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The ecology of some British rivers in relation to warm water discharges from power stations

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A number of detailed studies of the effects of heated discharges from power stations on the temperature, chemistry and ecology of British rivers have been carried out since 1965. This paper deals mainly with the Rivers Severn and Trent.

In the Severn, a relatively clean river, temperatures up to 28 °C below Ironbridge Power Station outfalls have not affected the diversity of the invertebrate fauna. There were slight alterations in the hatching of insect nymphs which may have been attributable to temperature, though natural variations from year to year were much more obvious. Emergence of adult Ephemeroptera and Trichoptera was not affected by temperatures of 26 to 28 °C.

The River Trent is used for cooling by some 14 power stations. There are no obvious changes in the diversity of the invertebrate fauna which can be related to temperature, though pollution from other sources causes very marked changes.

At Drakelow, in the most polluted reach, changes in the Oligochaete community were possibly attributable to temperatures below the outfall. Experiments showed that *Limnodrilus hoffmeisteri* had a wider temperature range for reproduction than *Tubifex tubifex*.

Studies of fish populations at Peterborough have shown that many coarse fishes can withstand quite sudden and wide temperature fluctuations.

1. INTRODUCTION

The importance of rivers as agents for the disposal of waste heat from power stations has increased considerably in the past two decades. By 1969, some 50% (i.e. 25000 MW), of the power produced in Britain was from power stations sited on rivers (Ross 1970). Until 1965, very few studies of the ecological effects of heated discharges had been carried out in British rivers (Alabaster 1962 *et seq.*; Brinkhurst 1965; Mann 1965, and others). In 1965 the Central Electricity Research Laboratories established a Freshwater Biology Unit, based in the Midlands.

Since then, a number of detailed studies of water temperature, dissolved oxygen, invertebrates and fish in various large rivers have been made, in relation to heated discharges from several different power stations. (Langford 1970, 1971; Aston 1972, Cragg-Hine, personal communication.)

It is not possible to describe all the results obtained from this research in this paper. It is our intention, therefore, to outline very briefly the results of the main projects with particular reference to the Rivers Severn and Trent.

2. THE RIVER SEVERN AT IRONBRIDGE

The Severn, in its upper-middle reaches at Ironbridge is a clean, fast-flowing river. Ironbridge 'A' power station, of 210 MW capacity, was commissioned in 1932. Under full load, it requires 910000 m³ of cooling-water per day, i.e. about

70 to 80 % of the normal summer flow in the river, and there are no cooling towers. During dry weather, there is some reversal of flow in the river (re-circulation) when water flows upstream from the outfall toward the intake. The station operates for 16 to 20 h per day.

Since 1965, research into temperature, invertebrate communities and insect life-histories has been carried out, mainly in the stony, shallow riffles upstream and downstream of the cooling-water outfalls (figure 1). In 1969, a new station, Ironbridge 'B' of 1000 MW capacity and with a full cooling-tower system began to operate, but is so far not fully in use.

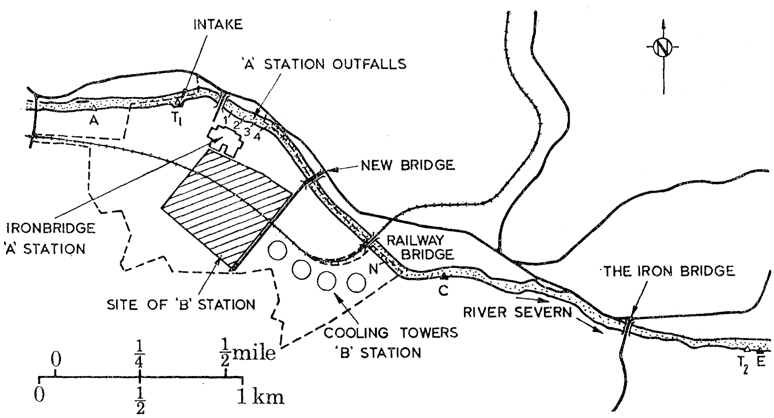


FIGURE 1. Map of River Severn around Ironbridge 'A' and 'B' power stations showing sampling stations and location of temperature recorder (after Langford 1970). T_1, Temperature recording station upstream; T_2, temperature recording station 2 km downstream. Biological sample reaches: A, upstream riffle; C, downstream riffle; E, downstream riffle.

