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Fish populations in Plynlimon streams

D.T. Crisp[1] and W.R.C. Beaumont[2]

[1] 21A Main Street, Mochrum, Newton Stewart, Wigtownshire, Scotland, DG8 9LY.
[2] Institute of Freshwater Ecology, The River Laboratory, East Stoke, Wareham, Dorset, BH20 6BB.

Abstract

In Plynlimon streams, brown trout (*Salmo trutta* L.) are widespread in the upper Wye at population densities of 0.03 to 0.32 fish m^{-2} and show evidence of successful recruitment in most years. In the upper Severn, brown trout are found only in an area of c. 1670 m^{-2} downstream of Blaenhafren Falls at densities of 0.03 to 0.24 fish m^{-2} and the evidence suggests very variable year to year success in recruitment (Crisp & Beaumont, 1996).

Analyses of the data show that temperature differences between afforested and unafforested streams may affect the rates of trout incubation and growth but are not likely to influence species survival. Simple analyses of stream discharge data suggest, but do not prove, that good years for recruitment in the Hafren population were years of low stream discharge. This may be linked to groundwater inputs detected in other studies in this stream.

More research is needed to explain the survival of the apparently isolated trout population in the Hafren.

Introduction

The fish studies in the Plynlimon streams have been opportunistic, largely executed as adjuncts to other work, and spread thinly over a number of years. A wide ranging survey of fish populations was made in June 1979 in the Severn upstream of Nat. Grid ref. SN/855872 (altitude 320 m.O.D.) and in the Wye upstream of Nat. Grid ref. SN/826838 (altitude 358 m.O.D.). Additional studies were made in the upper Severn system between 1984 and 1994. The methods were described in detail by Crisp & Beaumont (1996). The present paper discusses the main findings with special reference to the biology of fish in coniferous forest streams and the possible biological effects of groundwater inputs to the Hafren.

Additional, tentative analyses of the data have been made relative to:

(a) available information on water temperature for 1993 and 1994 in the Afon Hore after it has flowed for c. 1.5 km through a clear felled area and in the Afon Hafren after it has flowed through c. 2.5 km of forest (Table 1) using models from Crisp (1981, 1988) and Elliott (1975).
(b) discharge data from the Afon Hafren.

The Streams

The upper Wye and the upper Severn have similar geology, aspect and catchment areas. The main difference between them is that the Wye catchment is grassland grazed by sheep and the catchment of the Severn is mainly mature conifer plantations, though some of the Severn catchment (e.g. the Afon Hore catchment) has been felled in recent years. These differences in land use are correlated with differences in discharge regime, water temperature and water quality (Hudson *et al.* 1997*a*, *b*; Neal *et al.* 1997*a–d*).

Table 1. Monthly and annual mean water temperatures (°C) in 1993 and 1994 in the clear-felled Hore at Nat. Grid. ref. SN/845872 and the forested Hafren at Nat. Grid ref. SN/843877.

	1993		1994	
Month	Hore 1	Hafren 3	Hore 1	Hafren 3
January	4.6	4.5	4.5	4.4
February	4.6	4.4	3.2	3.1
March	4.9	4.6	5.1	5.0
April	7.1	6.7	5.7	5.4
May	8.9	8.2	8.3	7.7
June	11.7	10.7	10.6	9.8
July	11.9	11.1	14.0	12.7
August	10.8	10.2	12.2	11.6
September	9.8	9.3	9.6	9.3
October	6.7	6.6	8.0	7.7
November	4.6	4.6	8.1	7.9
December	4.9	4.7	6.6	6.1
Mean	7.54	.13	7.99	7.56

Fish Populations

DISTRIBUTION, POPULATION DENSITY AND BIOMASS

Only the brown trout (*Salmo trutta* L.) has been found in both streams. In July 1979 trout were seen or caught at six out of seven sampling stations in the Wye. Estimated population density at sites where trout were caught varied from 0.03 to 0.32 trout m^{-1} and biomass from 1.0 to 5.6 g m^{-2}. In the Severn, ten stations were electrofished in June 1979 but trout were found in only one, just downstream of Blaenhafren Falls, at an estimated population density of 0.05 fish m^{-2} and a biomass of c. 3.1 g m^{-2}.

