Hydrobiologia vol. 46, 1, pag. 71—114, 1975

The Emergence Of Insects From a British River Warmed By Power Station Cooling-water

Part I – The use and performance of insect emergence traps in a large, spate-river and the effects of various factors on total catches, upstream and downstream of the cooling-water outfalls

by

T. E. LANGFORD* & J. R. DAFFERN

ABSTRACT

During a programme of research on the fauna of the River Severn around Ironbridge Power Station, the emergence patterns of resident insect species were studied upstream and downstream of the cooling-water outfalls. This paper describes the traps used to catch emerging adult insects and relates their overall performance, total catches and species selectivity, to the physical characteristics of the river.

Upstream temperatures during 1970 and 1971 reached maxima of 22°C and 20.6°C respectively, while downstream maxima were 27.8°C and 23.4°C. The main cause of elevated temperatures downstream was cooling-water from Ironbridge "A" Power Station.

Analysis of trap catches showed that the total numbers of Ephemoptera species and of individuals were greater in certain types of trap but that catches of Trichoptera were less related to trap type. The total emergence period varied during 1969, 1970 and 1971 irrespective of the elevated temperatures and both Ephemeroptera and Trichoptera continued to emerge during and after water temperatures as high as 26—27.8°C and as low as 11°C, in June.

There was some relationship between emergence rates, river level (flow) and temperatures, but evidence suggests that river level was the most significant factor.

The general conclusion from this paper is that the temperature increases in the Severn, caused by normal operations at Ironbridge "A" and by sporadic operations at Ironbridge "B", did not have a significant effect on the total numbers and overall emergence period of Trichoptera, Ephemeroptera and Megaloptera downstream of the outfalls. Also the species-composition of trap catches

---

*Central Electricity Research Laboratories, Freshwater Biology Unit, c/o Scientific Services Centre, Ratcliffe-on-Soar, Nottingham, NG11 OEE.
Received July 19, 1973.

was very similar both upstream and donwstream of the power stations. The emergence periods of individual species are described in a second paper.

Introduction

It has been suggested by various authors (Bregman, 1969; Hawkes, 1969; Rothwell, 1971) that artificially induced temperature changes in rivers affected by cooling-water discharges could alter the timing of adult emergence in insects with aquatic immature stages. Early emergence of adults into lethally cold air could lead to the elimination of species from the habitat and also affect the feeding habits of predatory fish.

During a programme of research on the fauna of the River Severn around Ironbridge 'A' and 'B' Power Stations (Langford 1970; 1971b), attempts were made to compare the emergence patterns of insects in the heated and unheated reaches of the river, (Langford & Aston, 1972).

Many types of trap have been designed and used to trap insects emerging from a wide variety of habitats (Mundie 1956; Macan 1964; Southwood 1966), but there have been few attempts to trap insects emerging from a large, fast-flowing river, subject to large and often rapid fluctuations in flow and carrying massive amounts of debris when in flood (Lemke & Mattson 1969). Various trap designs were considered for the Severn work but none were found to be suitable for a long-term programme. This paper describes the emergence traps which were developed and used on the Severn during 1969, 1970 and 1971. River temperature and flow patterns are also described and the overall performance of the traps in relation to various factors is discussed. The composition of trap catches upstream and downstream of the outfalls is compared.

The emergence patterns of individual species are described in a second paper.

Description of the river and emergence-trap locations

The topography and physical characteristics of the Severn at Ironbridge were described previously (Langford 1970, 1971a). Briefly, Ironbridge 'A' and 'B' Power Stations are situated in the upper-middle reaches of the river, immediately upstream of the Ironbridge gorge. The width of the river in the vicinity of the power stations varies between 30 and 50 m, and under normal summer conditions, slow deep reaches alternate with short, 'riffle' areas.

The flora consisted mainly of *Ranunculus penicillatus* (DUMORT) BAB. in the shallower reaches with occasional patches of *Myriophyllum spicatum* L. in the margins. In the deeper reaches the margins were mainly overhung with grasses, though small clumps of *Acorus calamus* L. and areas of *Nuphar lutea* (L.) SMA. were also present.

Fig. 1 shows the location of the four main benthos-sampling areas (LANGFORD 1971a) in relation to the cooling-water outfalls from both Ironbridge 'A' and 'B' Power Stations. The emergence-trap locations are also shown by a code indicating trap number and year of operation. Traps prefixed with U – indicate upstream locations, D – downstream locations.

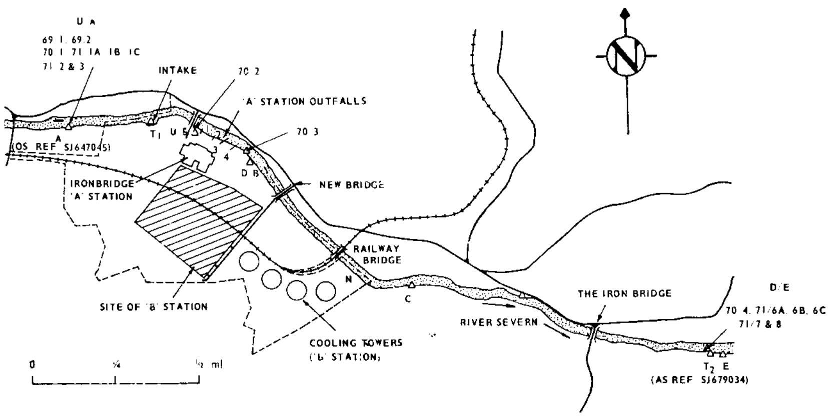


Fig. 1. Map of river severn around ironbridge "A" and "B" power stations showing benthos sampling stations location of temperature recorder and emergence trap locations. T_1 = Power station intake and temperature recorder. 1, 2, 3 & 4 = Ironbridge "A" cooling-water outfalls. N = Ironbridge "B" cooling-water outfall. T_2 = D/S temperature recorder (1965—67). A, C and E = sampling sites for benthos 1965—71. U = Upstream. D = Downstream. 70/2 = Emergence trap locations showing year and trap number.

In 1969 traps were located at sampling area U/A for field trials. In 1970 single traps were located at four places, i.e. U/A, U/B, D/A and D/E (Fig. 1) during April to November. Traps numbered 70/2 and 70/3, at U/B and D/B respectively, were intended to compare emergence from the slower reaches with that from the riffle areas. In 1971 ten traps were used, five located at U/A and five at D/E, during the period from March to November.

The substratum at U/A consisted mainly of limestone gravel and small rocks on a coarse sand matrix, while at D/E there were, in addition to these, amounts of brick rubble on the river bed. Basically the physical conditions at U/A and D/E were similar, though the current at D/E was generally slightly faster owing to an increase in width and gradient. At U/A there was, during low flows, a small almost static area of backwater at the margin of the stony run. There was no similar area at D/E. At U/B and D/C the substratum was mainly of coarse sand, and the river banks were steep and consisted mainly of clay.

Equipment and methods

River Gauging and Temperature Measurement

River levels at the water surface were recorded hourly at T_1 (Fig. 1) and measured in feet above Ordnance Datum (Newlyn). River flows were obtained or extrapolated from records published by the Severn River Authority (S.R.A. Annual Reports, 1970, 1971 and pers. comm.). Upstream temperatures were also recorded hourly at T_1 (Langford 1970), and readings were also taken both upstream and downstream of the power station on each visit to the emergence-traps. Where necessary, maximum downstream river temperatures were estimated using the equation: –

$$\triangle T = 0.47 + 0.5661 \; l/h^*$$

where $\triangle T$ = temperature rise above ambient at D/E (T_2 on Fig. 1)
l = load factor at Ironbridge 'A' Power Station in megawatts (MW)
h = river level on the gauge at T_1, in *feet** above O.D. Newlyn, minus 117

Correcting for current velocity and distance, the temperature rise at D/E occurs approximately two hours after the respective MW reading used for the calculation.