The temperature data from the heated and unheated reaches have been published (Langford 1970). Generally, the temperature pattern in the Severn is more stable than that of smaller streams (Macan 1958; Edington 1966), with small diurnal fluctuations. The greatest rise in any one day was 2 °C during summer and the greatest fall 3.5 °C after a heavy rain and hailstorm. The effects of the power station were to destabilize the temperature pattern downstream and to increase the natural annual range by up to 6 °C (table 1). Daily increments downstream ranged from 0.5 °C during spates, to 7.2 °C at low flows. Diurnal variation was increased downstream, during summer by 100 % or more (figure 2) and in winter, during low flows, a diurnal variation of 3 to 4 °C occurred downstream, but not upstream of the outfalls. At the recording station downstream, effluent and river water were fully mixed.

In the long-term, the rising weekly mean temperature in spring was 3 to 4 weeks in advance downstream, and the fall in temperature during autumn 1 to 3 weeks retarded (figure 3). Also, the accumulation of degree hours over 0 °C during winter and summer was advanced by 3 to 5 weeks.

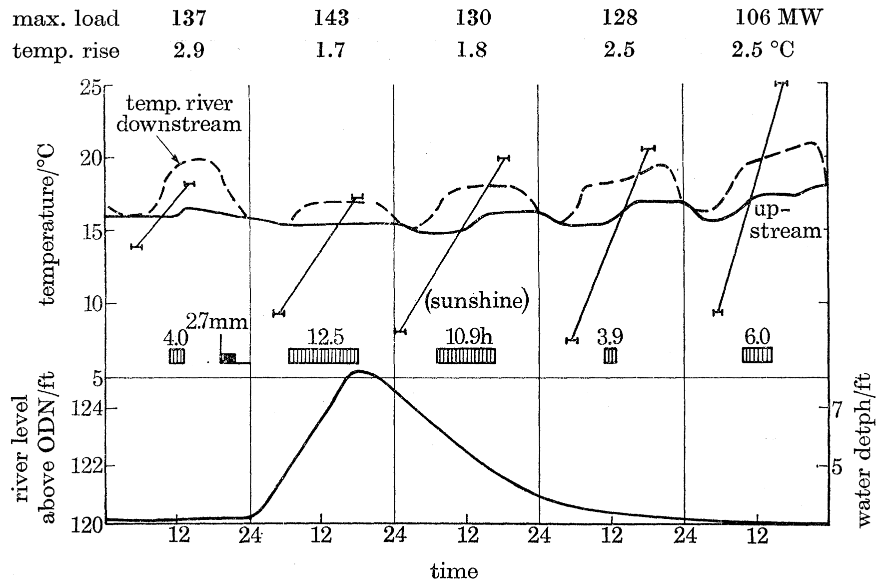


FIGURE 2. Effects of summer spate on the temperature of the river water (after Langford 1970). ■, rainfall; ▥, sunshine hours. The diagonal bars (⟙) indicate the minimum and maximum air temperatures.

TABLE 1. MAXIMAL TEMPERATURES RECORDED IN THE SEVERN UPSTREAM AND DOWNSTREAM OF IRONBRIDGE 'A'

year	maximum 400 m upstream of intake °C	maximum 2 km downstream of outfalls °C
1965	20.6	24.8
1966	19.6	23.5
1970	22.0	28.0

2(*a*). *The invertebrate community*

So far, 110 species of invertebrates have been identified from the Severn around Ironbridge. With few exceptions, these have been recorded both upstream and downstream of the outfalls at some time. The riffle fauna is, however, usually numerically dominated by *Gammarus*, Chironomidae and Simuliidae in winter, together with Baetidae and *Ephemerella ignita* in summer (Langford, unpublished). From 1965 to 1967, there were no changes in the fauna between the upstream and downstream reaches, though in 1969, a very marked change occurred in the river as a result of a heavy spring spate (Langford, unpublished).

The results of the community study are summarized in figure 4 where the mean number of species recorded from the riffles is plotted against temperature at the time of collecting. There is no apparent correlation between temperature and