Studies in later years were concentrated mainly on the trout population in the Hafren. Trout were found regularly in a 556 m length of stream (c. 1670 m^2) between SN/843877 (altitude c. 366 m.O.D.) and SN/836884 (altitude c. 427 m.O.D.) at population densities of 0.03 to 0.24 m^{-2} (mean = 0.12 fish m^{-2}).

Despite the fact that the Hore catchment was clear felled between 1985 and 1987, no fish were seen in the Hore during thrice yearly electrofishing of four stations from 1984 to 1993.

AGE, GROWTH AND WATER TEMPERATURE

Ages were determined by scale reading. The growth of trout in the upper Wye can be described by the equation $L_{t+1} = L_\infty (1 - k) + kL_t$ (Walford, 1946) when k is a constant, L_t is length at time t (years), L_{t+1} is length at time t + 1 (years) and L_∞ is the mean asymptotic length. For the upper Wye $L_\infty = 21.5$ cm and $k = 0.71$. Given that the mean length of trout aged 1 year in the upper Wye is 7.1 ± 0.29 cm (95% C. L.), the above equation can be used to estimate lengths at subsequent ages. The value of L_∞ is usually an inherent property of a given population, whereas the value of k is an indication of growth rate (higher values of k indicate lower growth rates, and vice-versa) and varies with such factors as temperature and food supply. The trout of Trout Beck, a Pennine stream at higher altitude than the upper Wye, have the same L_∞ (21.5 cm) but a lower growth rate (k = 0.82) than those of the upper Wye (k = 0.71) (Crisp *et al.*, 1975). The rather sparse data from the Hafren suggest that growth there is similar to, but a little more rapid than, that in the Wye. This is reasonable because trout growth rate may be inversely related to population density at low population densities (Crisp, 1993).

Trout in the Hafren have a mean length of c. 8.2 cm and weight of 6.0 gm at 1 year of age (Crisp & Beaumont, 1996). Mean weights on maximum rations can be predicted from 1 January to 31 December in each of the years 1993 and 1994 at each site, (Table 2) using monthly mean temperatures from Table 1 and the ready-reckoner from Crisp (1992). Zero growth has been assumed in those months when mean water temperature was less than 3.8°C. The predictions suggest that the depression of temperature at Hafren 3, relative to Hore 1, would give a reduction of c. 14% in 1993 and c. 9% in 1994 in predicted weight at 31 December and reductions in mean instantaneous growth rates between 5% and 10%.

These predictions are theoretical because there are no trout in the Hore and predictions of their growth are, therefore, quite hypothetical. In addition, the growth rates predicted in Table 2 are the maximum possible for fish in the presence of excess food. The observed growth rate of

Table 2. Predicted weight (g) at the end of each month in 1993 and 1994 of a trout that had a weight of 6.0 g (8.2 cm length) on 1 January of each year at Hore 1 and Hafren 3.

Month	1993 Weight at end of month (g) Hore 1	 Hafren 3	1994 Weight at end of month (g) Hore 1	 Hafren 3
January	6.4	6.3	6.3	6.3
February	6.7	6.6	6.3	6.3
March	7.2	7.0	6.9	6.8
April	8.5	8.1	7.6	7.4
May	10.8	10.1	9.5	9.1
June	15.1	13.6	12.9	11.9
July	20.7	18.1	18.1	17.3
August	26.5	23.0	24.6	23.1
September	32.0	27.6	29.7	27.7
October	35.2	30.4	34.1	31.6
November	36.3	31.4	38.7	35.8
December	37.8	32.6	42.2	38.6
Mean instantaneous growth rate day^{-1}	0.00504	0.00464	0.00535	0.00510