A check on the accuracy of the estimated rises, showed that of 61 occasions, 42 (68.9%) showed a difference of less than 1.0°C between expected and observed temperatures. A further 16 (26.2%) showed a difference of less than 2.0°C. On two occasions (3.3%) observed and calculated temperatures were more than 3°C different, but on one occasion the difference was +3.1°C and the other —3.2°C.

Temperatures downstream were usually measured between 11.00 and 14.00 hours, around which the maximum $\triangle T$'s were found to occur. Where the differences between observed and calculated temperatures were large, observed temperatures were probably read earlier or later than normal. Generally, however, the agreement between observed and estimated temperatures was good.

(*corrected from Langford 1970).

Load Factors at the Power Stations

In 1969, Ironbridge 'B' Power Station of 1000 MW installed capacity, began to operate spasmodically. Load factors were extracted from the station log, as were those of Ironbridge 'A'. The temperature of the discharge from each operating cooling-water outfall was measured at regular intervals.

The Emergence-traps

In 1966 and 1967, standard, conical emergence-traps were tried (MUNDIE, 1956) but these rarely survived even minor spates. A major problem was *Ranunculus sp.*, large mats of which, were carried downstream during much of the summer, and during spates. The *Ranunculus* strands became entangled with the trap floats and sank or capsized the traps very quickly. Also, some traps were smashed by large logs or whole trees carried by the river in flood.

It was obvious, therefore, that for long-term work, an emergence-trap should be: –

a. floating, to survive and operate during floods or summer spates

b. of shallow draught, to reduce drag and provide little obstruction to entangling weeds

c. able, if necessary, to support amounts of debris without sinking

d. able to absorb damage from collisions with large objects, or be shaped to deflect such objects.

Different designs of trap were used, designated Mk. 1 (float) traps (Fig. 2), Mk. 2 traps (Fig. 3) and Mk. 3 traps (Fig. 4).

The Mark 1 – 'float traps' – consisted of two main parts, i.e. the catching cone and the float (Fig. 2). The cone itself was similar to those used by other (MUNDIE, 1956; MACAN, 1964) being a four-sided aluminium framed unit measuring 50 cm x 50 cm, and 15 cm x 15 cm at the apex. The sides were covered with 40 mesh Nybolt gauze. This cone unit was hinged to the float-frame and tipped for access. Originally, each cone was surmounted by an inverted jar, but this was exluded from later models as it was found that most insects remained in the gauze covered area of the cone. The float, designed to withstand river conditions, was a double-pointed elliptical boat-shaped block of expanded polystryrene, 250 cm long, 120 cm in the beam, and 30 cm deep, with a 50 cm x 50 cm hole, cut through the float, over which the cone was set. The bottom of the float was curved upwards at each end so that the bow and stern were clear of the water. This reduced the obstruction for floating debris. As Plate 1 shows, the draught of the float was shallow, usually only 2—3 cm. Inset into the float was a wooden (later slotted steel) frame, bolted on top and underside through

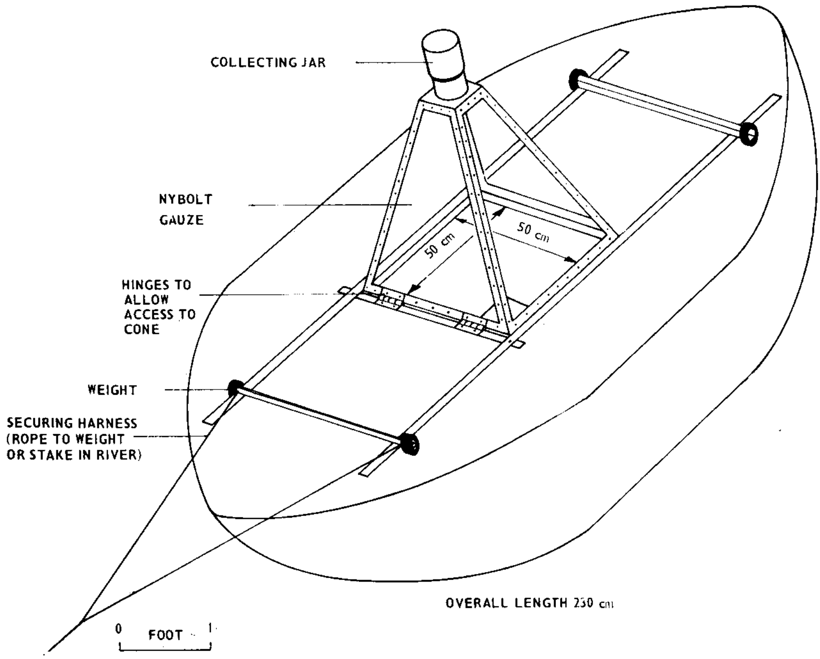


Fig. 2. Mark 1 trap with cone.

the float, to which the mooring ropes were attached. The mooring rope was actually attached with a V-shaped rope harness which projected over the bow of the float enabling the float to move freely as river level rose or fell, without tipping the trap into the current. Each emergence-trap was moored by a 7 m length of 453.6 kg (1000 lb) breaking strain polypropylene rope, to a stake driven into the river bed.

The Mark 2 trap (Fig. 3) was used in 1970 at U/B and D/B where there was less trouble with debris and as lower current. The catching cones used were similar to those on the float-traps (Mark 1) but the floats were plain rectangular polystyrene blocks.

The Mark 3 (outrigged) traps were designed in 1971 to: –

a. allow more cones to be used at each sampling station

b. to compare catches in traps without a solid base, with float traps, where the float acted as a solid base.

It was noticed that the nymphs of some insects, notably the mayflies *Heptagenia aulphurea* and *Ephemerella ignita* had colonized the floats during the 1970 trapping season. The Mark 3 adaptation consisted of outriggers, fixed to Mark 1 floats, and to which cones were hinged. A curtain of coarse, stiff Nybolt gauze (10 mesh) was

