy rainfall during the summer.

(xv) If erosion and soil inputs to streams/rivers occur, be prepared to modify operating procedures immediately (including cessation of the operation if necessary) and construct silt traps as appropriate. However, it is strongly recommended that construction of silt traps always occurs prior to commencement of clearfelling operations; see section 4.2.2, recommendations (i) and (ii).

3.5 STREAM CROSSING POINTS

As mentioned before, crossing points for machinery can be a larger and longer-term source of soil and (suspended) sediment than bank collapses, slippages or drainage channels.

3.5.1 Types of crossing points during use

In the south west of Ireland two types of crossing points have been observed. One is where the stream is crossed directly, without any construction material such as logs and where no measures are taken to protect stream banks or bed. In some cases, an existing ford is used and in other cases a new track is made directly across the stream (Plate 7b). However, this practice of crossing watercourses directly is inappropriate and can cause greatest impacts on stream environments. The second type of crossing point encountered involved logs and sometimes branches placed in the stream (parallel to the current) during felling operations (Plate 7a), creating a type of dam over which the machinery is able to cross. Generally, a temporary large pool forms behind the dam and sediment is trapped in the pool and in the dam itself.

Other methods of crossing such as (portable) bridges, pipe-bundles and culverts also exist, but it is not known to what extent these are in use in Ireland.

PLATE 7: EXAMPLES OF STREAM CROSSING POINTS ESTABLISHED DURING CLEARFELLING ACTIVITIES.

3.5.2 Potential impacts

The crossing of a stream or river by machinery during a clearfelling operation is a key area of forest management that can impact on stream ecology. Crossing points typically influence stream habitat by accelerating sediment delivery to the stream. The duration of sediment delivery from crossing points can be short- or long-term. Several factors influence the impact of crossing points on streams, including type of crossing point, the intensity and duration of use of the crossing point by vehicles, the gradient of the track, weather conditions and the character of the soil of the stream bank. If a large and long-term input of soil and sediment occurs from a crossing point the potential impact on the stream environment is as described in section 3.4.2 (Plate 8).

PLATE 8: AN EXAMPLE OF SIGNIFICANT SEDIMENTATION PROBLEMS THAT CAN ARISE FOLLOWING DAMMING AT A STREAM CROSSING POINT (BROSNA FOREST, SITE 2) (THIS ACTIVITY PRECEDED THE INTRODUCTION OF THE NEW FORESTRY AND WATER GUIDELINES).

3.5.3 Scientific findings

Studies elsewhere have shown that stream crossings points are a primary source of sediment and erosion and that the intensity with which machinery cross the stream is correlated to the degree of increase in sediment in the stream [7,32,37]. The frequency of use by vehicles and slope/gradient has been found to be important influencing factors in sediment runoff. Sediment input from crossing points tends to be highest during construction, following the first floods and during vehicle crossing itself [41]. Different forms of stream crossing vary in their impact on streams [42]. For instance, in one study it was found that sediment increases in the stream were higher at a culvert crossing as opposed to portable bridge installations [40].

The studies in the south west of Ireland [21] indicated that the presence of a stream crossing point appeared to be a key factor in the input of suspended solids. Generally, direct crossings were found to have a detrimental and relatively longer-term effect (within the time frame of the study) on the stream system and increased inputs of suspended solids were measured throughout the study period, especially during periods of high discharge. The absence of logs or other construction material at the crossing point caused bank collapses and instability, which formed a long-term source of input of suspended solids and sediment into the stream. Negative impacts on macroinvertebrate community were found at sites located downstream of these direct crossing points. Negative impacts on salmonids, such as decreases in abundance and *condition* of young-of-the-year fish and one year old fish, were also found at some of the sites downstream of crossing points where no logs or other materials had been used to cross the stream.

Crossing points where logs and branches were used appeared to have no obvious long-term effects on the stability of the stream bank, streambed or *biota* (in some cases no effects were found at all) and increases in suspended solids were relatively short-term and centred around the clearfell activity. However, a relatively large and short-term release of trapped sediment did take place when the logs and branches were removed after the felling operations, which could have an impact downstream where the sediment eventually settles. Quite soon after the removal of this type of crossing point, no further increases in soil and suspended sediment were recorded at the sites. However, the longer-term effect of such crossing points on bank stability is unknown.