Hafren trout is from 8.2 cm length (c. 6.0 g weight) at age 1 to 12.8 cm length (c. 23.3 g weight) at age 2. This corresponds to a mean instantaneous growth rate of 0.00371 day^{-1} which is 70 to 80% of the values predicted in Table 2. This is consistent with the results of an analysis of trout growth and temperatures in a range of UK streams and rivers (Edwards, Densem & Russell, 1979); they concluded that observed mean growth rates were between 60 and 90% of those predicted on maximum rations. This discrepancy between predicted and observed rates can be accounted for, in part at least, by 'hidden' growth which includes making good wear and tear (regrowth of fins and scales damaged in, for example, spates) and the shedding of gonad products by sexually mature trout.

Free-swimming trout have an optimum temperature range of 4 to 19°C. Between 0 and 4°C trout survive but feeding and growth may be negligible. The upper critical range for trout is 19 to 30°C. Within this range the fish cease feeding, show signs of distress and may die. However, these ranges can be only an approximate guide because the exact values may depend upon acclimation temperatures. In addition, the precise value of the upper lethal limit rises with fish age/size (Spaas, 1960). Over the four years 1991, 1992, 1993 and 1994, there were no days on which the daily maximum water temperature at Hafren 3 reached 19.0°C. In contrast, at Hore 1, daily maximum equalled or exceeded 19.0° on one or two days in each of the first three years and on ten days during July 1994. The highest daily maximum recorded at Hore 1 was 20.1°C. However, in none of these years did any daily mean reach 19.0°C. Therefore, even in Hore 1, temperature entered the upper critical range comparatively rarely and briefly and usually during periods of sustained warm weather that were likely to facilitate acclimation.

AGE COMPOSITION, REPRODUCTION, WATER TEMPERATURE AND DISCHARGE

The age frequency distribution of the sample of trout examined in the Wye in June 1979 indicates a relatively reliable level of recruitment in all or most years. In contrast, the June 1979 sample of 5 trout from the Hafren contained only fish from the 1974 and 1976 year classes. A further sample of 9 trout in September 1985 contained 7 from the 1984 year class and two from older age groups. The lengthier frequency distributions of later samples support the suggestion that appreciable recruitment in the Hafren occurred only at irregular intervals.

Trout eggs are deposited in gravel beds. Several stages can be recognised readily and the time of their occurrence can be predicted.

1. Oviposition date is influenced largely by day length rather than temperature (Bye, 1984). It usually occurs in autumn and, for present purposes, is assumed to occur on 1 November in the Plynlimon streams.
2. 'Eyeing' is the stage at which the eyes of the embryo become clearly visible through the eggshell. It is also the stage at which the embryo's sensitivity to mechanical shock greatly reduces.
3. 'Hatching' is the emergence of the 'alevin' from the egg. The alevin then remains in the gravel and subsists on its yolk sac.
4. 'Swim-up' occurs when the yolk sac is almost exhausted. The alevin emerges from the gravel, swallows an air bubble to fill its swim bladder and gain neutral buoyancy, and begins to take external foods.

Table 3 shows predicted dates at the two sites. It is apparent that the winter differences in temperature regime between the two sites are very small and have a negligible effect on the predicted development of the intragravel stages of the trout.

Table 3. Predicted dates of median eyeing, hatching and 'swim-up' for trout eggs laid on 1 November 1993.

	Hore (clear-felled)	Hafren (forested)
Median eyeing	18 December 1993	19 December 1993
Median hatch	6 February 1994	8 February 1994
Median 'swim-up'	6 May 1994	9 May 1994

Trout eggs survive at temperatures between <0°C and 15.5°C, though survival is less than 50% when temperature exceeds 12.0°C (Crisp, 1996). Throughout the incubation period (November to May) temperatures were well below 12°C at both stream sites. Therefore, the survival of intragravel stages is unlikely to be affected directly by extreme temperatures.

