2.0 Upland River Systems

By definition, upland rivers rise in mountainous areas. Thousands of small rivulets sliding down the side of steep precipices slice through the hard geology and join to form recognisable streams. Flowing through the often acidic surface geology, these steep gradient watercourses join together, creating main river stems, which then discharge over many kilometres, with ever reducing gradient until they enter the flatter, valley floor, and eventually discharge to sea via their estuary. This then is a stylised UK upland river. But what of the physical processes that influence and ultimately control the river's form? Arguably, the most fundamental are base geology, precipitation, erosion and its offspring sediment movement, and land use. Together, these elements are referred to as the **geomorphology** of the river. Simply, this is the study of landforms and the processes that act upon them.

2.1 Physical processes

Upland areas are generally formed from hard, acidic or neutral rocks, although small outcrops of base rich rocks can occur locally. Their geology is often the result of the impact of heat (volcanic activity) and pressure (tectonic activity) on sedimentary rocks over millions of years. Heated, squeezed, buckled and reformed by these processes, the resulting rock formations may be complex. They are generally resistant to rapid erosion, but have been extensively reshaped by successive glaciations, with the last one finishing some 8,000-10,000 years ago.

RIVER'S ARE FORMED BY A COMBINATION OF PHYSICAL PROCESSES AND MAN'S INFLUENCE.

supported by

Asiantaeth yr Amgylchedd Cymru
Environment Agency Wales

The acidic nature and low permeability of most of the rock formations influences both water-quality and the speed of surface water run-off, and also affects the local habitat. The pH of much of the surface water run-off from upland areas will be less than 7, meaning that it is acidic. As a consequence, much of the upland vegetation and fauna, both terrestrial and aquatic, is adapted to acid-neutral water quality.

Man's influences, particularly the generation of acidic gases as a by-product of fossil fuel burning, and the planting of large coniferous forest blocks (**see Section 4.0: Land Use**), can increase the acidity of surface water run-off still further. This can have profound and damaging impacts on the ecology of upland river systems. Additionally, one of the properties of acidic water is that it acts to dissolve and mobilise minerals from rock formations and soils. Many of these are potentially toxic, and hence harmful to a range of wildlife (**see Section 4.0**), with perhaps the most commonly known being bauxite, an aluminium ore, that can cause direct mortality of fish in so-called 'acid run-off' events.

Peak run-off from upland areas can be very intense, as a consequence of the steep gradient, impermeable nature of the geology, and the heavy rain often experienced. As a consequence, upland river flows encompass extremes with severe flooding often following periods of very low flows. This is in stark contrast to the relatively stable flows commonly occurring in limestone and particularly, chalk rivers[4]. Upland stream systems thus tend to have a simpler and less diverse ecology than the more stable base rich rivers of the lowland British Isles.

The reduced permeability of upland areas also results in the formation of a range of characteristic habitat types. Bogs and mire systems are the most common of these, both of which depend on the retention of large amounts of surface water for the development of specialised vegetation communities and associated fauna. Extensive bog and mire covering of upland catchments provides a huge reservoir of surface water, slowing its discharge into the river system over time and providing a degree of stability to flows. Removing or damaging these systems significantly undermines this natural process, leading to even more 'flashy' flows within the catchment (**see Section 4.0**).

MOORLAND AND LOCHS IN THE HEADWATERS OF A SCOTTISH RIVER SYSTEM

Erosion of the hard upland rocks is generally slow. However, the effects of past ice ages and associated glaciations have left a huge resource of boulders, pebbles and gravels. These are available for transport along river systems during heavy rainfall events. The high energy of upland rivers means that the substrate is generally very mobile, with car-sized boulders routinely migrating downstream. As a consequence, there is limited scope for lasting in-channel structures to be installed in the middle or lower reaches of these rivers.

In addition to the movement of the hard geology, the high rainfall experienced in upland areas can have a huge impact on the overlying alluvial soil, particularly where this is subject to agricultural activity. The consequent sediment laden surface water run-off can cause serious problems if it enters the river system. Impacts can include the smothering of shallow gravel riffles and the infiltration of fine sediment into spawning gravels, leading to a reduction in hatch rate of salmon and trout eggs, and the loss of habitat for key invertebrate species.

Diffuse run-off may also pour into field drains and onto the road network. These channels then enter the river via what are effectively point source discharges, with equally devastating impact on its ecology. The issue of sediment run-off is examined in more detail in **Section 4.0**.