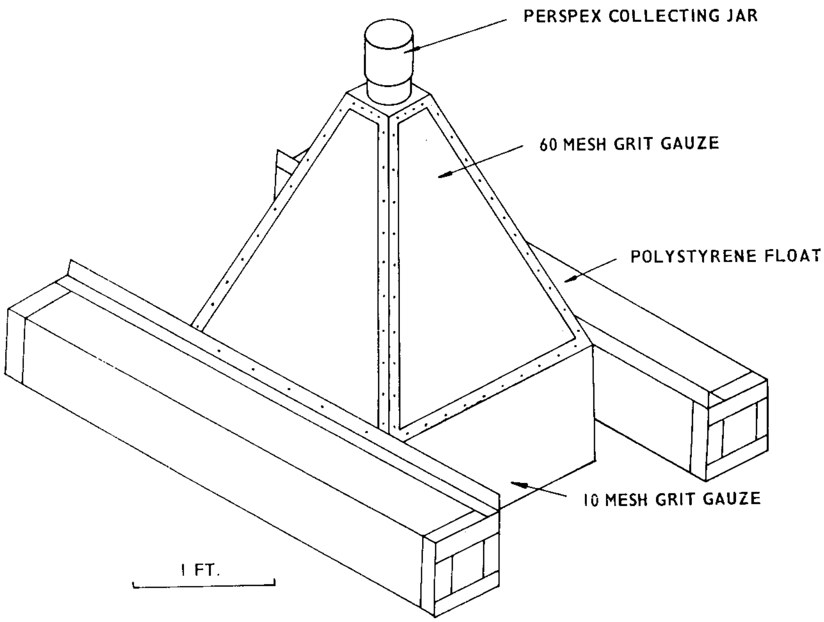


Fig. 3. Mark 2 float trap

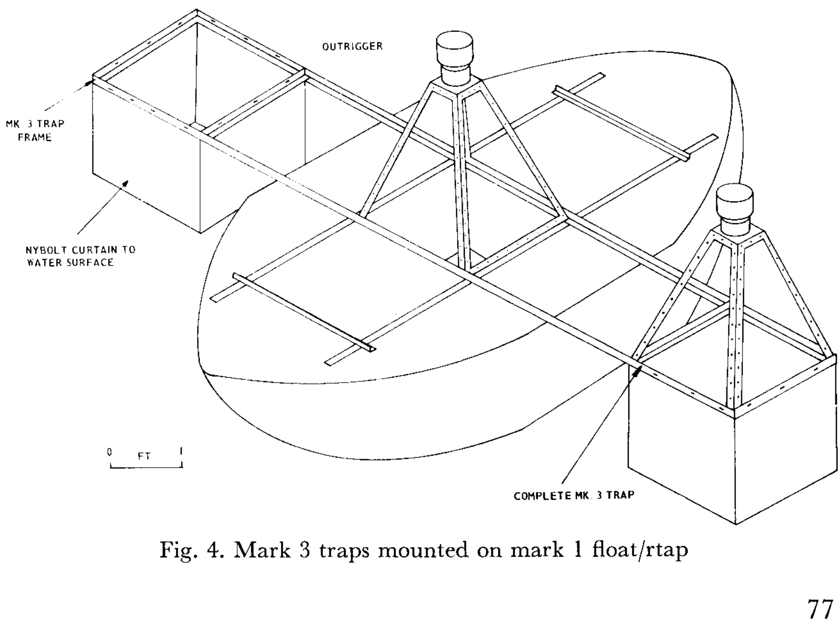


Fig. 4. Mark 3 traps mounted on mark 1 float/rtap

hung from the cone-base to the water surface. Even with the extra weight, the float draught was usually less than 5 or 6 cm.

Sampling Prodecure

Two Mark 1 (float) traps were located at U/A in July 1969 for a trial period. These were removed in November 1969, when on each of six consecutive visits, no insects were found in the cones. Owing to high river levels, emergence-traps were not set out again until April 23 1970. One Mark 1 trap was located at both U/A and D/E. At the same time, one Mark 2 /block) trap was installed at each of the stations on the slow reach, which were U/B and D/C. In 1971, Mark 1 traps were installed on March 23 at U/A and D/E. By April 20, three Mark 1 traps and two Mark 3 (outrigged) traps were located at both U/A and D/E. Table I shows the length of time each trap was in position and also the number of visits. Each year traps were left in position, where possible, until no insects were recorded from the cones on each of six consecutive visits after the end of October.

The traps were emptied three times each week, and insects were extracted from the catching cones using a standard aspirator or 'pooter' (SOUTHWOOD, 1966). In 1970 and 1971, the insects were

TABLE I

Number of Days and Number of Visits during Emergence Periods 1969—1971

Year Trap Number		Type of Trap	Number of days set	Number of visits	Number of days from first to last catch	Dates of first and last catch
1969/1		Mk. 1 (float)	123	41	110	July 3—Oct. 29
1969/2		Mk. 1 (float)	123	41	110	July 3—Oct. 29
1970/1	U/S	Mk. 1 (float)	184	45	112	May 21—Sept. 10
1970/2	U/S	Mk. 2 (blocks)	184	45	105	May 28—Sept. 10
1970/3	D/S	Mk. 2 (blocks)	184	45	105	May 28—Sept. 10
1970/4	D/S	Mk. 1 (fload)	184	45	112	May 21—Sept. 10
1971/1A	U/S	Mk. 3 (outrig)	112	36	92	May 10—Aug. 10
1971/1B	U/S	Mk. 1 (float)	112	36	92	May 10—Aug. 10
1971/1C	U/S	Mk. 3 (outrig)	112	36	92	May 10—Aug. 10
1971/2	U/S	Mk. 1 (float)	244	55	163	May 10—Nov. 3
1971/3	U/S	Mk. 1 (float)	252	55	163	May 10—Nov. 3
1971/6A	D/S	Mk. 3 (outrig)	112	36	92	May 10—Aug. 10
1971/6B	D/S	Mk. 1 (float)	244	55	163	May 10—Nov. 3
1971/6C	D/S	Mk. 3 (outrig)	166	48	166	May 10—Nov. 3
1971/7	D/S	Mk. 1 (float)	244	55	163	May 10—Nov. 3
1971/8	D/S	Mk. 1 (float)	252	55	163	May 10—Nov. 3

sometimes narcotized with carbon dioxide injected into the cones from a fire-extinguisher. They were collected on a perspex tray inserted under the base of the cone, before being transferred to the pooter. Usually, however, insects were collected by tipping the cone on its hinge and drawing directly into the pooter. Even though the insects were active, few were lost if the operation was carried out carefully.

Difficulties Encountered during Trapping

During the heaviest floods in both 1970 and 1971, some traps were swept from moorings when ropes broke. Later it was found that by mooring traps to a heavy weight resting on the river bed, the float could move slightly during floods by dragging it along. This relieved the stress on the mooring ropes at peak water levels. At times, winds moved traps laterally off-station owing to the high wind-resistance of the float. To prevent this, a rope weighted with large stones was trailed from the downstream end of the float. At normal river levels, the stone rested on the river bed, but was easily lifted by the float during floods, without harm to the trap. The durability of the floats themselves was ably demonstrated when two, which broke from their moorings, were recovered some 21 and 33 miles downstream of Ironbridge. Both had passed over weirs and rapids, but were readily re-usable on recovery, Vandalism was rare at Ironbridge, though this has been a major problem on other rivers.

A further difficulty, pertinent to other work on large rivers, was that of emptying the trap when the river was in flood. At such times the river was not wadeable, as there were depths of water up to 2 or 3 m below the traps. Also, during floods, the distance from the traps to the bank was increased. The traps could only be reached at such times by swimming, using rubber suits and safety lines, or by throwing a weighted rope over the trap mooring rope and hauling the trap to the bank. Using these techniques, traps could be emptied during most spates.

Results

River Levens and Flows

During the period from July 1969 to November 1971, the discharge rate of the Severn at Ironbridge varied from about 5 $m^3 s^{-1}$ to 475 $m^3 s^{-1}$. Water level at the gauge (T_1) varied from + 39.5 m to + 44.2 m O.D.N. Normal summer level was from + 39.5 to 40.0 m (Fig. 5). At U/A the depth of water under the traps varied from

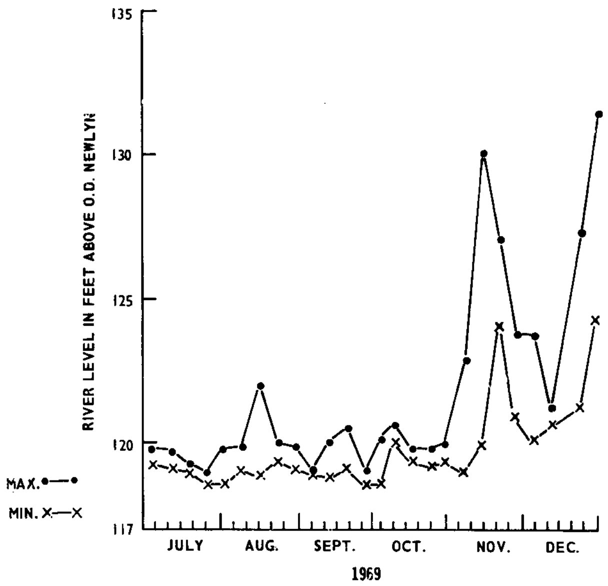
0.15 m (0.5 feet) to about 4.5 m (14 feet), during any one year. At D/E where the channel was wider, the depth range was 0.1 to about 3.0 m, while at U/B and D/C depths ranged from about 1.5 to 5m. Current velocities varied from 0.3 to 1.0 m/s at U/A; from 0.4 to 1.3 m/s D/E and 0.05 to 0.7 m/s at U/B and D/C. At U/B during low flows, the current could be reversed when the power station intake pumps caused the river to recirculate (LANGFORD 1971a, 1971b). After heavy rainfall in the catchment, river levels could rise by 0.3 m/hour, though 0.1 to 0.2 m/hour was more usual.

