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# Water temperature of Plynlimon streams

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## Abstract

Water temperature data were collected from five stations in the upper Severn system. Temperatures were compared between a stream with a 335 ha catchment after it had flowed for c. 1.5 km through clear felled land and a stream with a 347 ha catchment after it had flowed for c. 2.5 km through coniferous forest. The results suggest that the effect of forest cover was to lower the annual mean water temperature by c. 0.4°C, mainly in summer and through depression of both daily maxima and daily minima, though mainly the former. There was no clear evidence of temperature elevation in the afforested stream in winter.

It is important to note that these conclusions depend on several assumptions that cannot be substantiated objectively. There is some evidence that water temperatures in some parts of the upper Severn system may be influenced by groundwater inputs.

## Introduction

Changes in upland land use, such as impoundment, afforestation and deforestation, can effect stream water temperature. Most previous studies on the effects of coniferous forest on stream water temperatures have been made in N. America where the scale of operations and the nature of the rivers are different from those of the UK. The general effect of forest is to damp the water temperature fluctuations so that diurnal and annual fluctuations are smaller in afforested than in unafforested streams. However, there are some differences between studies in the amount of damping observed and in the manner in which it appears to operate. Gorman & Moring (1991) quoting Moring (1975), Corbett *et al.* (1978), Rishel *et al.*, (1982) and Lynch *et al.*, (1984) found that the main effects of deforestation were increases in daily maxima and, consequently, in diel fluctuations. Some studies (Corbett *et al.*, 1978) also showed an increase in daily minima but others (e.g. Feller, 1981) did not.

There have been three relevant studies within the UK. Roberts & James (1972) compared the upper Wye and upper Severn catchments as examples of unafforested and afforested catchments. They made 'spot' temperature recordings at weekly intervals and concluded that summer temperatures were up to 2.4°C higher in the Wye than in the Severn, whereas in winter the Severn was up to 0.6°C warmer than the Wye. The numerical aspects of these findings must be taken with caution because they are based on relatively infrequent recordings. Smith (1980) compared water temperatures in afforested and unafforested reaches in Kirk Burn, a tributary of the River Tweed (Scotland). No quantitative data were presented but the general conclusion was that shading by conifers reduced diel and seasonal fluctuations and the water was relatively cooler in summer and warmer in winter. Weatherley and Ormerod (1990) compared temperatures between several afforested and unafforested sub-catchments of the River Tywi (Wales). They concluded that, in general, forests caused lower mean and maximum summer temperatures in streams flowing through them.

The present study compared temperatures in the clear felled Hore catchment and in the afforested Hafren catchment. Where appropriate, the results have been compared with those of Weatherley & Ormerod (1990).

## Study Areas and Sites

Water temperature was recorded in two sub-catchments of the upper Severn (Fig. 1). Stations Hore 1 and Hore 2 were on the clear felled Afon Hore. Stations Hafren 3, 4A, 4B were on the afforested Afon Hafren.

Air temperature data from the meteorological station at Clywedog Reservoir, sited well clear of trees, have been used for comparison with the water temperature data. A summary of water and air temperature records is given in Table 1.

The Hore catchment at Hore 1 has an area of 335 ha and the whole of the catchment between Hore 1 and Hore 2 (c.1.5 km of stream length) was clear felled between 1985 and 1989. Upstream of Hore 2 there is c. 1.7 km of stream that is still partly afforested. However, trees are absent or scarce over most of the SW bank of the stream for 0.8 km