Upland streams can be exposed to extremes of temperature, with summer temperatures reaching near lethal levels for salmonid fish species, particularly during low flow events. Overwide channels caused by cattle poaching or past dredging, lack of shading bankside trees and the potential impact of climate change on river systems can all exacerbate this problem. There are a number of management tools that can help mitigate the worst impacts of temperature extremes on upland rivers. These are discussed in more detail in **Section 5.0**

AGRICULTURAL RUN-OFF ENTERING A ROAD SYSTEM AND ITS DRAINAGE NETWORK

2.2 Ecology

The high energy, mobile substrate and wide fluctuations in flow and temperature experienced in upland rivers, provides a demanding physical framework for their flora and fauna. A range of specialised adaptations have evolved over millennia as a result of these pressures. There is a limited number of truly aquatic plants that flourish in the larger tributary streams and main river. The most common of these is willow moss *Fontinalis antipyretica*, which as its name suggests is a moss rather than a higher plant. Notwithstanding this, its relatively small size, and strong holdfast system allow it to remain firmly attached to rocky substrates, even during spate events.

AN INVERTEBRATE SAMPLE TAKEN FROM AN UPLAND STREAM

Many of the macroinvertebrate species show a similar range of adaptations. Nymphs of the mayfly genera *Ecdyonurus* and *Heptagenia* are dorsally/ventrally flattened, allowing them to crawl under rocks and boulders, where they are protected from high water velocity. Cased caddis species use stones to create their protective 'body armour', with their increased body mass anchoring them to the river bed, even in turbulent flow. Other species face the challenges of upland rivers by remaining adaptable, and able to live in a range of habitat types.

Fish stocks in the higher reaches of upland rivers are often relatively restricted; brown trout, sea trout, Atlantic salmon and eel *Anguilla anguilla* dominate the species exploited by man. Other species that regularly occur include the three lamprey species, brook (*Lampetra planeri*), river (*Lampetra fluviatilus*) and sea (*Petromyzon marinus*), along with bullhead *Cottus gobio*, minnow *Phoxinus phoxinus*, and Allis (*Alosa alosa*) and Twaite (*Alosa fallax*) shad.

Interestingly, of the species that spawn in freshwater, there is generally tendency towards laying small numbers of eggs, with a high degree of care provided to them. For instance, the salmonid fish species (trout and salmon) deposit their eggs in carefully excavated redds, whilst bullheads lay eggs in nest sites under stones, with the male standing guard over the nest until the fry have hatched. This strategy is in stark contrast to many of the fish

LARGE BROOK DUN NYMPH (*Ecdyonurus torrentis*): A TYPICAL UPLAND STREAM INVERTEBRATE (*Photo © Cyril Bennett*) species that occupy lower energy streams, which rely on depositing large numbers of eggs with a reduced degree of care.

The spawning requirements of trout and salmon are well reported.[1,2] In essence, trout require a strong flow of good quality water, passing over a substrate dominated by silt-free gravel, between 5-50mm diameter. Sea trout are able to make use of larger sizes of gravel, due to their often physically larger size. This may therefore result in a degree of separation of brown trout and sea trout spawning zones. In many upland systems, much of the spawning of both sea trout and brown trout takes place in tributary streams or upper reaches of the main river.

The hatching success of deposited trout eggs is dependent on a number of factors, including the quality and volume of water flowing through the redds, and the volume of suspended solids carried in the water column. Infiltration of sediment within trout redds causes significant mortalities of eggs, due to reduced oxygen levels. Similar problems can affect the survival of trout alevins, which remain within the gravel until their yolk sacs have been exhausted. As a result of these factors, spawning success can vary from year to year, influenced by the extreme fluctuations in rainfall and sediment transport experienced in upland areas. The emergence rate of swim up trout fry in upland rivers can therefore be very variable. However, in general, hatch rate and subsequent emergence of fry are high in comparison with chalkstreams and other lowland streams.

Recently emerged trout fry generally occupy shallow riffles, with gravel or cobble substrate and water velocity varying between 10cm/sec and 40cm/sec. They often seek refuge in low velocity areas adjacent to these riffles. A high rate of mortality and to a lesser degree, migration (many of the downstream migrating fish subsequently dying, with upstream migrating fish having a higher rate of survival)[1] occurs immediately post emergence, with the resulting density of trout a direct reflection of the availability and complexity of suitable habitat.