It is possible to compare the occurrence of known years of good recruitment in the Hafren with the hydrological record. Daily mean discharge data for the Hafren at Nat. Grid ref. SN/843877 are available from 1976 to 1995 and values for 1973 to 1975 can be estimated from values at the Severn trapezoidal flume (Nat. grid ref. SN/853872) by means of a linear regression ($r^2 = 0.98$). These have been consolidated as monthly means. As concentrations of both hydrogen ions and inorganic aluminium appear to vary with streamflow throughout the observed range of streamflows in the Plynlimon streams (Neal *et al.*, 1989), it is not at present possible to assess the relationship between discharge and recruitment in terms of some threshold discharge above which measurable effects on salmonids might be expected. Instead, it is necessary to consider mean discharge during three different periods subjectively selected as being of possible importance in the early life of trout. These are:

(a) 'The first year of life' from 1 November (assumed oviposition date) of one year to 31 October of the following year. This period corresponds, approximately, to the period of incubation and most of the first growing season.

(b) 'The first full calendar year of life' from 1 January to 31 December. This includes the latter part of the incubation period and the first seven or eight months of free-swimming life.

(c) 'The first summer' (1 April to 30 September). This comprises the last month of incubation and most of the first growing season.

Table 4 shows mean discharges (m^3s^{-1}) during each of these periods in each year, together with long term (22 or 23 year) averages and their 95% confidence limits. Values of the Coefficient of Variation of discharge with time (CV_t%) are also shown. $CV_t\% = 100s/q$, when s = standard deviation and q = mean discharge. Note that the value of CV_t% is much higher (c. 40%) for the first summer than for the first year or the first full calendar year of life (c. 15%). The observed good trout recruitment in the 1976 and 1984 year classes corresponded to occasions when mean discharge in the first year of life was less than 90% of the long term mean and discharge in the first summer was less than 50% of the long term mean. In these years of low mean discharge, the incidence of episodes of low pH and high hydrogen ion and inorganic aluminium concentration would be expected to be correspondingly low. Washout of intragravel stages would also be low during winters of low discharge. Hence, in such years, survival of 0 group trout would also be good. By the same token, good recruitment might be expected in the 1989 and, possibly, the 1995 year classes, though field data to verify this are lacking. However, the 1974 year class was also a strong one, despite the fact that the present analysis

Table 4. Mean yearly discharges (m^3s^{-1}) for various periods of the year expressed as percentages of the long term mean values. Long term mean values, together with 95% confidence limits and values of percentage coefficient of variation with time (CV_t%) are also shown.

Year class	Mean discharge for year as a percentage of 1973 to 1995 mean.		
	First year of life (1 Nov to 31 Oct)	First calendar year (1 Jan to 31 Dec)	First summer (1 Apr to 30 Sep)
1973	—	96	117
1974*	103	110	115
1975	87	79+	80
1976*	69+	61+	43++
1977	90	105	109
1978	96	96	102
1979	101	110	116
1980	107	105	87
1981	122	110	80
1982	96	110	117
1983	106	96	81
1984*	78+	83+	43++
1985	100	96	168
1986	90	110	95
1987	112	92	95
1988	110	105	131
1989	84+	92	50++
1990	97	101	68
1991	96	96	99
1992	133	140	228
1993	94	96	117
1994	128	127	110
1995	104	83+	47++
Mean discharge (m^3s^{-1})	0.229 ± 0.015	0.228 ± 0.015	0.144 ± 0.025
± 95% C.L.			
CV_t%	15.1	15.9	41.5

* = year classes when trout recruitment is known to have been good; + = year classes for which mean discharge was less than 90% of the long term mean; ++ = year classes for which discharge was 50% or less of

does not suggest a favourable hydrological regime for that year class.

Therefore, the present evidence suggests, but does not prove, that the occurrence of strong year classes of trout in the Hafren population may be related to hydrological regime but that the mechanisms in play are too complex to be accommodated fully by the present simplistic analysis.