The patterns of river flow and spates varied markedly from year to year (Fig. 5). In 1969, there was only one small rise in river level of about 0.3 m between July and October and river levels did not rise significantly until early November.

In 1970, the river reached its 'normal' summer level toward the end of May, and remained at this low level until mid-August, when a major spate occurred, and the river level rose by a maximum of 2.5 m. This spate was followed fairly quickly by a second spate in mid-September, with only a very short period of low water level in between. The river did not return to its normal summer level again until early October and the period of winter spates began in late October.

In 1971, river level dropped below the 120 foot (+ 40 m) level about four days earlier than in 1970, but the first significant summer spate also occurred earlier, i.e. in mid-June. The river regained

5a



5b

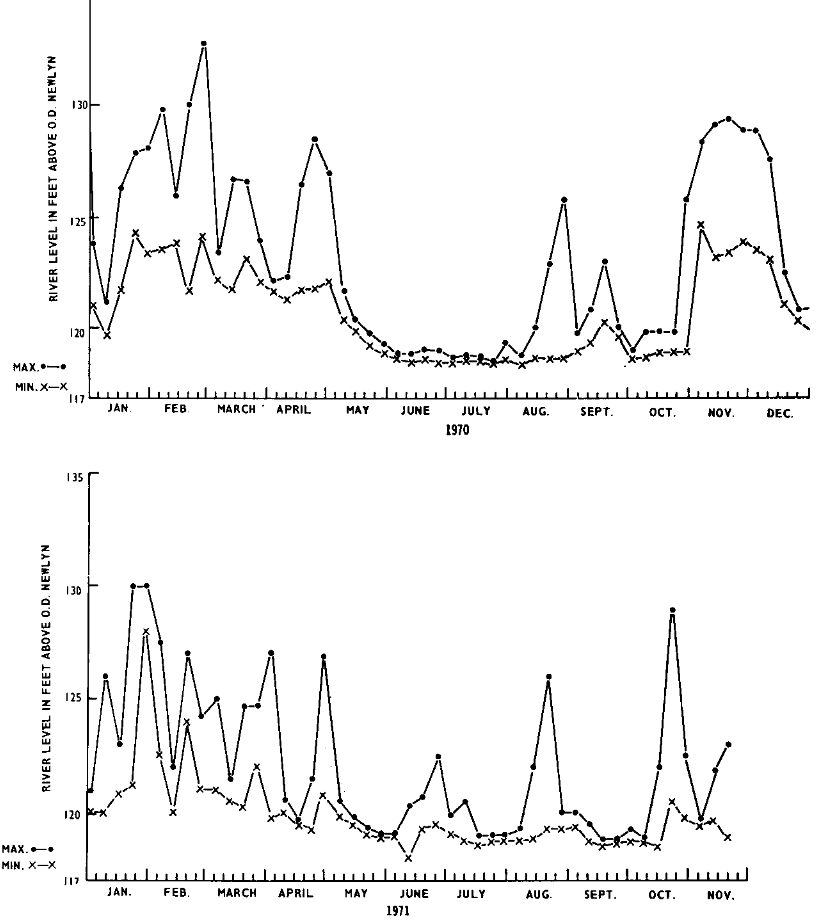


Fig. 5. River Severn, ironbridge. Maximum and minimum weekly river levels, measured at the power station intake (T). (The levels are shown as feet above ordnance datum, Newlyn)

its normal summer level in July. In mid-August a second, larger spate occurred, when river level rose by 2.5 m, but by early September the level had fallen again. In mid-October yet another spate occurred.

The winter period in each year was characterized by higher, widely fluctuating river levels. The future effects of river-regulating reservoirs on the flow of the Severn have not been analysed in detail for this paper, though this will become much more important in future work on the river.

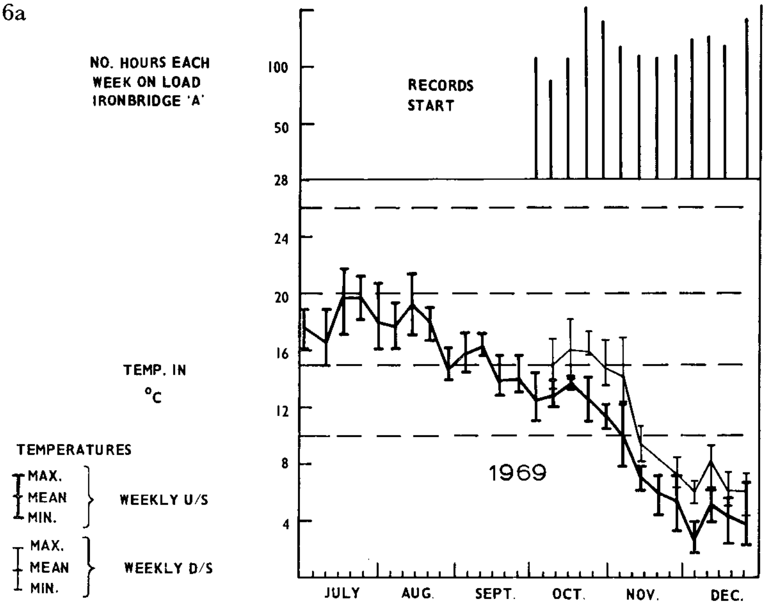
River Temperature (1969—1971)

Natural temperatures

The natural temperature patterns for 1970 and 1971 varied considerably (Fig. 6). In both 1970 and 1971 mean weekly water temperature rose during mid-May to similar levels, i.e. 14—15°C. In 1970, temperatures continued to rise to a peak in mid-June, when a maximum temperature of 22.2°C was recorded, and the mean weekly temperature was about 20.0°C In June 1971, this did not occur and a maximum of only 17°C was reached, with a maximum weekly mean temperature of 16°C. Further, during this month a minimum temperature of 10°C was recorded. Thus in the same month, in two successive years, natural temperatures ranged from 10°C to 22.0°C, with weekly means ranging from 11.5°C to 20.0°C. In July 1971, water temperatures averaged 16—19°C, only slightly higher than in July 1970, when mean weekly temperatures were 16—17°C.

A second peak water temperature occurred in August 1970, though this did not occur in 1971. The decreasing temperature trend began during mid-August in both years and from then trends were very similar, and mean autumn river temperatures were generally higher and mean weekly temperatures did not all to 10°C until early November.