3.5.4 Recommendations in relation to crossing points

(i) Felling and extraction must be properly planned to minimise the number of stream crossings. However, in practice this is only effective if, as a consequence, the length of certain off-road routes and the number of machine passes over them are not intolerably increased. As the ultimate goal is to reduce overall sediment input, an additional crossing point[6] should be included if reducing the number of stream crossings will increase sediment run-off from off-road routes because they are longer or more intensively used.
(ii) (Portable) bridges are the most desirable types of crossing with minimum disturbance to the aquatic environment and should be used where practical and possible.
(iii) Where bridges are not used, machinery should never directly cross the stream without protecting the stream banks and streambed. Thus the practice of creating a new track directly across a stream without using any construction materials should be avoided.
(iv) Given the accumulation of sediment when a crossing point composed of logs and felling debris is considered, other types of crossing points, such as bridges and culverts are still preferred.
(v) Even small channels or drainage ditches which may be dry before felling may flow again during operations. If they must be crossed by machinery it is recommended they be modified (e.g. install a pipe) to prevent bank collapse, erosion and soil inputs.
(vi) Construct a crossing point where bank sides and soil are stable.
(vii) A brash path leading to the bankside should be provided to avoid soil damage.

3.6 WINDTHROW

3.6.1 Sources

During the growth and maturation of trees, within-crop trees develop a relatively weaker root anchorage compared to edge trees. Their root systems have therefore a lower resistance to strong winds than edge trees, which are more exposed to wind. When previously unexposed trees are left standing during a clearfell operation they become prone to *windthrow* (e.g. where they are part of a different compartment or are left to function as a buffer between the clearfell area and the stream).

3.6.2 Potential impacts

Woody debris has been shown to enhance conditions for aquatic life by providing food, shelter and pool habitat. However, when woody debris is too abundant and dense, for example after windthrow, it can cause undesirable changes in a stream environment such as too much shading, a change in habitat structure and flow patterns and can provide barriers for movements of fish. Additionally, large build-ups of woody debris in watercourses can form blockages of bridges and culverts and lead to local flooding (also see section 3.7 on woody debris). Trees planted close to the streambank and that are windthrown can cause bank instability and erosion. It is often necessary to remove windthrown trees from the stream and the process of doing so can cause damage to the stream bank by machinery and an input of soil.

3.6.3 Scientific findings

There is not much literature available that specifically looks at the effects of windthrow on streams. In the study conducted in the south west of Ireland [21] windthrow of trees into the stream occurred at several clearfell areas after felling. In one case 30% of the streambank was covered over by coniferous trees following damage by wind, between the upstream reference sampling station and a station just downstream of the clearfell area. Some indirect effects of felling on salmonid populations were found and appear to be related to windthrow. For example, a decrease in young-of-the-year fish condition at one clearfell site may be linked to the large number of trees that had fallen into the stream after windthrow. Windthrow and the dense accumulation of detritus may also be linked to the decrease in abundance of one-year old fish at another clearfell site.

3.6.4 Recommendations in relation to windthrow

(i) Windthrow of trees into the stream cannot always be avoided, especially if the trees are part of the buffer zone between the clearfell area and the stream. Windthrow of a few trees into the stream, provided that the trees[7] do not create a migration barrier for fish nor pose a risk in blocking bridges, is unlikely to impact on the water quality and biota of the stream and is likely to be beneficial in the longer term.
(ii) Excessive windthrow is undesirable and should therefore be removed (while keeping sediment inputs to a minimum in the process).
(iii) In areas of high windthrow risk, buffer zones composed solely of several rows of trees left standing after a clearfell are not advisable. They should either be removed (taking all necessary precautions to protect the stream environment) and the area replanted with ‘permanent’ riparian vegetation to create a buffer zone for future forest management activities or their crowns decapitated to a lower height (see iv below).
(iv) Plans for windthrow management in relation to riparian systems need to be included in felling plans (or perhaps even in plans at planting or reforestation stage) in order to avoid windthrow (refer to Forestry and Harvesting guidelines). Possible options are to:
    - design buffer strips to be stable and wind firm. Ideally commence the retention or buffer area with some wind firm ‘starting point’ such as an area with low vegetation (e.g. shrubs) or broadleaf trees, which will only be semi-mature (and thus of low height) if an adjoining conifer area is being clearfelled,
    - to create a wind-firm area artificially by retaining a few rows of trees along a watercourse of which progressively decreasing amounts of crown have been removed (like stairs). Crowns can be reduced or decapitated using the reach of a harvesting head, and
    - allow enough width for some windthrow damage to the edge of the clearfell area and still have a buffer zone after this.

3.7 WOODY DEBRIS INPUTS FROM CLEARFELLING

3.7.1 Sources

During a clearfell operation logging debris and brash can find their way into an adjacent watercourse, especially if there is no buffer zone present. This can lead to an accumulation of woody debris and large woody debris dams are sometimes formed (Plate 9).

[6] Ideally, an objective model incorporating site-specific factors such as number of crossing points, the intensity and duration of use of the crossing point, slope and soil condition would benefit the decision-making process at each individual site regarding the minimisation of sediment inputs to surface waters during clearfelling operations. However, more specific research is required to form the basis of such model.