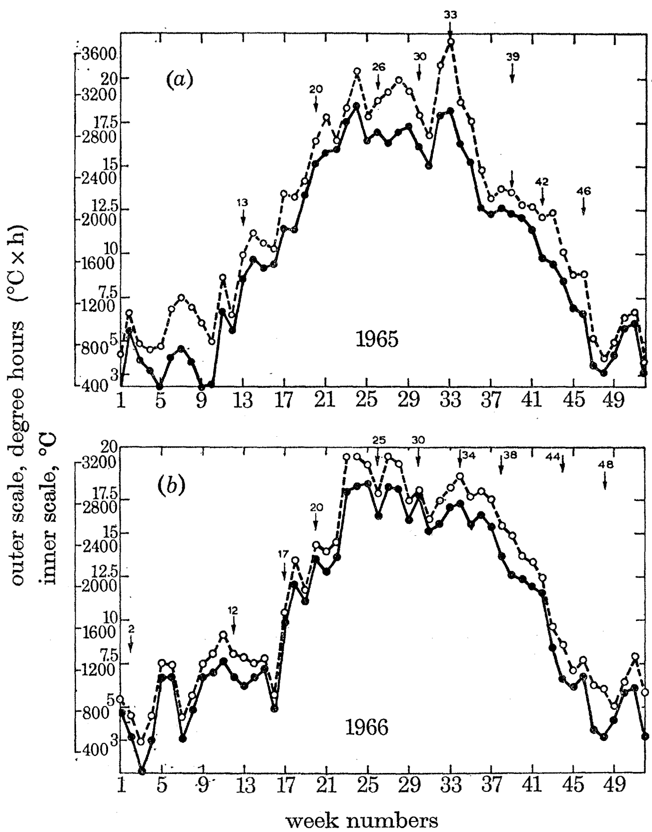


FIGURE 3. Mean weekly temperature in the River Severn upstream and downstream of Ironbridge 'A' outfalls. •—•, upstream; o---o, downstream.

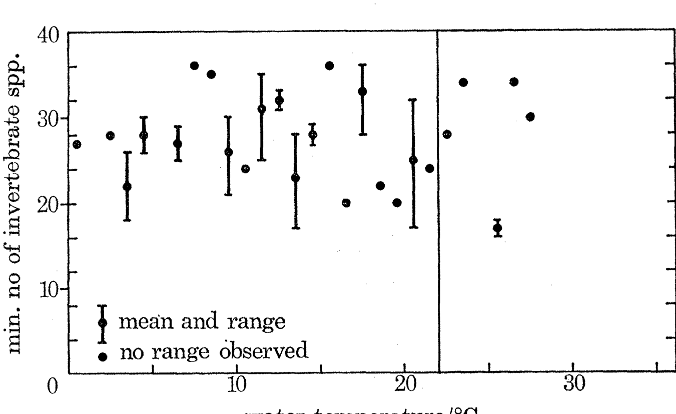


FIGURE 4. Species diversity at River Severn sampling stations relative to temperature.

'species diversity' up to 28 °C though the full results for 1970 have yet to be fully analysed.

2(*b*). *Insect life-histories*

Field studies of the life-histories and emergence of seven species of insect were carried out (Langford 1971). In this brief account I have included data on three species.

Taeniopteryx nebulosa (Linn) is a stonefly, which normally occurs as nymphs from September to March, and as adults from February to April (Hynes 1941). In the Severn, newly hatched nymphs were recorded upstream in May and June during 1966 (figure 5), but not in July. Nymphs disappeared in July but were collected again in August and from then on they grew, as temperatures fell. Downstream of the power station, nymphs were absent from June to September but