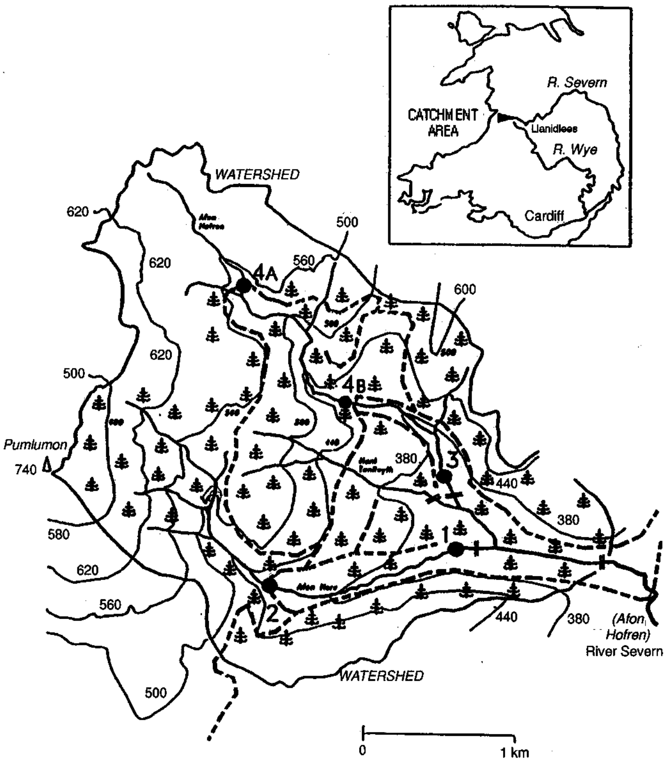


Fig. 1. *The upper Severn catchment, based on a site map from the N.E.R.C. Institute of Hydrology to show the positions of the temperature recording stations. Contours are in m.O.D., double dashed lines represent forest roads and the symbol ‖ shows the positions of flumes. The tree symbols indicate forest*

upstream of Hore 2 so that the effects of the trees on temperature at Hore 2 will probably be minimal.

The Hafren at Hafren 3 has a catchment of 347 ha and is 50% afforested. However, the lower part of the catchment between Hafren 3 and Hafren 4B is nearly 100% afforested. Above Hafren 4A there is c. 0.8 km of stream that flows through forest. There is a further c. 2.2 km of afforested stream between Hafren 3 and Hafren 4A. During the early part of the study, it became clear that temperature patterns of Hafren 4A were anomalous and the instrument was moved to Hafren 4B, situated approximately halfway between Hafren 3 and Hafren 4A (Fig. 1) and at an altitude similar to that of Hore 2.

## Equipment and Methods

Daily mean temperature at Clywedog Reservoir was estimated as the mid-point between recorded daily maximum and minimum.

Water temperatures were recorded at hourly intervals by Grant 'Squirrel' loggers (type SQ 32–2U/2V–1D) equipped with thermistor probes. At intervals of 3 to 6 months each logger was downloaded to a 'Husky Hunter 2' field computer and was supplied with a new battery. The data from the 'Hunter' were later transferred to a desk-top computer for storage. Soft-ware was developed to give a print-out of daily maximum, minimum and mean, in addition to the raw (hourly) data points. During December 1991 and January 1992 (Table 1) all logger-probe combinations were laboratory tested over the temperature range 2 to 20°C by means of a Hewlett Packard precision quartz thermometer with resolution of 0.0001°C and accurate to ± 0.01°C. The logger-probe combinations were accurate to within ± 0.1°C. The variability of the results arose mainly from the fact that each individual logger-probe combination had a constant zero error within ± 0.1°C of the true value. Corrections for zero error were then made to all data.

The management of the water temperature recording equipment and the processing of the data followed Crisp (1992). For the purpose of summarising the data, each day was taken as running from 0900 h GMT on that day to 0900 h GMT on the following day. This gave comparability between meteorological and hydrological data.

The recording stations were first set up in June 1990. By January 1991 various 'teething' problems had been overcome and, apart from a break for calibration checks in December 1991 and January 1992, unbroken records were obtained up to December 1994 from the instruments at Hore 1 and Hafren 3. The Hafren 4A instrument was resited at Hafren 4B in January 1992 and the Hore 2 and Hafren 4B stations were closed at the end of October 1993.

*Table 1.* Summary of recording stations and of the duration and completeness of records. Note that from December 1991 to January 1992 the instruments and their probes were removed from their sites for laboratory checks on their accuracy.

| Station | Altitude (mOD) | National Grid Reference | Duration of Records | Major Gaps |
|---|---|---|---|---|
| Hore 1 | 350 | SN/845872 | August 1990–December 1994 | December 1991–January 1992 |
| Hafren 3 | 364 | SN/843877 | October 1990–December 1994 | December 1991–January 1992 |
| Hore 2 | 413 | SN/831869 | July 1990–October 1993 | December 1991–January 1992 |
| Hafren 4A | 548 | SN/829891 | August 1990–November 1991 | — |
| Hafren 4B | 427 | SN/836884 | February 1992–October 1993 | — |
| Clywedog Met Station | 345 | SN/912870 | March 1983–December 1994 | — |

## Results

1. A summary of monthly means of daily means, daily maxima, daily minima and daily ranges from July 1990 to December 1994, inclusive, is given in Appendix I.