[7] The terms ‘windthrow of a few trees’ and ‘excessive windthrow’ are open to subjective interpretation and to date no scientific, objective data are available to quantify such amounts. This poses a practical difficulty for forest managers in some situations when deciding whether windthrow should be removed or not. Factors such as whether or not the windthrow creates a migration barrier for fish, poses a risk in blocking bridges or causes local flooding and erosion are important. In specific situations Fisheries Boards could be consulted.

PLATE 9: WOODY DEBRIS ACCUMULATION IN A STREAM.

3.7.2 Potential impacts

Woody debris in a stream can be beneficial for both macroinvertebrates and fish by providing food, and increasing the range of habitats and shelter. However, massive accumulations of woody debris can also produce barriers to fish migration and, if dislodged by high flows, can cause debris torrents, channel scour, erosion and blockages of bridges. Inputs of woody debris from forestry operations can be a problem because the pieces are generally smaller than naturally produced woody debris (e.g. woody debris that falls into a stream from a woodland riparian zone) and generally result in denser accumulations. Traditionally, woody debris was removed to protect fish stocks. However, the removal of all debris can reduce habitat availability and cover for fish, leading to decreases in fish densities. An intermediate approach, dependent on size, nature (coniferous and/or deciduous) and mobility of the woody debris, appears to be the logical solution.

3.7.3 Scientific findings

Although several studies have shown that the input of woody debris in the stream system increases immediately following felling [5,12], the size of large woody debris pieces, and hence their potential benefit, is lower than naturally produced woody debris, since felling debris often consists of small sized brash [33]. The presence of a 30 m buffer zone has been found to prevent the input of clearfell-related woody debris, as the majority of debris entering the stream is derived from within 30 m of the stream [27].

Studies regarding removal of woody debris after clearfell operations show variable results, due to the effect of woody debris being dependent on site-specific factors [4,16]. In some studies, researchers found no significant change in salmonid populations in streams where the debris was left in the stream following clearfelling [43], whilst other studies did show significant reductions in salmonid density when woody debris was removed [8].

Although present Forestry and Water Qualities guidelines state that branches, logs or debris should be removed from aquatic zones, woody debris was left in streams at several clearfell sites studied in south west Ireland. However, it was also found that the removal of woody debris caused bank collapse and a relatively large input of soil at one clearfell site. At another site, removal of a woody debris dam appeared to be associated with decreased fish abundance. On the other hand, at one site there was a dense build-up of detritus and woody debris which decreased numbers of one-year old fish. Further investigation on the interaction of salmonids and woody debris is clearly required[8].

3.7.4 Recommendations in relation to woody debris

(i) Care should be taken to avoid the input of felling-related woody debris, particularly small pieces of woody debris, tops and brash into streams during felling operations.
(ii) Trees should be felled away from streams.
(iii) Measures must be taken to avoid sediment input and/or bank collapses when removing woody debris from a stream after a clearfelling operation. Debris removal should therefore be carried out using the minimum of heavy equipment. If there is a high risk of sedimentation of streams during the process of woody debris removal (e.g. in the case of unstable or erodible banks, or steep slopes) consideration should be made to leave woody debris in the stream. In such specific situations Fisheries Boards should be consulted.
(iv) Leaving a woodland riparian buffer strip, which is in existence or established at the time of planting, along stream banks is recommended, since such buffer strips will reduce the risk of logging debris reaching the stream. A woodland riparian buffer strip of variable canopy cover will also provide a supply of large woody debris to the stream in natural quantities and sizes and over a long time period, thus enhancing stream habitat.
(v) Further study on the interaction between woody debris and salmonid populations under a wide range of conditions, such as in streams of different orders (headwater streams versus streams/rivers further downstream) or of different functions (e.g. nursery stream versus angling waters), is required so that a policy can be drawn up to the benefit of salmonid populations in the catchment as a whole. It is recommended that a classification system or visual key be developed and eventually used by managers on a site-specific and day-to-day basis in forest operations.
(vi) Felling plans should include a provision for woody debris management.

3.8 FURTHER READING

- Gurnell, A.M., Gregory, K.J. and Petts, G.E. 1995. The role of coarse woody debris in forest aquatic habitats: implications for management. *Aquatic Conservation: Marine and Freshwater Ecosystems* 5: 143-166.
- O'Halloran, J., Giller, P.S., Clenaghan, C., Wallace, J. and Koolen, R. 1996. *Plantation forestry in river catchments: disturbance and recovery*. In: Giller, P.S. and Meyers, A.A. (Eds). Disturbance and recovery in ecological systems. Royal Irish Academy. Dublin. p 68-83.
- MacDonald, L.H., Smart, A.W. and Wissmar, R.C. 1991. *Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska*. US EPA report EPA/910/9-91-001, region 10, Seattle, WA 98101. (NPS Section WD-139). 166 pp.
- Welch (jr.), R.A., Taylor, S.E., Yoo, K.H., Thompson, J.D., Rummer, R.B. and Albright, R.A. 1998. *Life-cycle water quality impacts from low-water stream crossings*. ASAE meeting presentation - paper no. 98-7027.