6a



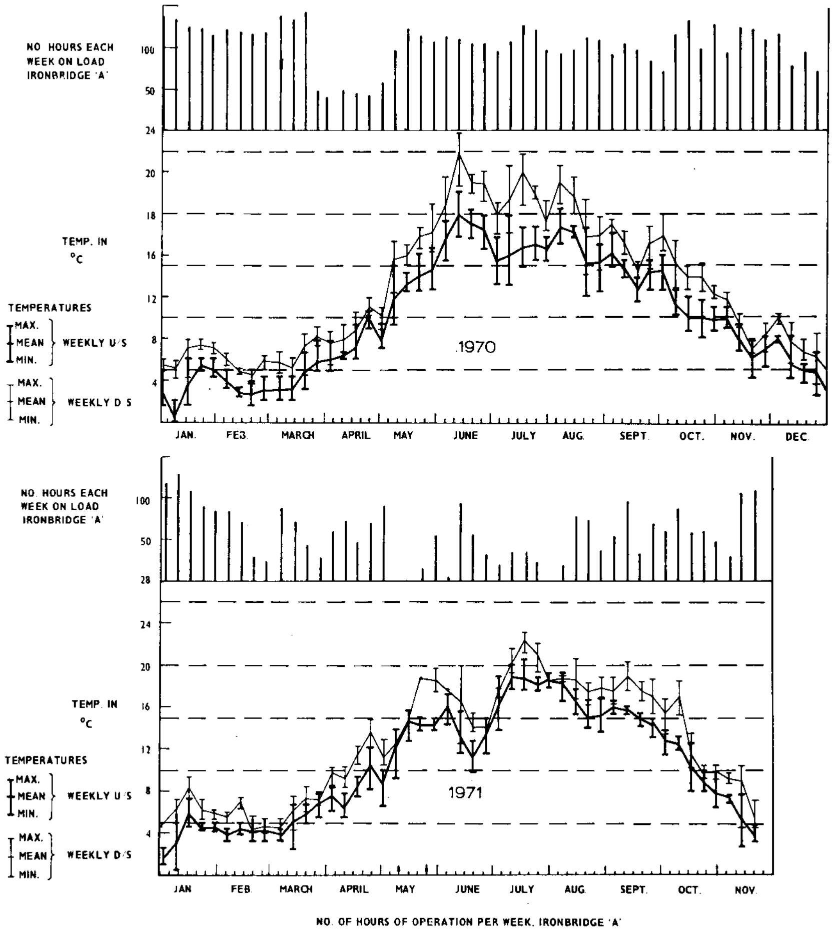


Fig. 6. Weekly maximum and minimum water temperatures of the river Severn upstream and downstream of ironbridge power stations 1969—71, in relation to operating hours at ironbridge "A".

The effects of power station operation on river temperature

During the previous studies at Ironbridge (LANGFORD 1970, 1971), only Ironbridge 'A' Power Station was in operation. Thus the equation for calculating $\triangle$T's in the Severn used only laod-factor (1) at this station. In 1969, 1970 and 1971, Ironbridge 'B' Power Station of 1000 MW installed capacity was operating spasmodically on loads of up to 750 MW. However, as the cooling system on the newer station is of the closed (i.e. cooling tower) type, the discharge of cooling water was much smaller than from the older, direct-cooled power station. Ironbridge 'A' in fact discharged 12 million gallons of cooling water per hour on full load, whereas Ironbridge 'B' discharged approximately 1 million gallons per hour.

A series of measurements taken in both 1970 and 1971 (Table II) showed clearly that the discharge from Ironbridge 'B' Power Station resulted in no significant, (and usually no measurable) rise in river temperature at the downstream sampling station, D/E. The ΔT at D/E, therefore, was still related to the discharge from Ironbridge 'A' Power station and it was not necessary to alter the equation.

TABLE II

Records of River Water Temperature Taken during the Operation of Ironbridge "B" Power Station

Date	Temp. U/S °C	Temp. D/S "A" U/S "B"	Temp. B Outfall	Temp. at Area E—D/S	
30/ 6/70	16.2	20.6	19.6	20.8	"A" and "B" Stations operating
3/ 7/70	14.4	20.2	12.4	19.9	
11/ 8/70	17.7	23.0	20.0	20.6	
16/ 9/70	12.6	13.8	18.8	13.5	
2/ 7/71	18.0	19.3	24.5	19.3	
17/ 7/71	19.8	19.8	23.5	19.2	
5/ 9/71	17.5	17.5	20.0	17.3	
15/ 9/71	15.1	15.1	19.5	15.3	
12/10/71	14.0	14.0	20.5	14.2	

Maximum "A" Station outfall temperature recorded = 31.6°C (in 1970)
Maximum "B" Station outfall temperature recorded = 24.5°C (in 1971)

Downstream of the power stations, the river temperature varied with the natural temperature, plus power station operation. The diurnal effects were similar to those in previous years, though there was a marked decrease in hours of operation at Ironbridge 'A' during 1971 (Fig. 6). Consequently, in 1971 the total effects of the cooling-water discharge on river temperature were greatly reduced, though daily ΔT's did reach 7°C on occasions.

In June 1970, river temperature at D/E reached 27.8°C, the highest recorded since research began at Ironbridge. On the same day, i.e. June 10, an effluent temperature of 31.6°C was recorded at Ironbridge 'A'. Downstream maxima and minima in 1970 were well above those in 1971, during the summer, and mean weekly temperatures were mainly well over 20.0°C. during the period from early June to mid-August. In 1971, downstream daily maxima exceeded 20.0°C only on five or six occasions and mean weekly temperatures exceeded 20.0°C on only three occasions.

Thus, there were considerable differences in the temperature patterns both upstream and downstream of the power stations in

1970 and 1971. Some maximum, minimum and mean weekly temperatures are summarized in Table III.

TABLE III

Maximum and Minimum Daily and Weekly Mean Temperature at Emergence-Trap Locations on the Severn at Ironbridge, 1969—1971

		Minimum in °C		Maximum in °C		Month in which min.	Month in which max.
Year	Site	Daily	Weekly Mean	Daily	Weekly Mean	occurred	occurred
1969	U/A	0	0.5	21.8	19.6	February	July
1970	U/A	0	0.5	22.2	20.0	January	June
	U/B	0	1.5	25.0	22.5	February	June
	D/B	4.0	5.5	30.0	25.0	February	June
	D/E	1.5	3.0	27.8	24.5	February	June
1971	U/A	0.5	1.0	20.6	19.5	January	July
	D/E	2.0	2.5	23.4	22.0	January	July

The composition of the total catch

A total of 22,271 insects were extracted from the traps, of which 17,220 (77.32%) were Diptera; 2283 (10.25%) were Trichoptera; and 2694 (12.10%) were Ephemeroptera (Table IV). The numbers of both Plecoptera and Megaloptera were small, being 15 (0.01%) and 34 (0.26%), respectively. In 1970, Diptera were not collected but even without these it is obvious that Diptera were numerically dominant in the totalled collections.

The numbers of Diptera extracted from the traps were somewhat lower at times than the actual number present. On these occasions, the inside surfaces of the catching cones were literally covered with small Diptera, many of which were laying eggs. Not all of these could be collected and although the figures in Table 4 indicate the extent to which Diptera were represented in the catches, it can be assumed that the actual numbers were higher.

Comparison of species recorded in the traps and in the benthos

In any programme of emergence-trapping, it is important to know which of the species present as immature stages in the river are represented as adults in the traps. Table V shows the species so far identified from both traps and benthos samples. Their relative abundance is indicated, though actual numbers are not shown (LANGFORD, in press). The species identified belonged to the Plecoptera, Ephemeroptera, Trichoptera and Megaloptera. Forty-seven (47) species were identified as adults of which four (4) belonged to the Plecoptera, eighteen (18) to the Ephemeroptera, twenty-four (24) to the Trichoptera and one (1) to the Megaloptera. Diptera were not identified.