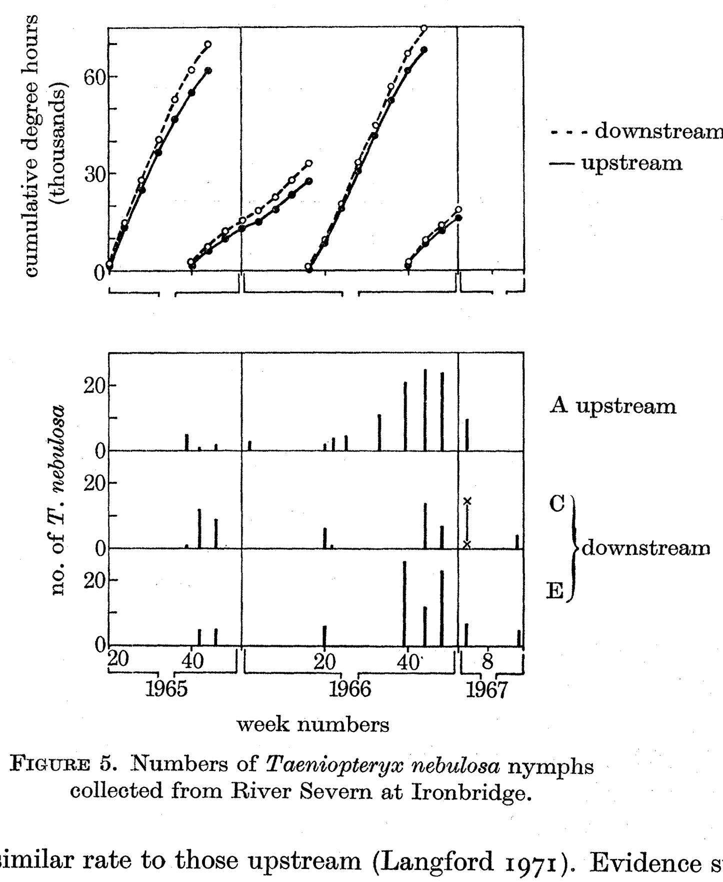


FIGURE 5. Numbers of *Taeniopteryx nebulosa* nymphs collected from River Severn at Ironbridge.

then grew at a similar rate to those upstream (Langford 1971). Evidence suggest that nymphs of this species are killed by temperatures over 17 to 18 °C. In April 1967, nymphs were collected downstream but not upstream. Temperatures were then 4 °C above ambient during the day.

Ephemerella ignita (Poda) is a mayfly which occurs in the Severn as nymphs from April to September, as adults from June to September and overwinters in the egg stage (figure 6). In 1966, nymphs appeared simultaneously at all three sampling stations during April, though mean weekly temperatures, and cumulative degree hours were 3 to 4 weeks advanced downstream. In April 1967, however, nymphs were only collected downstream, in both reaches.

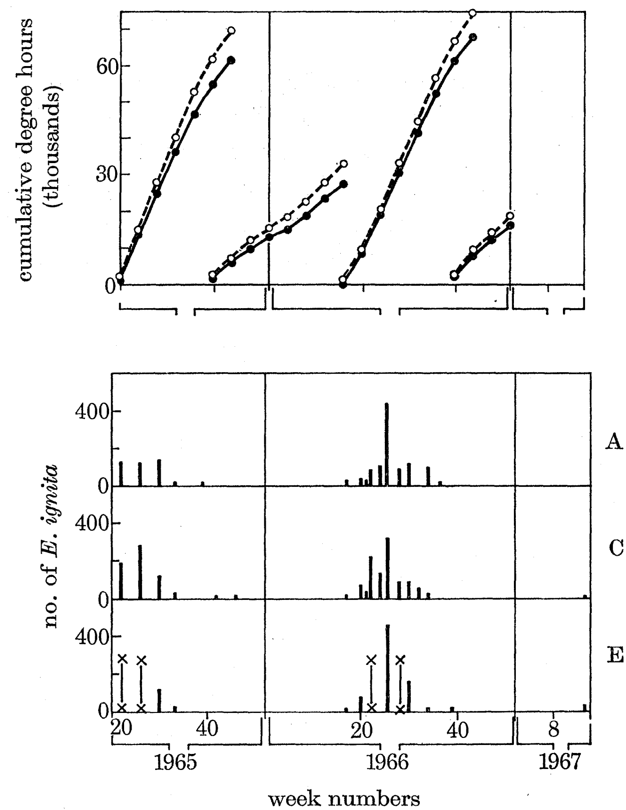


Figure 6. Numbers of *Ephemerella ignita* nymphs collected from River Severn at Ironbridge.

Heptagenia sulphurea Eaton is a mayfly which occurs as nymphs, in various stages of development, all year round. Emergence is from May to September. There were no significant differences in occurrence, or growth at the sampling stations (figure 7). It is evident from the data that these species have a wide temperature range over which eggs can hatch, for example, from 6 to 25 °C in the summer growers, and 17 to 5 °C for winter growers. This is no doubt an adaptive mechanism, evolved to withstand changes in climate from year to year. In fact, there were considerable natural variations in hatching times in *Ephemerella ignita* from year to year (Langford, unpublished).

During 1969 and 1970, emerging adults were trapped from upstream and downstream riffles. Water temperatures are shown in figure 8. The emergence period of *Heptagenia sulphurea* was longer upstream than downstream (figure 9), the reverse