[8] A recent Irish study on the interaction between salmonids and woody debris entitled *Experimental provision of large woody debris in streams as a salmonid management technique* has been carried out by B.M. Lehane, P.S. Giller, J. O'Halloran, C. Smith, and J. Murphy, and is published in the journal Aquatic Conservation 2002, 12, p289-311.

4. PROTECTIVE MEASURES TO MINIMISE THE EFFECTS OF CLEARFELLING OPERATIONS ON THE STREAM ENVIRONMENT

4.1 BUFFER STRIPS

4.1.1 Role in protecting the stream environment

Buffer strips or protective riparian zones are a widely selected tool by most management and regulatory bodies to minimise the effects that forest operations, such as clearfelling, might have on aquatic habitats. They are strips of land vegetated by trees and other vegetation bordering water courses, often of designated size and deliberately left unharvested or deliberately planted (Plate 10). They are not clearfelled, with the intention of:

- preventing excessive fine organic debris and brash from entering the stream or river;
- protecting stream banks from erosion;
- acting as a filter and barrier against surface movements of sediment that may be produced after a clearfelling operation and of other substances, such as phosphorus and nitrogen compounds, which may be released and carried with small soil particles or in the surface flow;
- acting as a physical barrier against casual stream crossings by machinery during the clearfelling and extraction processes;
- supplying a major portion of organic litter, such as leaves and twigs, as a food source for organisms living in the stream;
- providing the stream environment with some shading and thus protecting the stream against extreme daily and seasonal temperature changes and enhancing general habitat structure for macroinvertebrates and fish (it is important to provide balance and variation between canopy openness and shading);
- providing corridors for wildlife travelling from one desirable habitat to another and/or functioning as additional desirable habitat for birds, mammals and amphibians.

PLATE 10: A COMPARISON OF STREAMS (A) LEFT WITH A BUFFER STRIP OF VEGETATION AND (B) ONE CLEARED TO THE STREAM EDGE.

4.1.2 Recommendations in relation to buffer strips

(i) Determination of the nature and size of buffer strip required to protect streams from clearfelling operations is difficult, since this can vary in individual circumstances and depend on specific conditions at a clearfell site.

(ii) Ideally, the nature, size and management of a buffer strip should be determined on a site-specific basis, rather than on very general guidelines, and should incorporate a variety of factors:
- the dominant function of the buffer strip, for example to retain soil/sediment generated by clearfelling or to provide instream shading, salmon habitat or both.
- site-specific risk factors or site sensitivity such as steep slopes, catchment topography, unstable and/or erodible soils, the presence of fish spawning grounds, large area clearfelled, wet conditions for clearfell operation (i.e. season/timing of felling), percentage area of the catchment afforested and/or clearfelled and grazing pressures.

The nature and size of the buffer strip should thus be determined according to the dominant function, presence/absence of risk factors and site sensitivity[9]. However, in practice this may be difficult to determine for each individual clearfell area, thus a practical classification system, with each class with different criteria for defining the buffer zone is suggested.

(iii) The investigation in south west Ireland showed that the presence of a buffer strip appeared to be effective in preventing the input of soil/sediment into the stream at a number of sites.

(iv) However, it has also become clear from the study that the presence of a buffer strip alone, even one of 15 to 20 m in width, does not always prevent an input of sediment into the stream, particularly if there is even a single direct link between the clearfell area and the stream, such as a run-off channel, a bank collapse or a crossing point for machinery. Such bypassing of the buffer zone should therefore be avoided at all times in order to sustain the protective function of the buffer strip.

(v) If an objective is to reduce nutrient inputs into a watercourse, a buffer strip of 10 m may not be large enough to prevent the release of nitrates into the stream after clearfelling (increased nitrates were also found at a site with a non-bypassed 15 to 20 m buffer during the clearfelling study in south west Ireland).

(vi) Buffer strips need to be stable and wind firm (see section 3.6.4. for recommendations in relation to windthrow).

(vii) A buffer zone composed solely of several rows of coniferous trees left standing after a clearfell is not advisable at exposed sites because of the risk of windthrow (see section 3.6.4):
- Where semi-mature trees are planted to the stream bank[10] consideration should be given to removing the conifers in the riparian zone well in advance of the clearfell date (i.e. at 1st and 2nd thinning stage) so that a more natural vegetated riparian buffer strip may regenerate at the clearfelling stage (unless this procedure increases the risk of windthrow to the remaining stand).
- Where mature trees are located on the stream bank[11] and the recommendation above is not applicable, then a buffer strip of conifers should be maintained for a period, until at least the soil of the clearfell area has been stabilised and clearfell-related run-off has ceased.