Discussion

CONIFEROUS AFFORESTATION AND SALMONID FISH POPULATIONS

Various workers in Europe and N. America have postulated a relationship between coniferous forestry activity and declining stocks of trout and salmon. For example, Egglishaw *et al.*, (1986) found a statistically significant relationship between the decline in the recorded catch of adult Atlantic salmon (*Salmo salar* L.) and the relative amounts of coniferous forest in different upland areas of Scotland where salmon nursery streams occur. There were, however, insufficient data on water quality to establish a causal relationship. There are many ways in which coniferous forest and the associated husbandry practices can influence the biology of salmonid fishes and these were reviewed by Egglishaw (1985). In practice, many of the measures proposed to ameliorate the effects of coniferous forest on salmonids are based on the selection by a given advisor or consultant of a factor or factors that he considers, subjectively, to be most relevant. This can lead to the use of remedies that may work but that may also be costly beyond the real need. Rational solution or amelioration of these problems is unlikely to be possible until there is:-

(a) A sound quantitative knowledge of the effects of coniferous forestry upon the physical, chemical and biotic environment of salmonid fishes.
(b) Quantitative knowledge of the mechanisms by which forestry modifies those variables and by which, in turn, modification of those variables affects the fish.
(c) A clear assessment, in any given context, of the relative importance of the different mechanisms that have been identified and of the life stages of salmonids upon which they exert most influence.

Progress towards the substantial acquisition of such information depends upon continuation of studies on the effects of land use on catchment hydrology (with attention to water quality as well as quantity), further development of relevant studies in fish ecology and closer integration of these two lines of research. There is also a need for more detailed analysis and collation of existing information. Much information on environmental requirements of fish has been summarized in two recent reviews (Crisp, 1996; Mann, 1996).

Within this general framework, possible reasons for the marked observed differences between the trout populations of the two Plynlimon catchments are listed in Table 5.

Differences in angling mortality could, in theory, give rise to different trout populations between otherwise similar stream systems. However, angling activity in the upper parts of both Wye and Severn is negligible and its effects on fish populations can be disregarded.

There is some evidence (Crisp, 1993) that some headstream trout populations might be extinguished if recolonization from downstream were to be prevented by natural or man-made barriers. The Institute of Hydrology weirs/flumes in each catchment are probably not a serious barrier, at least to the upstream movement of larger trout, and there is no clear reason why the weirs/flumes in the Severn should have a more severe effect than those in the Wye.

In the Severn catchment, there is an old lead mine beside the Afon Hore. In the Wye catchment there are disused lead mines beside the Afon Cyff, the Nant Iago and in the Gwy below the confluence of the Nant Iago.

Table 5. Summary of human activities (past or present) in the Plynlimon catchments and of consequent effects that might influence salmonid fish populations.

Human activity	Consequent effects that might impinge upon salmonid fishes.
Fishing	Overfishing could reduce stocks.
Obstacles (weirs, flumes)	Prevent or reduce freedom of fish movement and hence limit spawning and dispersal.
Mining	Old adits and/or spoil heaps may release toxic materials over many years.
Land use change	Changes in:
	Total run-off
	Temporal pattern of run-off
	Movement of large bed material
	Suspended fine solids
	Deposition of fine solids
	Water temperature
	Various chemical effects
	Vegetation cover

Information on heavy metal concentrations in the Plynlimon streams is patchy and is based mainly upon a survey by the Welsh National Rivers Authority in 1976, geochemical mapping (Ball & Nutt, 1976) and water samples taken by the Freshwater Biological Association in 1979. The general pattern that emerges is that biological problems from toxic metals (zinc, lead, cadmium, copper) are more likely in the upper Wye than in the upper Severn though they are more likely to be exacerbated by low pH episodes in the Severn. As the trout population of the upper Wye appears to be healthy, it is reasonable to assume that the sparse and limited population in the Severn is not primarily a result of past mining activity, especially as the Hore mine would not be a direct cause of the absence of trout from the Hafren upstream of Blaenhafren Falls.