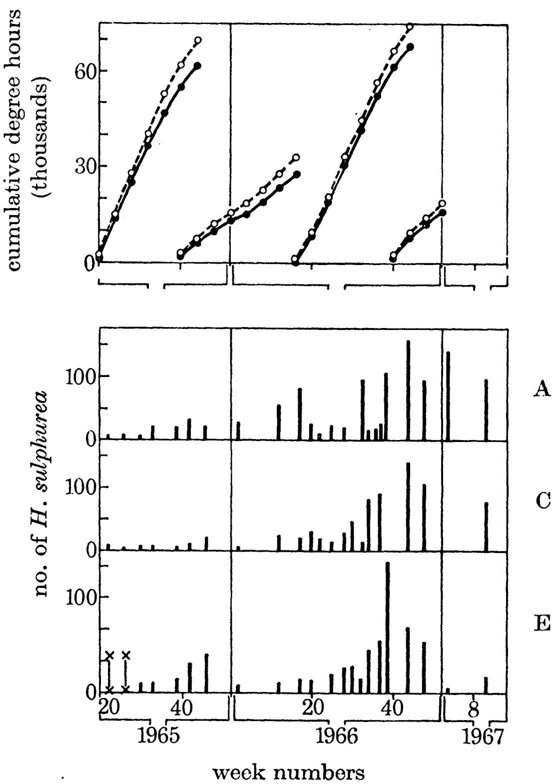


FIGURE 7. Numbers of *Heptagenia sulphurea* nymphs collected from River Severn at Ironbridge.

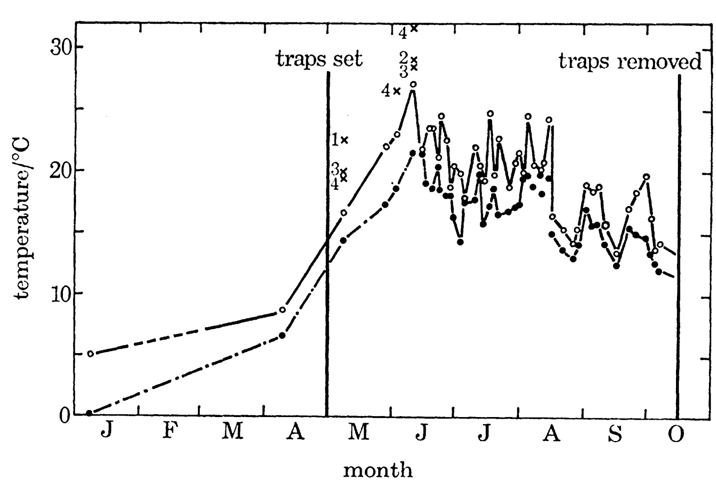
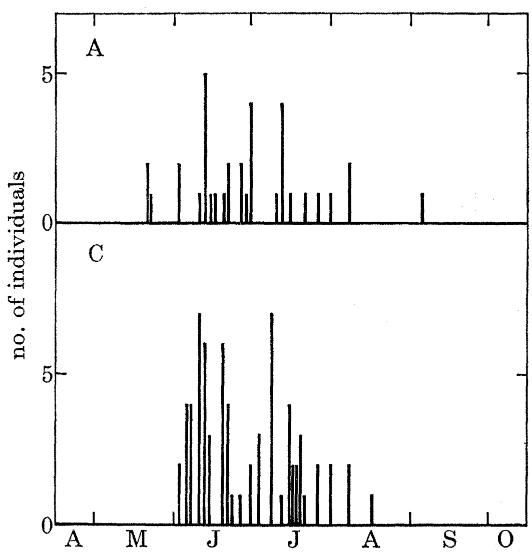
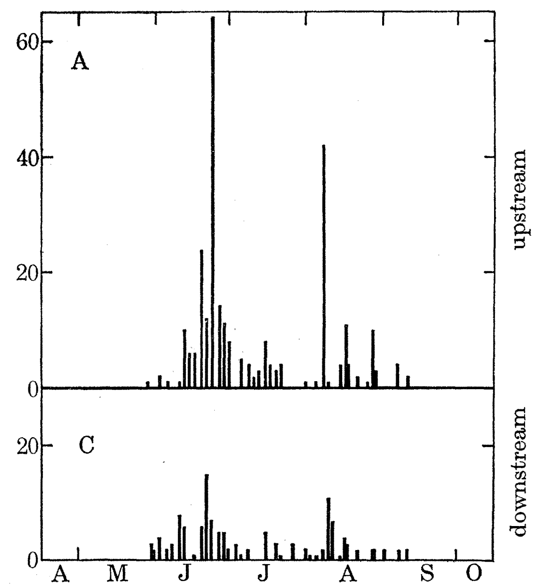


FIGURE 8. Water temperature at emergence traps upstream and downstream of Ironbridge power station 1970. ×, outfall temperature recorded; 1–4, outfall number.

of that which might be expected if emergence is directly related to temperature. The emergence patterns of the caddis-fly *Psychomia pusilla* (figure 10) were very similar in both reaches, though more were caught upstream. Emergence of all the main species continued through the highest temperatures downstream, and was not depressed by temperatures of 26 to 28 °C during June.





month

Figure 9. Catches of adult *Heptagenia sulphurea* River Severn 1970.