(viii) Before commencement of clearfelling, buffer zones could be colour-flagged on the ground, with variations in distance according to the degree of threat to a watercourse. The harvesting contractors and machine operators should be provided with site maps outlining aquatic zones, buffer areas and stream crossing points. Complete communication with the harvesting contractor is of utmost importance.

(ix) At establishment stage, unplanted strips should be obligatory along all watercourses as set out on an Ordnance Survey 6" map, including minor ones. This will avoid problems at clearfelling stage when such areas will be clearly visible on the ground to the machine operator.

(x) It is recommended that fencing be erected at the time of forest establishment to protect the buffer area from grazing, to encourage development of the riparian vegetation.

[9] Ideally, foresters must have access to a site sensitivity analysis for operation planning purposes. As yet, this analysis is not available and a national freshwater forest sensitivity analysis for the whole of Ireland needs to be developed.

[10] This situation will progressively arise less frequently in the future, since planting of conifers is not to take place within 10 m (and 20 m on very steep slopes) of a watercourse (according to the present Forestry and Water Quality Guidelines) and 'permanent' riparian or buffer zones are incorporated at the re-afforestation stage. Sites that have been planted in the last 10 years would thus generally carry an unplanted buffer strip, of varying distances bordering watercourses, in marked contrast to older forests where trees were planted to the streambank.

[11] Same as footnote above.

4.2 SEDIMENT/SILT TRAPS

4.2.1 Role in protecting the stream environment

The construction of sediment/silt traps can be an effective method of reducing the input of soil and sediment into a stream, particularly in areas with high erosion risk. However, construction is not enough as they also need to be maintained and emptied. To illustrate this, a very large and sustained (i.e. several months) input of suspended solids was recorded at one clearfell site, due to the overflow of a sediment trap installed as part of the clearfelling operation. Effects of the sediment trap were observed 2.4 km downstream of the clearfell area and on one occasion sediment was observed to travel 4 to 5 km downstream from the clearfell area.

4.2.2 Recommendations in relation to sediment traps

(i) An audit of sediment movement and mitigation should be included in felling plans, perhaps at planting or reforestation stages.

(ii) Sediment traps should be constructed prior to clearfelling and maintained throughout operations.

(iii) Sediment traps should most certainly be constructed in areas with a steep slope and/or a high risk of erosion. In areas particularly sensitive to erosion, it may be necessary to install double or triple sediment traps.

(iv) Sediment traps should be constructed at locations that will intercept run-off to streams.

(v) Traps should not be constructed immediately adjacent to natural watercourses (certainly not within 10 m of the aquatic zone).

(vi) A buffer zone should remain between the sediment trap and the watercourse with natural vegetation left intact to assist sediment/silt interception.

(vii) Sediment/silt traps should be constructed from or supported by durable materials, as they are required to function for a number of years after clearfelling operations (refer to Forest Drainage manual).

(viii) Where sediment traps have been put in place, a regime of inspecting and emptying sediment traps should accompany each felling schedule.

(ix) It is recommended to carry out an extra inspection of sediment traps after large storms and extreme wet weather conditions to assess damage or whether they are overflowing.

(x) Sediment traps should as far as possible be located on flat ground, so that the water can fan out and sediment can settle out, rather than be allowed to run into the trap in a concentrated flow.

(xi) The cleaning of sediment traps located close to the stream bank should not take place during the spawning season or during the period when salmonid eggs and newly hatched fry are living in the gravel (October to May inclusive), in case of an accidental spillage. Thus cleaning can take place from June to September.

(xii) If possible, cleaning of sediment traps should be carried out during dry weather.

4.3 WINDROWING

4.3.1 Role in protecting the stream environment

Although originally not a specific measure to protect the stream environment from clearfelling operations, but to clear the felled area of woody debris for planting, the study in south west Ireland showed that windrowing also formed a barrier against the input of soil and sediment into the stream[12]. The stacks of felling debris, which were distanced 5 m or more from the watercourse, appeared to trap soil and fine brash when they were carried towards the stream by surface water. Windrowing may also have a role in preventing loose pieces of woody felling debris from being blown into streams. The potential for the use of windrows to filter run-off from sites should be further investigated.

[12] Please note: In some cases, and probably dependent on soil type, the practice of windrowing can actually initiate the presence of mobile sediment. In a clearfelling study in Cloosh, Co. Galway, where the soil is generally more erodible than soils in south west Ireland, no surface mobility of soil particles was observed in the absence of windrowing. However, when windrowing was done, the whole surface became mobile in some cases (pers. comment T. Cummins, Forest Ecosystem Research Group, UCD).