2. Comparisons within the Hore.

A plot of monthly means at Hore 1 and Hore 2 (Fig. 2) shows a similar pattern at both stations but with temperatures lower at Hore 2 than at Hore 1, especially during the warmer part of the year. Similarly, monthly means of daily maxima and minima were always higher at Hore 1 than at Hore 2. The mean annual temperature difference between the two stations was c. 0.5°C (i.e. c. 0.75°C per 100 m of altitude) and this is reasonably close to the adiabatic lapse rate in air temperature of c. 0.6°C per 100 m of altitude (Whittow, 1984). Daily range was also smaller at Hore 2 than at Hore 1 but by an average of less than 0.1°C.

The data, therefore, suggest that temperature differences between the two Hore stations were predominantly a reflection of altitudinal differences and, for comparison with data from Hafren 3, temperatures at Hore 1 were taken as typical of this unafforested stream.

3. Comparisons within the Hafren.

Temperatures at Hafren 4A were lower in summer and higher in winter than those at Hafren 3 (Fig. 3). These differences mainly reflect lower summer maxima and higher winter minima at Hafren 4A, though the mean temperature difference between the two stations over a full year was only 0.3°C. The small annual amplitude of the annual temperature cycle at Hafren 4A relative to that at Hafren 3 was not expected. The upper reaches of the Hafren flow through open moorland and only enter the forest 0.8 km upstream of Hafren 4A so that, if anything, a larger amplitude would be expected at Hafren 4A than at Hafren 3. The marked equability of the annual fluctuation at Hafren 4A as compared with all other stations (see also next section) is peculiar and suggests a substantial input of groundwater, or some other damping effect at or somewhere upstream of Hafren 4A.

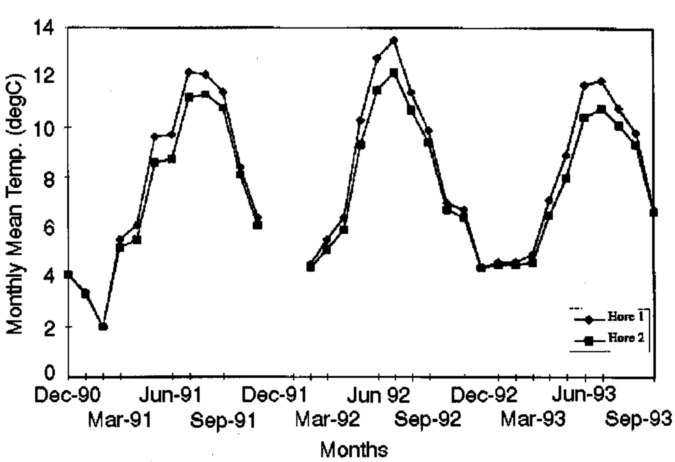


Fig. 2. *Comparison of monthly mean water temperatures (°C) between Hore 1 (♦) and Hore 2 (■) for the period December 1990 to October 1993.*

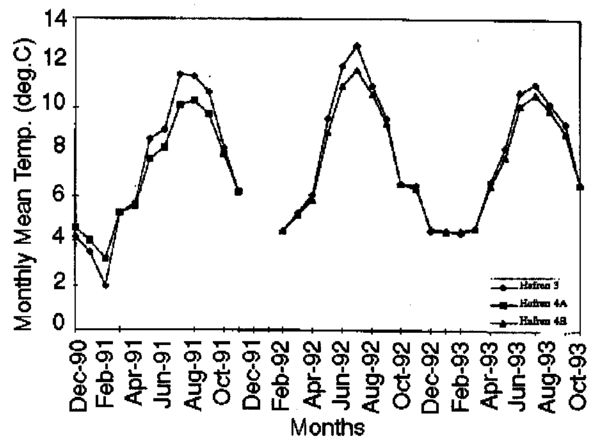


Fig. 3. *Comparisons of monthly mean water temperatures (°C) between Hafren 3 (♦) and (A) Hafren 4A (■) from December 1990 to November 1991 and (B) Hafren 4B (▲) from February 1992 to October 1993.*