SPAWNING TROUT
(*Photo: © Peter Henriksson*)

FREEZE CORE SAMPLING TO ASSESS QUALITY OF SPAWNING GRAVEL

Of particular importance is visual isolation of each fish from its neighbour, with each fry holding a small but keenly defended territory. This 'density dependent' mortality highlights the importance of diverse and abundant habitat at this critical period. Careful manipulation of habitat elements within spawning zones can be used to decrease mortality and hence increase numbers of surviving fry.

As the fish grow during their first summer, their ability to occupy faster water areas increases. The size of their territory also expands. Habitat utilistion by parr varies diurnally, with some authors[2] reporting increased usage of deeper water during the night. Some clumping of parr can occur, particularly in their first winter when they seek deeper water areas.

Estimates of the survival of deposited trout eggs to parr at the end of their first summer provide an indication of the high mortality experienced. Studies[2] have suggested survival rates of up to 80% for hatching after egg deposition in good areas of spawning habitat. However, high rates of deposited sediment within redds can reduce this figure to less than 10%. Estimates of the subsequent survival of emerging fry are dependent on the quality and quantity of habitat available, with density dependent mortality often resulting in less than 5% living to reach their first birthday. Survival rates then increase significantly, with between 30-50% annual survivorship recorded. There is a difference in survivorship of the sexes, with female trout having the lower rate of annual mortality.

The habitat of larger, 1+ and 2+ (adult) trout is mainly characterised by an increased use of deeper water (20cm -50cm), with a clear link between the size of trout and the depth of habitats used. There is also a tendency for adult trout to occupy areas of slower water velocity, generally with larger structural elements (boulders, tree roots, large woody debris) present to provide cover. Territory size increases, with some localised migration of 1+ fish taking place, both for brown trout from tributary streams to the main stem, and for sea trout, as smolts to the sea. However, studies suggest that for the majority of rivers, the major migration is of 2+ fish, both as sea trout smolts and brown trout parr. This mechanism helps both to fill available adult trout habitat in the main river stem, and to fuel the subsequent run of returning adult sea trout. It is also the mechanism by which trout populate freshwater lake systems.

References cited

1. *Quantitative ecology and the brown trout* (1994) Elliot JM

2. *Biology and ecology of the brown and sea trout* (1999) Bagliniere JL and Maisse G

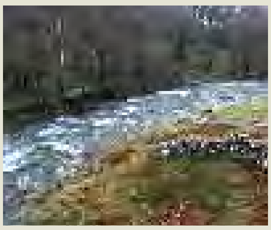
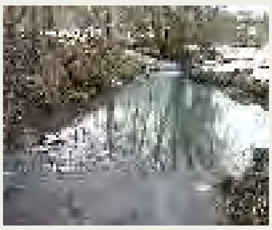
3. *Trout & Salmon - Ecology, Conservation & Rehabilitation* D.T. Crisp

4. *Chalkstream Habitat Manual* (2008) Wild Trout Trust

2.3 Summary of habitat requirements for salmon and trout

Habitat Variable	Trout			
	Spawning	**Fry**	**Juveniles**	**Adult**
Velocity (cmsec^{-1})	15-95	0-40	5-50	6-70
Substrate (mm)	10-75	8-70	8-256	2-256
Depth (cm)	20-46	3-60	25-60	20-120
Other	Excess of fine sediment can clog spawning gravels	Fry often lie close to banks and utilise cover from fringing vegetation		

Habitat Variable	Salmon			
	Spawning	**(0+)**	**(1+)**	**Adult**
Velocity (cmsec^{-1})	30-70	20-40	25-75	25-75
Substrate (mm)	16-256 Less than 20% fines of <2mm	16-256	64-256	64-256
Depth (cm)	15-75	<20	20-40	20-40
Other	Need for up/down welling water through spawning gravel	Fringing riparian flora, although not so extensive that it causes tunnelling	Riparian vegeta-tion should not be so extensive as to cause excessive shading	Free access to spawning areas essential. >9.5m^{-2} habitat required per pair of spawning fish

Lifestage	Spawning	Fry	Parr	Adult
Habitat				
Survival from previous lifestage (%)	Emergence up to 80%, but will be less if entrained sediment in redds	5% survival from emergence to first birthday (1+)		Annual survival rate from 30% (male) to 50% (female)