4.3.2 Recommendations in relation to windrowing

(i) Management of windrowing and likely impacts on streams should be included in felling plans.
(ii) Machinery used for windrowing should be kept as far as possible from streams and rivers.
(iii) Windrowing should not take place closer than 5 m to a watercourse. In sensitive areas with erodible and/or unstable banks, the distance from the watercourse should even be larger.
(iv) Where possible, one windrow should be placed parallel to the stream to ensure that all furrows/tracks/wheel ruts draining towards the river have a barrier. This would have to be decided prior to clearfelling and the machine operator informed.

4.4 OTHER FELLING METHODS AND GENERAL PROTECTIVE MEASURES TAKEN DURING FELLING

(i) An important aspect of protecting the stream environment during clearfelling is the use of suitable machinery and equipment (taking into account factors such as overall size and weight, number of wheels, width of tyres, use of band tracks, load size) depending on the particular conditions at a site. Site wetness, nature and depth of soil and soil compaction and prevailing weather are important factors.
(ii) Machine operators should be trained. Communication between forest managers and contractors and machine operators is essential to ensure awareness of the clearfelling plans and of any site-specific precautionary measures that need to be taken to avoid damage to nearby watercourses. The harvesting contractors and machine operators should be provided with site maps outlining aquatic zones, buffer areas and stream crossing points.
(iii) A good density of forest roads and tracks will help alleviate excessive tracking by harvesting machinery, although the construction of these can affect nearby watercourses. Necessary precautions must therefore also be taken during road construction to avoid damage to aquatic resources and roads and tracks should ideally be constructed clear of aquatic zones (also see section 3.4.4).
(iv) Roads, forest tracks and drains should be well maintained before clearfelling commences. This will help prevent the possibility of machinery and lorries getting bogged down, which could result in excavation and adjacent drains becoming contaminated with silt.
(v) Harvesting machines should not refuel near watercourses. Oil storage, maintenance and filling of machines should be at a location where surface-water access to streams is not possible. The work area should drain into permeable substrate, with no direct overland route (including drains) to surface waters, in heavy rain (refer to Forestry and Water Quality Guidelines).
(vi) Stacking and loading of timber should not be carried out in proximity to a watercourse, and ideally should be located on dry ground.
(vii) It should be kept in mind that an individual management activity such as a clearfelling, in combination with other forestry activities such as ground preparation, fertilization and re-afforestation in various stream reaches or tributaries of a catchment, can over time produce significant cumulative impacts in the whole stream or river system[13](see section 2.2.3). It is therefore important that (if possible and the information is available) management at a particular site will always take into account earlier and possibly future forest management activities in the whole landscape or catchment unit[14].

4.5 FURTHER READING

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[13] This does not apply to forestry activities alone. A combination of any other land-use activities can also cause cumulative impacts.
[14] Ideally, management of all types of land-use activities (including agriculture, waste disposal, industries) will in future be co-ordinated in a catchment approach. Geographic Information Systems will be an important tool in achieving this.

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GLOSSARY

Algae
Informal term covering many simple photosynthetic plants. Algae are either aquatic or occur in damp situations. There are many growth forms of algae, such as single-celled or multi-celled, flattened or filamentous. They may be microscopic or visible to the naked eye. In streams, they coat the substrate, forming a layer of organisms on rocks or other surfaces.

Allochthonous source of energy
Energy (food) in the form of organic matter derived from outside a particular habitat, such as leaves of terrestrial plants that fall into a stream (compare autochthonous).

Alkalinity
The capacity of water to accept H+ ions, is a measure of its acid neutralizing capacity (ANC) and is often described as the buffering capacity.

Autochthonous source of energy
Energy (food) in the form of organic matter derived from within a system, resulting from photosynthesis and primary production by aquatic plants and algae (compare allochthonous).

Aquatic
Relating to water.

Brash
Woody residue left on the ground after trees are felled, or accumulated there as a result of storm or silvicultural treatment, composed of branches, tops and occasionally logs.

Biota
Living organisms.

Biotic
Relating to living organisms.

Buffer strip
A protective strip of land of variable size and vegetation composition between a watercourse and a particular land-use activity in the surrounding landscape, to buffer the effects that management operations, such as forest clearfelling, might have on aquatic habitats.

Canopy cover (of a stream)
Vegetation projecting over a stream, including crown cover (generally more than 1 m above the water surface) and overhang cover (less than 1 m above the water).

Catchment
Also termed drainage basin and watershed. It comprises the area of land draining into an identified surface-water body, such as a stream or river, and is a widely recognised natural unit of landscape, combining physical, chemical and biological features of linked terrestrial and aquatic ecosystems.