Figure 10. Catches of adult *Psychomia pusilla* River Severn 1970.

3. The River Trent

The Trent, in direct contrast to the Severn is polluted for much of its length, and is used for cooling by some 14 power stations in its freshwater reaches (Hawes 1970). The 'species diversity' of the invertebrate fauna collected in preliminary surveys of various reaches is shown in relation to temperature, dissolved oxygen and ammonia concentration in figure 11. There is a marked reduction in diversity just below the confluence with the grossly polluted River Tame. Although there is some recovery over the next 32 km, the sharp increase in diversity is clearly related to the increase in dissolved oxygen concentrations, irrespective of temperature or ammonia concentrations.

3(*a*). *The Trent at Drakelow*

In this reach, some 8 km, downstream of the Tame confluence, the Trent is grossly polluted. Drakelow A, B and C power stations discharge some 800000 m^3 of cooling water per day, part of which is from 'once-through' cooling, and part passed through cooling towers. The discharge is large in relation to river flow, up to 10 °C above ambient, and, owing to turbulence and the cooling towers, is richer in dissolved oxygen than the river water (figure 12). Estimates show that up to 3.9 tonnes of oxygen per day are introduced to the Trent, via this discharge (Aston 1972).

During 1966–7 a field study was made of the river fauna at four stations, two upstream and two downstream of the discharge. The results are outlined very briefly below.

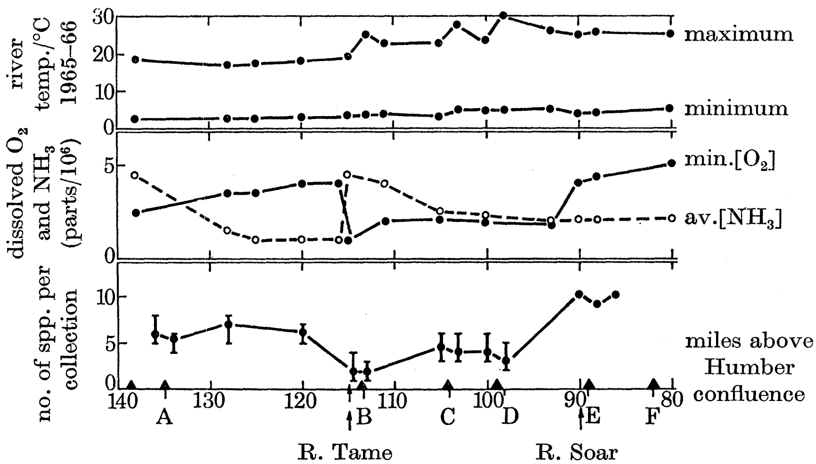


FIGURE 11. Average number of invertebrate species collected from reaches of the River Trent in relation to temperature and chemical factors in 1965. A, Rugeley; B, Drakelow; C, Willington; D, Castle Donington; E, Ratcliffe; F, Wilford (Nottingham).

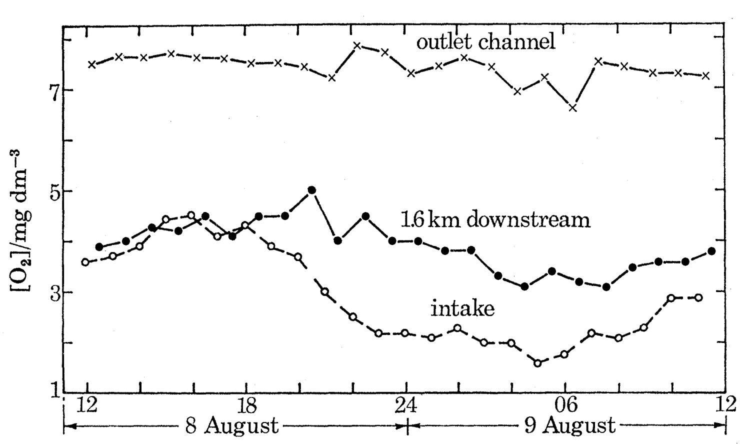


FIGURE 12. Oxygen content of the River Trent adjacent to Drakelow power stations, 8 and 9 August 1967.