In contrast, temperatures at Hafren 4B were below or equal to those at Hafren 3 throughout the year (Fig. 3B). This pattern is similar to that shown by the two Hore stations (c.f. Figs 2 and 3B) and is consistent with the hypothesis that, by the time the water has reached Hafren 4B, temperature effects of any upstream groundwater inputs have been lost so that the temperature differences between Hafren 4B and Hafren 3 represent mainly altitudinal effects and imply a lapse rate of c. 0.47°C per 100 m of altitude. It is not at present practicable to test this hypothesis.

4. Comparisons between air and water temperatures.

There is usually a good correlation between air and water temperatures, even when the air and water temperature recording stations are several tens of km apart (Crisp & Howson, 1982). A summary of calculated regressions relating monthly mean water temperature at the Hore and Hafren stations to monthly mean air temperature at Clywedog reservoir is shown in Table 2. A similar set of regressions was calculated (Crisp, 1988) for a number of streams and rivers in northern England. In most of these streams the gradient (b) approximated 1.0 (0.8 to 1.2) and the values of the intercept (a) were positive and variable. A major influence upon values of 'a' was likely to be the difference in air temperature between the meteorological station and the various stream sites. Exceptions to this general pattern were sites in predominantly spring fed streams close to the spring sources and impounded rivers close to the points of release. At such sites values of 'b' were low (0.5 to 0.8). The values of 0.5 to 0.7 in the present study may, therefore, imply that there are appreciable

*Table 2.* Summary of calculated regressions of the form y = bx + a, where y is monthly mean water temperature, x is daily mean air temperature at Clywedog Reservoir and a and b are constants.

| Period | Water Temperature Station | n | a ± 95% CL | b ± 95% CL | $r^2$ | P |
|---|---|---|---|---|---|---|
| December 1990–November 1991 | Hore 1 | 12 | 2.2389 ± 0.6528 | 0.7310 ± 0.0761 | 0.97 | <0.001 |
| December 1990–November 1991 | Hore 2 | 12 | 2.3393 ± 0.5678 | 0.6647 ± 0.0662 | 0.97 | <0.001 |
| December 1990–November 1991 | Hafren 3 | 12 | 2.2486 ± 0.6618 | 0.6611 ± 0.0771 | 0.97 | <0.001 |
| December 1990–November 1991 | Hafren 4A | 12 | 3.2076 ± 0.5506 | 0.5058 ± 0.0642 | 0.97 | <0.001 |
| February 1992–January 1993 | Hafren 3 | 12 | 1.8617 ± 0.7184 | 0.7114 ± 0.0782 | 0.97 | <0.001 |
| February 1992–January 1993 | Hafren 4B | 12 | 2.2431 ± 0.6936 | 0.6298 ± 0.0755 | 0.96 | <0.001 |

inputs of groundwater throughout the upper Severn system. However, the Hafren 4A station stood out from all the other upper Severn stations by reason of its very low value of 'b' and its relatively high value of 'a'. For the period December 1990 to November 1991, values of 'a' and 'b' from Table 2 were compared by means of a 'd' test. The results (Table 3) showed that values of both 'a' and 'b' at Hafren 4A differed significantly (P<0.05) from the values at Hafren 3 and at the two Hore stations. There were no other significant differences. Similar tests showed no significant differences between the 1990 to 1991 and the 1992 to 1993 regressions for Hafren 3 and between Hafren 3 and Hafren 4B during 1992 to 1993.

5. Comparisons between Hore 1 and Hafren 3.

Differences between monthly means of daily maximum, daily minimum and mean (Fig. 4) imply that daily means were depressed by an average of c. 0.4°C at Hafren 3 relative to Hore 1. In summer months the mean difference was c. 1.0°C, whereas in winter the difference was smaller, sometimes zero and was generally small relative to the accuracy (± 0.1°C) of the recording equipment. The depressed mean temperature in Hafren 3, relative to Hore 1, reflected depressed maximum and minimum, but chiefly the former. There is no evidence in Fig. 4 of elevated winter temperatures in Hafren 3 relative to Hore 1. There were indications of such elevation in earlier years (Crisp & Beaumont, 1996), though generally by c. 0.1°C or less.