Clearfelling
Removal of the entire standing crop of trees from an area (also called clear-cutting, clearfell logging, clearcut logging).

Community
An assemblage of species populations living in an area or physical habitat, inhabiting some common environment. The biotic community is the living part of an ecosystem.

Condition (of fish)
Measure of the relative well-being of fish, based on a relationship between their length and weight.

Conductivity
A numerical expression of the ability of a solution to carry an electric current, depending on the presence, concentration and mobility of ions. This value therefore provides a relative measure of the concentration of dissolved salts in water.

Detritus
Dead organic matter, such as leaf litter, twigs, etc.

Discharge
A measure of the amount of water moving down the channel past a given point per unit time (m^3/second).

Dissolved organic matter (DOM)
Organic matter transported in streams and rivers that would pass through a filter with a pore size of 0.45 µm. DOM is composed of small dissolved particles such as sugars, lipids, proteins and humic substances.

Drift (of macroinvertebrates)
Collectively, stream invertebrates (mainly the aquatic larval stages of insects) that voluntarily or accidentally leave the substrate and are carried within the current, as well as terrestrial invertebrates that fall into the stream and are carried on the water surface.

Ecology
The study of the inter-relationships between organisms and their environment.

Ecosystem
Community of organisms plus the physico-chemical environment in which they live and with which they interact.

EPT taxa
Macroinvertebrate taxa belonging to the orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies), which are recognised as particularly sensitive to various pollutants, especially organic pollution.

Eutrophication
Usually rapid increase in the nutrient status of a body of water, which may be caused by run-off of artificial fertilizers. It leads to increased production of aquatic plants and algae, often accompanied by massive growth of dominant species. Excessive production increases respiration and dissolved oxygen demand. Anaerobic conditions are created, commonly through microbial decomposition of accumulated decaying plant matter and animals intolerant of low oxygen concentrations are killed, leading to an even larger amount of decaying material.

Food chain
A metaphorical chain of organisms, existing in a natural community, through which energy and matter are transferred. Each link in the chain feeds on, and hence obtains energy from, the one preceding it, and in turn is eaten by and provides energy for the one succeeding it. Food chains interlink to form a food web.

Glide
A relatively shallow stream section with water velocities of 10-20 cm/s and little or no surface turbulence (compare to riffle and pool).

Habitat
Place or environment in which specified organisms live.

Hardness
The amount of (calcium) carbonate in the sample plus all other cations capable of buffering H^+.

Herbivore
Animal feeding on plant products.

Hydrogen ion concentration
Used to represent pH; the higher the hydrogen ion concentration in a solution, the lower the pH (i.e. the more acidic the solution).

Inorganic sediment
Sand and silt deposited on the stream substrate; colour is often light sandy brown to grey.

Invertebrates
Animals without a backbone.

Ion
An electrically charged atom or group of atoms.

Kick sample
A standardised semi-quantitive method to collect macroinvertebrates from the streambed by disturbing/kicking the substrate to a depth of about 50 to 100 mm immediately upstream of a hand-held net for a specified time period to standardise effort.

Labile Monomeric Aluminium
The species of aluminium most toxic to fish leached out at low pH.

Liverwort
Small plants, closely related to mosses and belonging to the class Bryophyta (Hepaticopsida), consisting of a thallus, a central stem of three rows of leaves, and attached to the substratum (usually large stones and rocks) by rhizoids. The majority of liverworts occur in moist soils or on rocks and relatively few are aquatic.

Macroinvertebrates (aquatic)
Animals without a backbone inhabiting the substratum of lakes, rivers, estuaries and marine waters, clearly visible to the naked eye (dominated by insect larvae in streams). Macroinvertebrate community responses to environmental changes are useful in assessing the impacts of land-uses on surface water bodies.

Macroinvertebrate taxon (plural: taxa)
Any taxonomic unit or category of macroinvertebrates, e.g. a particular order, class, family, genus or species.

Macrophyte (aquatic)
Larger, vascular flowering plant, which can be floating, submerged or emersed.

Microhabitat
Place or environment at a very small scale, in which specified organisms live.

Moss
Small plants with distinctly differentiated leaves and stems, belonging to the class Bryophyta (Bryopsida). Aquatic forms vary widely in morphology, but all have poorly developed vascular tissue and are attached to the substratum (usually relatively larger stones and rocks) by rhizoids. Mosses have a wide distribution and occupy wide ranging habitats.

Nitrate
An essential nutrient compound for many photosynthetic autotrophs (algae, plants, trees) generally found in small quantities in unpolluted, 'natural' surface water, but may attain high levels in some groundwater. In excessive amounts (above 50 mg/L NO_3 or 11.3 mg/L N) it is undesirable for public health.

Organic matter
Matter pertaining to or derived from organisms.