Upstream temperatures ranged from 5 to 17 °C, and those immediately downstream from 15 to 27 °C. The fauna consisted almost entirely of tubificid worms of four species, i.e. *Limnodrilus hoffmeisteri*, *L. profundicola*, *L. udekemianus* and *Tubifex tubifex*. Significantly higher numbers of sexually mature *L. hoffmeisteri* were found downstream (figure 13), and while cocoon production reached a peak in May upstream, the downstream peak was in October (figure 14).

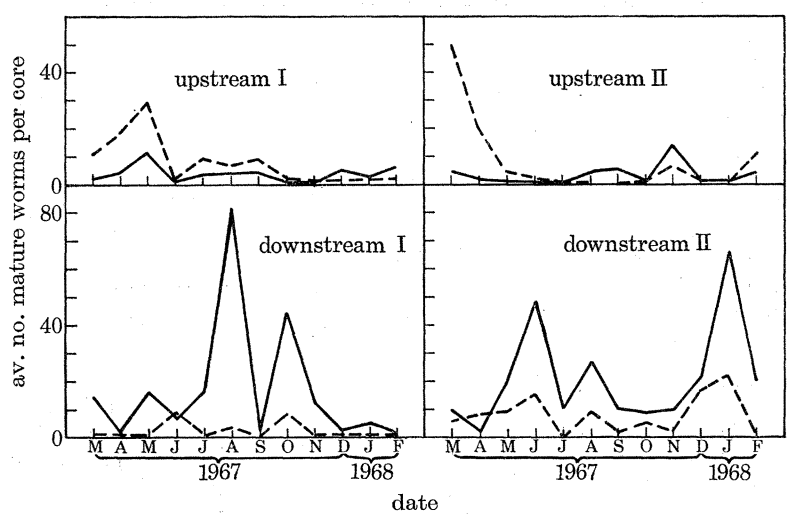


FIGURE 13. The average number of sexually mature worms of *L. hoffmeisteri* (—) and *L. profundicola* (----) per core sample taken from the River Trent upstream and downstream from Drakelow power stations.

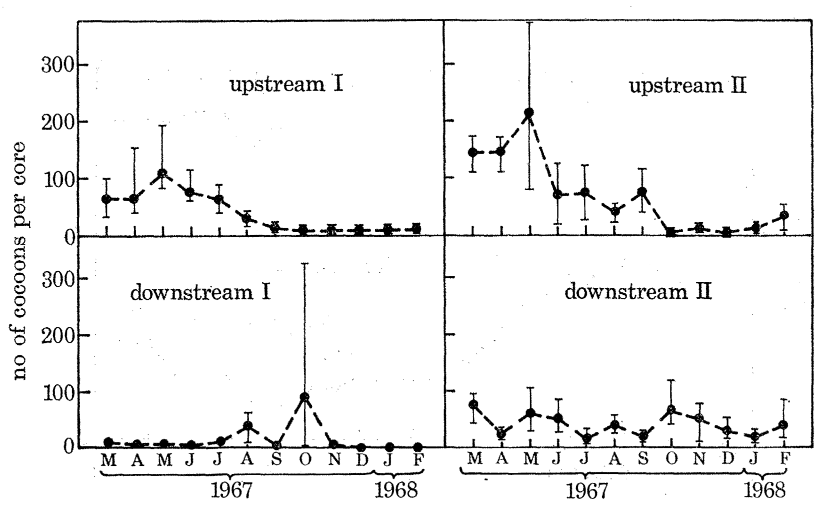


FIGURE 14. The numbers of tubificid cocoons in core sample taken from the River Trent above and below Drakelow power stations showing averages and the total spread of results.

Subsequent experiments have shown that both *L. hoffmeisteri* and *T. tubifex* reproduce successfully over a wide range of temperature. That of the former is 5 to 30 °C, the latter 10 to 25 °C (figure 15).

The rate of reproduction, i.e. cocoon production, increased with temperature in both species, but while the number of eggs per cocoon also increased in *L. hoffmeisteri*, it decreased in *Tubifex tubifex* (Aston 1972).

Further studies of the effects of oxygen concentration and fluctuating temperatures on Tubificidae have been carried out, and will be published in the near future.