*Table 3.* Probability values, based on a 'd' test, for the significance of differences in values of 'a' and 'b' between different regressions in Table 2 for the period December 1990 to January 1991.

| | Hore 1 | Hafren 3 | Hafren 4A |
|---|---|---|---|
| Values of 'a' | | | |
| Hore 1 | >0.10 | >0.10 | <0.02 |
| Hore 2 | — | >0.10 | <0.01 |
| Hafren 3 | — | — | <0.01 |
| Values of 'b' | | | |
| Hore 1 | >0.10 | >0.10 | <0.001 |
| Hore 2 | — | >0.10 | <0.001 |
| Hafren 3 | — | — | <0.002 |

## Discussion

There are several different general approaches to the task of obtaining information to assess the influence of afforestation upon water temperatures. First, it is possible

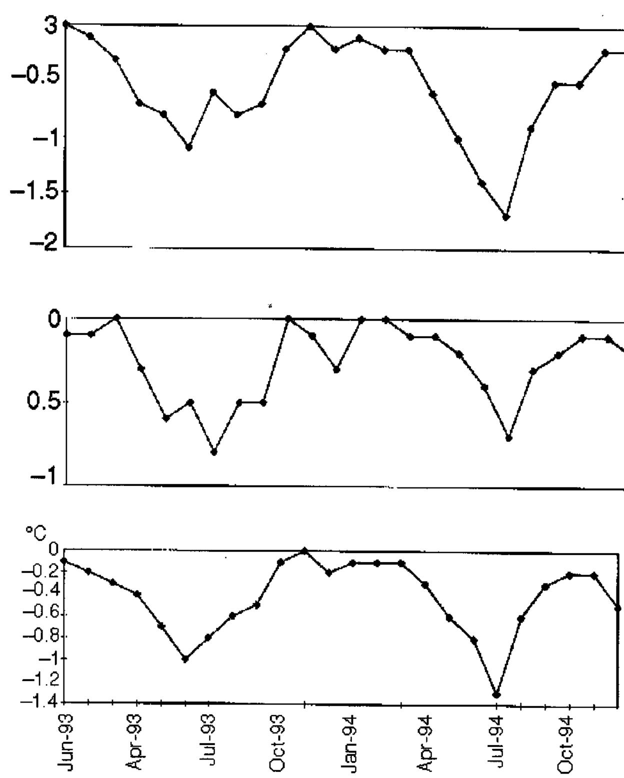


Fig. 4. *Monthly means of daily maximum (A), minimum (B) and mean (C) water temperature at Hafren 3 after subtraction from corresponding values at Hore 1. The values are assumed to be measures of the effects of forest cover.*

to compare temperatures between afforested and unafforested reaches of the same stream (e.g. Smith, 1980). These comparisons are open to the criticism that local differences in climate (e.g. altitudinal effects) or hydrology (e.g. groundwater inputs) may be influencing the results. Second, it is possible to compare temperatures between catchments that are fairly similar in all respects, apart from the presence or absence of forest. This approach was used by Weatherley and Ormerod (1990) and has been used in the present comparison between the Hore 1 and Hafren 3 stations. The possibility that there were other differences between the catchments, which influenced water temperatures but were not apparent to the investigators, cannot be ruled out. A third approach is to compare temperatures at the same station in the same stream before and after a change from forest to open land, or vice versa. The drawback of this approach is that climate (including temperature patterns) varies between years and this makes it difficult to interpret water temperature differences between different periods of time. One way to overcome this problem is to use the fact that air temperature is a good predictor of water temperature and the relationship between air and water temperature is likely to vary little from year to year unless there is a change in the thermal characteristics of the stream catchment. It is possible to calculate linear regressions relating air and water temperature and, for example, make statistical comparison between regressions for the period before clear felling and the period after clear felling. The possibility for such comparison in the future has been created by the present study. Should the Hafren catchment be clear felled in the near future, a 'before' and 'after' comparison of water temperatures will be possible.