There is, therefore, no clear evidence that angling, hydrological structures or past mining have had a major lasting influence on the Plynlimon trout populations. The evidence, if anything, indicates the contrary. The observed differences are, therefore, likely to lie in the present and past forms of land use of the two catchments.

Land use change can lead, via changes in vegetation cover and/or changes in land drainage, to changed total run-off and modified temporal pattern of flow fluctuation. Direct consequences of this are changes in water velocity and wetted area and in their temporal patterns of fluctuation (Milner *et al.*, 1981). In addition, changes in flow patterns and land drainage can modify catchment soil erosion rates, frequency of bed scour, concentrations of fine suspended solids and patterns of deposition of fine silt. In general, afforestation decreases total run-off but, through the influence of forest drains and more rapid run-off, leads to increases in soil erosion, turbidity and bed scour. These consequences are generally harmful to salmonid fishes, especially to the intragravel stages (Crisp, 1989). Water temperature regime is also modified by the presence of coniferous forest. These modifications of temperature regime may modify the rate of incubation of trout eggs and the growth of free-swimming trout.

Assuming that the observed temperature differences between Hore 1 and Hafren 3 reflect the absence of forest at the former and its presence in the latter, then the present analysis gives no reason to believe that afforestation threatens the survival of salmonid fishes through direct effects of water temperature. Temperature differences between the two sites are very small during the trout incubation period and temperature effects on survival or incubation rate are similar at the two sites. High temperature extremes during the summer months are more common at Hore 1 than at Hafren 3 and, therefore, high temperature stress of trout is less probable in the afforested than in the unafforested stream, though death from this cause is unlikely even in the latter. Depression of summer water temperatures in the afforested stream will give appreciably lower potential growth rates than in the unafforested stream but this is not likely to have much bearing upon the survival of the species. These findings are similar to those reached by Weatherley & Ormerod (1990) in the headstreams of the River Tywi.

Direct effects upon fish are possible from the pesticides and fertilisers used in forestry and also from the solvents, carriers and additives with which they are used. Huet (1951) suggested that spruce trees may produce a toxin which can affect freshwater organisms. It has become apparent in recent years that, in streams whose water is poorly buffered, coniferous forest can exacerbate the effects of 'acid rain' and lead to episodes of low pH (usually during high flow). Values of pH below 4.5 can be directly harmful to various stages of salmonids (Carrick, 1979; McWilliam, 1982; Waiwood & Haya, 1983) but pHs above 4.5 can be lethal when associated with high concentrations of aluminium in its labile, monomeric form (Brown, 1983) or some heavy metals. An unpublished report by three NERC Institutes (see Crisp & Beaumont, 1996, Table 2) showed that, during baseflow, the pH, hydrogen ion concentration and aluminium concentration were similar in parts of the upper Severn (Hore & Hafren) and in parts of the upper Wye (Cyff & Gwy). However, during stormflow, pHs were lower at 4.4 and 4.5 (c.f. 4.8 and 5.2), hydrogen ion concentrations (μ equiv l^{-1}) were higher at 30 and 37 (cf. 7 and 18) and aluminium concentrations (mg l^{-1}) were much higher at 0.43 and 0.49 (c.f. 0.03 and 0.1) in the Hore and Hafren than in the Cyff and Gwy.

Stream animals have four main sources of food:

(a) Plant material (chiefly algae in upland streams) produced in the stream.
(b) Plant material and debris that falls into the stream.
(c) Other animals produced in the stream.
(d) Other animals produced on the land that fall or are washed into the stream.