TABLE IV

Total Numbers of Each Insect Order, Collected from Each Emergence-Trap

Year	Trap	Plecoptera	Ephemeroptera	Trichoptera	Megaloptera	Diptera
1969	1	1	101	162	0	1468
1969	2	2	71	93	0	1442
Total (U/S only)		3	172	255	0	2910
1970	1	1	155	318	25	Not collected
1970	2	0	50	22	0	Not colelcted
Total (U/S traps)		1	205	340	25	—
1970	3	0	6	19	0	Not collected
1970	4	0	539	227	0	Not collected
Total D/S traps)		0	545	246	0	—
1971	1A*	0	48	148	0	373
1971	1B	2	231	172	2	617
1971	1C*	1	87	137	1	718
1971	2	1	470	343	2	3288
1971	3	5	234	166	3	1329
Total U/S traps)		9	1070	966	8	6325
1971	6A*	0	43	95	0	1152
1971	6B	0	173	111	0	1015
1971	6C*	0	69	152	0	2090
1971	7	2	315	54	1	1191
1971	8	0	103	64	0	2537
Total D/S traps)		2	703	476	1	7985
Total – All Years		15	2694	2283	59	17 2200
% Comp. of Insects sorted		0.01%	12.10%	10.23%	0.26%	77.32%
% Comp. each year						
1969	U/S only	0.06%	3.78%	5.60%	0	63.94%
1971	U/S only	0.10%	12.77%	11.53%	0.10%	75.49%
1971	D/S only	0.02%	7.67%	5.19%	0.01%	87.11%

* Mk. 3 outrigged traps

(*i*) *Plecoptera*

The nymphs of eleven species were recorded from the river but only three of these species were recorded as adults from the traps. *Taeniopteryx nebulosa* was the only species found to be reasonably common in its immature stages. (LANGFORD 1971). It was shown that nymphs were mature in December/January in the Severn, so that emergence-traps set in March or April would be unlikely to

TABLE V

A Comparison of the Species of Plecoptera, Ephemeroptera and Trichoptera Recorded as Nymphs and as Adults. River Severn, Ironbridge 1966—1971

Species	Nymphs	Adults
A. *Plecoptera*		
Taeniopteryx nebulosa (LINN)	++	—
Brachyptera risi (MORTON)	r	—
Capnia bifrons (NEWMAN)	r	—
Amphinemura sulcicollis (STEPHENS)	r	—
Nemoura avicularis (MORTON)	r	—
Nemoura cinerea (RETZIUS)	r	—
Leuctra fusca (LINNÉ)	+	r
Leuctra inermis (KEMPNY)	r	—
Leuctra moselyi (MORTON)	+	r
Leuctra geniculata (STEPHENS)	—	r
Isoperla grammatica (PODA)	+	r
Rhabdiopteryx anglica KIMMINS...	r	—
Number of Species	11	4
B. *Ephemeroptera*		
Caenis macrura (STEPH)	++	+
Caenis moesta BENGTSS	+	r
Caenis rivulorum ETN.	++	r
Brachycercus harrisella CURT.	r	—
Ephemera danica MÜLL.	+	+
Ephemerella ignita PODA	+++	+++
Ephemerella notata ETN.	r	—
Heptagenia sulphurea (MÜLL)	+++	++
Rithrogena semicolorata (CURT)	r	+
Ecdyonurus insignis (ETN.)	r	+
Baetis rhodani (PICT)	+++	++
Baetis buceratus ETN.	++	++
Baetis pumilus (BURM)	+	+
Baetis vernus (CURT) }	++	++
Baetis tenax (ETN.) }		r
Baetis bioculatus (L.) }	+++	++
Baetis scambus ETN. }		r
Centroptilum luteolum (MÜLL.)	r	r
Centroptilum pennulatum ETN.	—	r
Cloëon dipterum (L.)	+	++
Procloëon pseudorufulum KIMMINS	r	r
Paraleptophlebia submarginata (STEP)	r	—
Haprophlebia fusca (CURT)	r	—
Number of Species	20 (+ 2?)	18
C. *Trichoptera*		
Rhyacophila dorsalis (CURTIS)	+	++
Glossosoma boltoni (CURTIS)	?	+
Agapetus ochripes (CURTIS) }	++	++
Agapetus delicatulus MCLACHLAN }	?	r

TABLE V (Continued)

Species	Nymphs	Adults
Hydroptila tineoides DALMAN }	?	r
Hydroptila sparsa CURTIS }	+	r
Hydroptila forcipata EATON }	?	+
Hydroptila sp. (indet) }	?	+
Polycentropus flavomaculatus (PICTET)	+	++
Psychomyia pusilla (FABRICIUS)	+++	+++
Lype phaeopa (STEPHENS)	—	r
Lype sp. (indet)	—	r
Hydropsyche pellucidula (CURTIS)	++	++
Hydropsyche contubernalis McLACHLAN	+	+
Hydropsyche fulvipes (CURTIS)	+	—
Hydropsyche angustipennis (CURTIS)	+	—
Hydropsyche spp. (indet)	++	++
Arthripsodes albifrons (L.) }	?	r
Arthripsodes alboguttatus (HAGEN) }	?	+
Arthripsodes annulicornis (STEPHENS) }	?	++
Arthripsodes cinereus (RETZIUS) }	++	r
Arthripsodes dissimilis (STEPHENS) }	?	++
Arthripsodes nigronervosus (RETZIUS) }	?	r
Arthripsodes sp. (indet) }	?	+
Mystacides azurea (LINNÉ)	—	r
Setodes punctatus (FABRICIUS)	r	r
Limnephilidae (indet)	r	—
Number of Species	13 (+ 13?)	24
D. *Megaloptera*		
Sisyra terminalis	+	+
Number of Species	1	1

\+ = common but never abundant
++ = common
+++ = common and abundant in correct season
r = rare and occasional records
— = absent
} = groups of species not separately identified as larvae

catch emerging adults. Nymphs of *Leuctra geniculata* were never recorded from the river, though a small number of adults were caught in the earlier traps set during 1966 and subsequently in the traps set in 1971.

(ii) Ephemeroptera

Seventeen of the twenty-three species shown in Table V were recorded from benthos samples and from emergence-traps. The rarer species, *Ephemerella notata*, *Paraleptophlebia submarginata*, *Brachy-*

cercus harrisella and *Haprophlebia fusca* were recorded only in their immature stages, while only adults of *Centroptilum pennulatum* were recorded. Nymphs of the 'slow-water' species (MACAN 1957), e.g. *Cloëon dipterum*, *Centroptilum* spp. and *Procloëon* sp. were recorded only from benthos samples taken from the marginal grasses and backwaters in the Severn at Ironbridge.

Nymphs of *Baetis vernus* and *Baetis tenax* are difficult to separate taxonomically as are those of *Baetis scambus* and *Baetis bioculatus*. Adults of all four species were recorded, though those of *Baetis tenax* and *Baetis scambus* were somewhat scarcer than the others. Table V shows clearly that the emergence-traps caught adults of most of the species represented in the benthos, probably in proportion to their relative abundance as nymphs.

(iii) Trichoptera

The immature stages of a number of adult Trichoptera recorded from the Severn have not been described from British material (HICKIN, 1967). Thus until further taxonomic work has been carried out, some genera are grouped together in Table V. It seems probable, however, that the emergence-traps caught most of the species available in the benthos, probably in proportion to their relative abundance.

(iv) Megaloptera

Only one species, viz. *Sisyra terminalis* was recorded in immature stages and as an adult.