Comparison of temperatures of the clear felled Hore 1 catchment and the afforested Hafren 3 catchment, in order to assess the effects of afforestation upon water temperature depends upon the assumption that temperatures at Hafren 4A are aberrant, probably as a result substantial groundwater inputs (see Fig. 3 and Tables 2 & 3 ). The evidence suggests, but does not prove, that this assumption is justifiable. It is apparent that the Hore 1 and Hafren 3 stations are similar in terms of altitude (350 and 364 m. O.D. respectively), area (335 ha and 347 ha), aspect and length of stream upstream (3.2 km and 3.4 km). By the time the water reaches the Hore 1 station it will have flowed 1.5 km through clear felled land from Hore 2. Above Hore 2 there is some sparse forest that is not likely to have a major effect on water temperature. By the time water reaches Hafren 3 it will have flowed through c. 2.5 km of forest.

The main temperature difference between the afforested and the felled catchments was a depression of the annual mean in the former by c. 0.4°C. A similar difference between forest and moorland catchments was observed by Weatherley & Ormerod (1990). A similar depression of summer temperatures in forest streams was observed in both studies. Weatherley & Ormerod noted an elevation of winter temperature in their forest streams and it is important to note that, though the elevation was usually less than the accuracy of their equipment (±0.5°C), the finding was consistent between three replicates of each treatment. No such elevation of winter temperatures could be clearly shown in the present study.

## Acknowledgments

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## References

Corbett, E.S., Lynch, J.A. & Sopper, W.E. 1978. Timber harvest practices and water quality in the eastern United States. *J. Forestry*, 1978, 484–487.

Crisp, D.T. 1988. Water temperature data from streams and rivers in northeast England. *FBA Occasional Publication*, **26**, 1–60.

Crisp, D.T. 1992. Measurement of stream water temperature and biological applications to salmonid fishes, grayling and dace (including ready reckoners for calculating median eyeing, hatching and swim-up of embryos, and growth rates, maximum, optimum and minimum maintenance rations for brown trout at various temperatures). *FBA Occasional Publication*, **29**, 1–71.

Crisp, D.T. & Beaumont, W.R.C. 1996. The trout (*Salmo trutta* L.) populations of the headwaters of the Rivers Severn and Wye. *Sci. Tot. Environ.*, **177**, 113–123.

Crisp, D.T. & Howson, G. 1982. Effect of air temperature upon mean water temperature in streams in the north Pennines and English Lake District. *Freshwat. Biol.*, **12**, 359–367.

Feller, M.C. 1981. Effects of clear cutting and slash burning on stream temperature in southern British Columbia. *Wat. Res. Bull.*, **17**, 863–867.

Gorman, G.C. & Moring, J.R. 1991. Initial effects of deforestation on physical characteristics of a boreal river. *Hydrobiol.*, **209**, 29–37.

Lynch, J.A., Rishel, G.B. & Corbett, E.S. 1984. Thermal alteration of streams draining clearcut watersheds: Quantification and biological implications. *Hydrobiol.* **111**, 161–169.

Moring, J.R. 1975. The Alsea watershed study: Effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon, Part II—changes in environmental conditions. *Oregon Fish and Wildlife Fisheries Research Report*, **9**, 1–35.

Rishel, G.B., Lynch, J.A, & Corbett, E.S. 1982. Seasonal stream temperature changes following forest harvesting. *J. Environ. Qual.*, **11**, 112–116.

Roberts, M.E. & James, D.B. 1972. Some effects of forest cover on nutrient cycling and river temperature. In: Taylor, J.A. (Ed.) *Research Papers in Forest Meteorology*. Cambrian News, Aberystwyth, UK.

Smith, B.D. 1980. The effects of afforestation on the trout of a small stream in southern Scotland. *Fisher. Manage.*, **11**, 39–58.

Weatherley, M.S. & Ormerod, S.J. 1990. Forests and the temperature of upland streams in Wales: a modelling exploration of biological effects. *Freshwat. Biol.*, **24**, 109–122.

Whittow, J. 1984. *The Penguin Dictionary of Physical Geography*. Penguin Books—London, New York, Australia, Canada, & New Zealand.