All of these can be changed in both quantity and quality by changes in streamside vegetation. The shading effect of coniferous trees is likely to reduce algal production in the stream and may alter algal species composition. This may, in turn, modify the production and/or the species composition of the stream invertebrates. Thus, reduced light input is likely to reduce algal production and this will reduce the numbers of algal-feeding invertebrate groups, particularly Ephemeroptera. In most upland stream ecosystems, a large proportion of production is based on allochthonous inputs. Terrestrial casualties can contribute a substantial fraction of the diet of trout in upland streams (Crisp *et al.*, 1978). Changes in streamside vegetation will give rise to changes in both the quality and quantity of the input of allochthonous vegetation and animals. Quantitative knowledge of these mechanisms and of consequent effects on fish populations is limited. Any effects are, however, more likely to influence growth than fish species survival.

Therefore, of the mechanisms that could be inimical to the survival of trout within the upper Hafren the most important may well be the occurrence of acid episodes accompanied by high concentrations of monomeric aluminium. This alone might explain the absence of trout from most of the Hafren, though the hydrological effects of afforestation (changed patterns of flow, bed scour, suspended fines and silt deposition) could also contribute and might prove to be limiting should it be possible to eliminate the 'acid rain' effect.

THE 'RELICT' TROUT POPULATION IN THE UPPER SEVERN SYSTEM

The above arguments present a reasonable, though not conclusive, case for the absence of trout from the upper Severn system. Such absence appears to have been assumed in the past by the National Rivers Authority (upstream limit of brown trout at Geufron, Nat. Grid ref. SN/882855). A UK Acid Waters Monitoring Site at Nat. Grid ref. SN/882855 (ENSIS, 1990) was downstream of the detected downstream limit (SN/843877) of the 'relict' population. The existence of this trout population, despite the presence of coniferous forest for c. 30 to 58 years and, probably, an acidification problem for an appreciable part of that period, appears anomalous and demands explanation. Several hypotheses can be advanced:

(a) That this is a truly 'relict' population and that it is an 'acid tolerant' strain of brown trout. If so, why is this strain not more widespread in the upper Severn system (see b below).

(b) That this is a truly 'relict' population but not necessarily an acid tolerant strain. It is possible that, as a result of groundwater inputs, the water in that portion of the Hafren inhabited by these trout is better buffered than has been supposed. Borehole studies give some support to this view (Neal *et al.*, 1997*a–d*). However, water temperature data suggest appreciable inputs of groundwater above Blaenhafren Falls (Neal, *et al.*, 1997*a*; Hill and Neal, 1997) though there are no trout above them. These falls may not be passable in an upstream direction by the small trout of the upper Hafren. Should this be true, then extinction of the isolated population upstream of the falls as a result of a series of bad years is possible. Examples of this occur in the N. Pennines (Crisp, 1993). If this hypothesis is accepted, then the survival of the small and apparently isolated population downstream of the falls is rather surprising.

(c) That this is simply a sub-population of the trout stocks present below Geufron and that it is augmented, from time to time, through incursions of spawners from downstream. However, such spawning visits would be likely to occur during autumn spates at times when high acidity might be expected.

It is important to note that these three hypotheses are not mutually exclusive and that the true explanation might involve interactions of two or more of them. The presence of 0 group and I group trout in some years suggests that some, at least, of the recruitment arises from spawning within the study reach and the available data suggest, but do not prove, that recruitment may be most successful in dry years when the occurrence of high acidity would be less frequent. A modest, but carefully designed, multidisciplinary research project would be needed to investigate these questions.

CLEAR FELLING OF THE AFON HORE CATCHMENT

Clear felling of the Hore catchment between 1985 and 1987 did not lead to any recolonisation by brown trout, at least up to 1994. It is possible that this simply reflects failure of trout from downstream to move into the Hore. There is evidence of some recovery of elements of the stream invertebrate fauna (see 000–000 of this volume). However, in the two years after felling there was actually an increase in water acidity, followed by a return to pre-felling values (Neal *et al.*, 1992; Neal *et al.*, 1994 and see pp 000–000 of this volume). It is, therefore, unlikely that trout would survive in the Hore even if they were introduced, at least until there had been some improvement in the water quality.

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