Factors affecting emergence-trap catches

MORGAN, WADDELL & HALL (1963) summarized the various factors known to affect the efficiency of emergence-traps, including the shading effect of traps on ascending larvae or pupae, predation by other invertebrates and fish, the effects of wind and rain on insects already in traps and the decomposition of the catch between visits. In addition to these, the traps on the Severn were also subject to the effects of serious floods.

In any quantitative emergence trapping programme, it is necessary to empty traps at very frequent intervals. MUNDIE (1956) found that weekly visits were too infrequent as insects began to decompose. SPRULES (1947) showed that by emptying emergence-cages at two-hourly intervals, he collected more than twice the number of insects collected by emptying traps at twenty-four hour intervals. As the work on the Severn involved travelling some distance, it was possible to empty traps only three times each week. As a result catches are expressed either as average number of insects per visit, or per week in later sections.

It can be reasonably assumed that most of the factors affecting trap efficiency were affecting all upstream and downstream traps in a similar manner and care was taken to use the same combination of trap types and trapping effort at all sampling stations in 1970 and 1971.

However, before relating catches to river conditions, i.e. floods, temperature and location, it is necessary to assess the effects of other factors viz: –

a. the design of the trap and

b. the siting of each trap in each location, on the overall capture rate, the number of species and the species/composition of the catch.

As only single Mk. 1 and Mk. 2 traps were available in 1970, it is necessary to assess the effects of trap design using mainly 1969 and 1971 data.

TABLE VI

Average Number of Insects Collected Per Visit from Each Emergence Trap

Year	Trap	Plecoptera	Ephemeroptera	Trichoptera	Megaloptera	Diptera
1969	1	0.024	2.462	3.951	0	35.804
1969	2	0.048	1.730	2.268	0	35.171
Total	(1 & 2)	0.036	2.095	3.109	0	35.488
1970	1	0.023	3.444	7.067	0.555	—
1970	2+	0	1.111	0.489	0	—
Av. U/S	(1 & 2)	0.011	2.278	3.778	0.277	—
1970	3+	0	0.133	0.422	0	—
1970	4	0	11.978	5.044	0	—
Av. D/S	(3 & 4)	0	6.044	2.733	0	—
1971	*1A**	*0*	*1.333*	*4.111*	0	*10.361*
1971	1B	0.056	6.417	4.778	0.056	17.139
1971	*1C**	*0.028*	*2.417*	*3.806*	*0.028*	*19.944*
1971	2	0.018	8.545	6.236	0.036	59.782
1971	3	0.091	4.255	3.018	0.055	24.164
Av. U/S	(A.T.)	0.041	4.908	4.431	0.037	29.014
1971	*6A**	*0*	*1.194*	*2.111*	*0*	*32.000*
1971	6B	0	3.145	2.018	0	18.455
1971	*6C**	*0*	*1.438*	*3.167*	*0*	*43.541*
1971	7	0.036	5.728	0.982	0.018	21.655
1971	8	0	1.873	1.164	0	145.18
Av. D/S	(A.T.)	0.008	2.823	1.912	0.004	69.156

* Outrigged traps

+ Traps on slow reaches

A.T. = All Traps

Catches in traps of different design in the same location

An analysis of the variance was carried out on the 1971 catches of Ephemeroptera and Trichoptera to test the effects of trap design and location.

The Mark 3 (outrigged) traps caught significantly fewer (at 1% level) Ephemeroptera per visit than the Mark 1 (float) traps (Table VI and Appendix A, Table A2). This was not true, however, for the Trichoptera (Appendix B, Table B1). The analysis of variance also showed that the variation between the Mk. 1 and Mk. 3 trap catches was similar at both the upstream U/A and downstream D/E location in 1971. It is obvious, therefore, that the presence of a large float has an effect on the catches of adult Ephemeroptera, either because of the observed colonization by nymphs or because of some different pre-emergence behaviour exhibited by the group. Also, at the upstream locaton U/A, the Mk. 3 traps both caught fewer *species* of Ephemeroptera and Trichoptera than the Mk. 1 traps (Table VII). This was not obvious at the downstream location D/E.

TABLE VII

Number of Ephemeroptera and Trichoptera Species Caught by Each Trap River Severn, Ironbridge 1969—1971

Trap	Ephemeroptera	Total	Trichoptera	Total
69/1	7	10	9	10
69/2	8		8	
70/1	11	12	16	18
70/2	5		8	
70/3	2	9	6	14
70/4	9		13	
71/1A	8	16	8	16
71/1B	11		10	
71/1C	9		8	
71/2	13		11	
71/3	12		12	
71/6A	9	13	8	16
71/6B	9		11	
71/6C	8		11	
71/7	10		11	
71/8	8		11	

More detailed analysis shows that generally the Mk. 3 (outrigged) traps caught fewer species of *Baetidae* than the Mk. 1 traps (Fig. 8).

Species-selectivity of each trap was assessed by comparing the percentage compositions, by species, of the total catch, of each of the

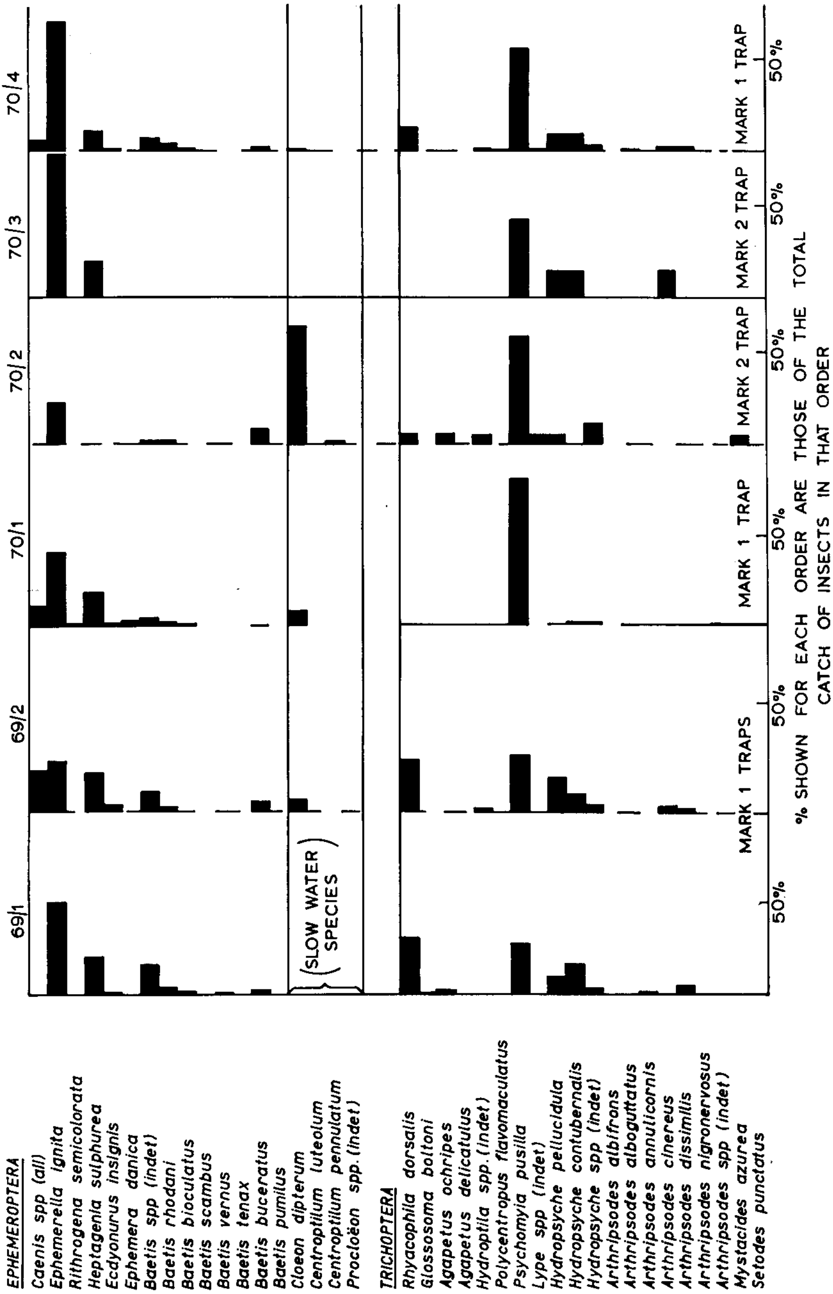


Fig. 7. Percentage composition of the catches of adult ephemeroptera and trichoptera in each emergence trap 1969 1970 river severn.