Organic sediment
A layer composed of organic matter such as fine particulate detritus and microorganisms, sometimes mixed with a peat-like substance, slippery/slimy to the touch due to the glues and gums in the cell walls of microorganisms. Colour is usually dark brown/black.

Particulate organic matter (POM)
Organic matter, greater than 0.50 µm, transported in streams and rivers. POM can be coarse (CPOM) or fine (FPOM) in nature. CPOM includes substances such as leaf litter, twigs, woody debris or dead plants or animals. FPOM is mainly produced from the breakdown of CPOM by the activity of microorganisms, physical breakdown, and breakdown by animals that feed on CPOM.

pH
The measure of the acidic or basic character of a solution (at a given temperature); calculated from the negative log10 of the hydrogen ion concentration ($-\log_{10}[H+]$).

Pollution (of surface waters)
The direct or indirect introduction of substances or energy (heat) into surface waters through human activities*, which result in harmful effects, such as damage to biological resources, hazards to human health, hindrance to instream aquatic activities (such as fishing), and impairment of water quality, both with respect to the desired consumer process or use (e.g. drinking supply, amenity, fisheries) and the nature and functioning of the natural ecosystem.
* (or less frequently through natural events such as hurricanes, torrential rainfalls, mudslides and volcanic eruptions).

Pool
Portion of a stream with significantly reduced current velocity and finer sediment, often with deeper water (> 25 cm) than surrounding areas and with a smooth surface.

Reach (stream)
A section of stream or river that includes one or several pools and riffles.

Resilience
Capacity of a system to recover to from a disturbance. A high resilience indicates a rapid recovery to pre-disturbance conditions and the effects are therefore generally of short duration.

Resistance (to disturbance)
The disinclination or lack of tendency of a system to change in response to a disturbance.

Retention time (of organic materials/food particles in the stream)
Length of time in which organic materials are available in a particular stream reach before they are lost to downstream parts (related to stream flow, slope, types of organisms present as well as their method and speed of food processing).

Riffle
Shallow section of a stream or river with relatively rapid current and a turbulent surface broken by coarse substrate of gravel, rubble or boulders.

Riparian vegetation
Vegetation growing on the banks or in the flood plain of a stream/river.

Riparian zone
A boundary area on the stream bank between the stream channel and the surrounding landscape and includes all the bankside and immediately surrounding vegetation that directly influences the stream system. Riparian zones are often used as a tool by management and regulatory bodies to buffer the effects that management operations, such as forest clearfelling, might have on aquatic habitats, since they help to prevent pollutants from reaching the stream environment by acting as sinks, filters and transformers for potentially polluting substances. Riparian zones also serve to modify instream temperature and habitat structures.

Salmonids
Fish of the family Salmonidae, including salmon and trout.

Sediment
Unconsolidated particles of inorganic or organic origin, which have been deposited or precipitated from a suspension or solution.

Sedimentation
Deposition of material suspended in water, usually when the velocity of the water drops below the level at which the material can be supported.

Soil deposits
Soil sedimented on top of the stream substrate (often in clumps) where the origin is clearly from the bankside (bank collapses, slippages or stream crossings can cause the input of soil).

Spate
A period of increased stream discharge following a period of heavy or prolonged rainfall.

Species richness
The total number of species present in a sample or habitat (often related to specific taxonomic groups).

Substrate
The material on the bottom of streams and rivers which provides living space for organisms and a variety of functions, such as movement, shelter, resting, reproduction, as rooting or attachment surface and provides a surface on which food collects.

Surber sample
A standardised quantitative method to collect macroinvertebrates from the streambed by disturbing the substrate within a frame of specified area behind which a collection net is attached, to a depth of about 100 mm for a specified time period to standardise effort.

Suspended solids
Inorganic or organic solid particles carried or held in suspension in water and which are retained by a standard glassfibre filter, expressed as milligrams per liter. In high concentrations they can interfere with photosynthesis of aquatic plant life, affect fish and insect life and form deposits on the bed of rivers and lakes.

Taxa richness
The total number of taxa present in a sample (cf. species richness).

Terrestrial
Relating to land.

Total hardness
Sum of the calcium and magnesium concentrations in a solution, both expressed as calcium carbonate, in milligrams per litre (m/l).

Windthrow
The uprooting and falling of trees by strong gusts of wind.

Young-of-the-year
Juvenile fish hatched in the year in question (often referred to as 0+ fish)

APPENDIX I

List of contributors to the consultation process to review this report:

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- Mr F. O'Donoghue - Senior Fisheries Environmental Officer, Southern Regional Fisheries Board.
- Mr C. O'Donovan – Divisional Office, Forest Service, Dungarvan, Co. Waterford, on behalf of Mr D. McAree, Forest Service.

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