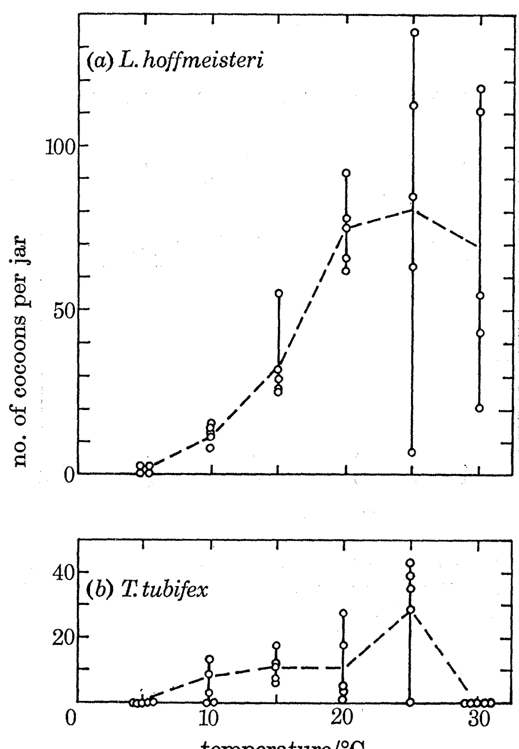


FIGURE 15. Cocoon production in relation to temperature in (*a*) *L. hoffmeisteri* and (*b*) *T. tubifex*. Each point represents the number of cocoons laid by 10 worms over a period of 5 weeks.

3(*b*). *Other research*

The fishes of the Peterborough Cut, i.e. a power station outfall channel, and the River Nene were studied during 1966–8 (Cragg-Hine 1972). Also, temperature data and invertebrates have been collected from a number of other rivers. In some of these, notably the Great Ouse (figure 16), and the Witham, summer flows are very low and considerable recirculation from outfall to intake may occur. Research into the effects of these conditions is in progress. So far the highest temperature recorded was 32 °C in the Great Ouse, though 30 °C was recorded regularly in the River Trent during 1970 (Bottomley 1971).

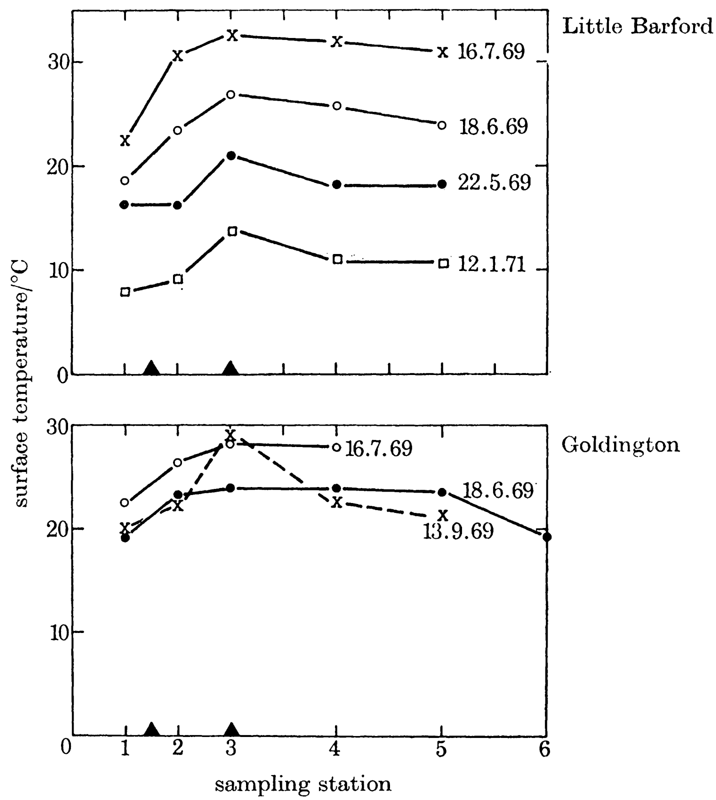


FIGURE 16. Results of temperature surveys at biological sampling stations on the Great Ouse. 1, upstream intake; 2, midway between intake and outfall; 3, outfall temperature; 4, 100 m downstream outfall; 5, 400 to 600 m downstream; 6, > 1 km downstream.

4. Conclusions

It is early in the research to produce many firm conclusions, but a number of indications have emerged.

For example, it is evident that some invertebrates in both clean and polluted rivers are capable of surviving and reproducing at temperatures of 28 °C and up to 30 °C.

Also, insects are not apparently prevented from emerging by temperatures over 26 °C and up to 28 °C, and species intolerant of pollution are not always the least tolerant to heating.

The research into coarse fishes also showed that a number of species are capable of surviving, feeding and reproducing in very changeable temperature conditions. At times rapid fluctuations of up to 12 or 15 °C in the Peterborough Cut were noted which did not apparently affect the fish present (Ross 1970).

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