two main orders, i.e. Ephemeroptera and Trichoptera. The results are shown in Fig. 7 and 8. It is evident that, in 1971, all the traps at each location produced catches with fairly similar compositions, though minor differences between the Mk. 1 and Mk. 3 traps suggested some slight species selection. For example, at U/A the Mk. 1 (float) traps showed an increased proportion of adult *Heptagenia sulphurea* (12.4%) in comparison to that in the Mk. 3 traps (5.5%). A similar trend was shown at D/E where the respective proportions were 14.2% (Mk. 1) and 5.5% (Mk. 3). No other species showed such a consistent tendency at both locations, though at D/E the Mk. 3 traps caught an much larger proportion of adult *Baetis buceratus* (20.2%) than the Mk. 1 traps (8.9%).

Among the Trichoptera, catches of adult *Psychomia pusilla* and *Arthripsodes dissimilis* were relatively larger in Mk. 3 traps (Fig. 8) both upstream and downstream of the power stations. There is evidence, therefore, of some slight selection for species between traps of different types, but not enough to exclude one of the commoner species from either type of trap.

Catches in traps of similar construction at the same location

The analysis of variance showed that there were also significant differences between the catches of Ephemeroptera per visit, in traps of the same type at the same location (Appendix A, Tables A1 and A2). Table IV also shows that 71/2 caught twice as many adult Ephermeroptera as either 71/1B or 71/3, though all were located within an area of 20 m x 5 m. 71/7 also showed this tendency at D/E.

Trichoptera catches did not vary significantly between traps of the same type, over the period analysed i.e. May-October 1971, though the total catch of Trichoptera in 71/2 was higher than in the other traps.

Species-composition of the catches in similar traps was generally very similar (Fig. 7 and 8). 69/2, however, showed a significant percentage of *Caenis spp.* which was not shown by 69/1 (Fig. 7). 71/3 showed greater proportions of adult *Ephemerella ignita* than 71/1B or 71/2 (Fig. 8). At D/E, the only apparent difference between similar traps was the relatively high proportion of adult *Rhyacophila dorsalis* in the catch from 71/8. Where species were absent from any individual trap, they were usually the least common species, representing only a small proportion of the total catch.

Comparison of catches in different locations

(*i*) *Totalled catches*

The main object of the programme was to compare catches at

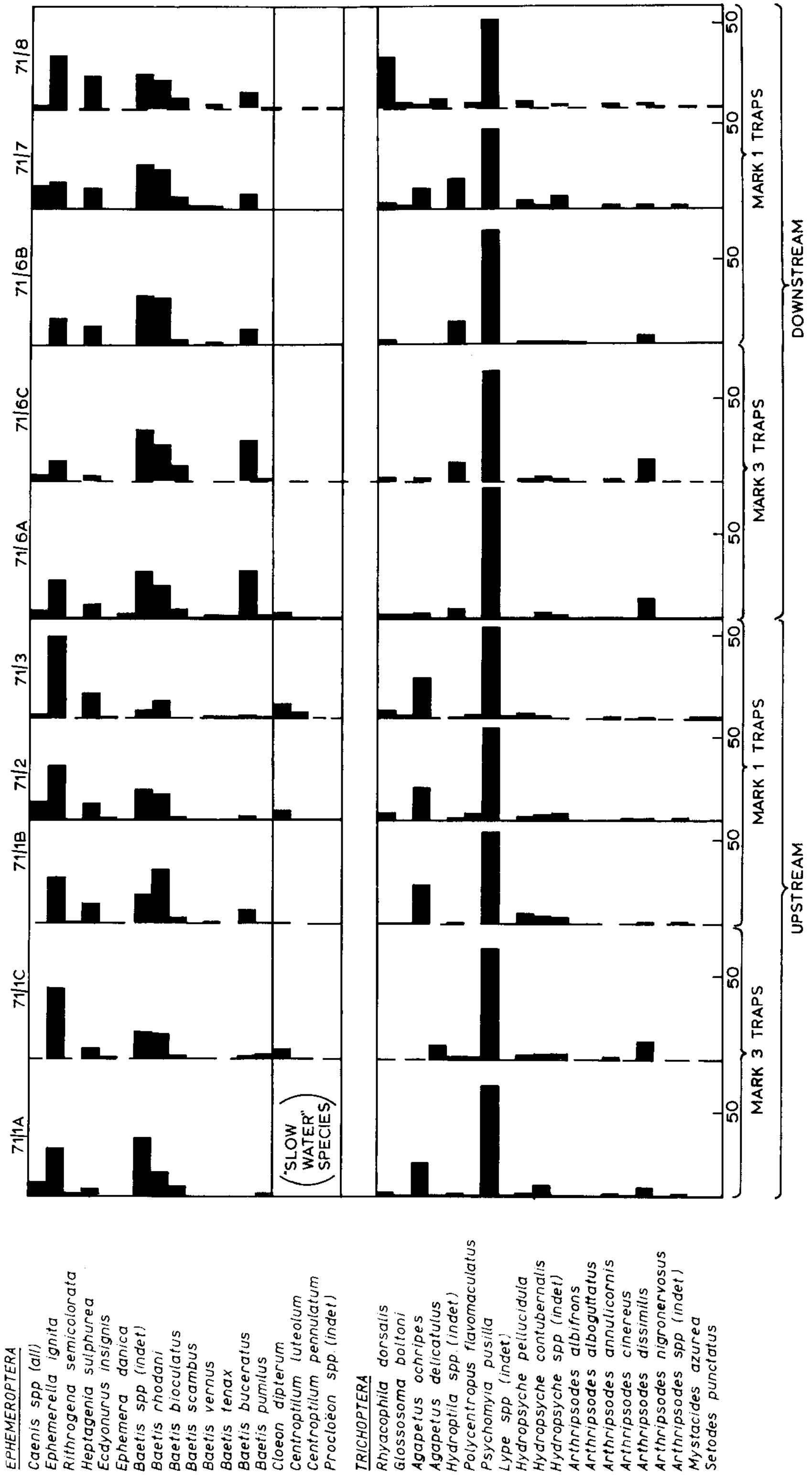


Fig. 8. Percentage composition of the catches of adult ephemeroptera and trichoptera in each emergence trap. River Severn 1971.

locations upstream and downstream of the power stations, and this can be done using both 1970 and 1971 data.

It is evident from Table 3 and Fig. 7 that 70/2 and 70/3 produced the smallest total catches and the least number of species. Surveys on these slow reaches, i.e. U/B and D/B respectively, showed that the bottom fauna here was very sparse in relation to that of the stony runs (LANGFORD, 1971a). There were fewer species and fewer individuals than at U/A and D/E, and the available habitat for colonization was restricted to the small areas of weed and overhanging grasses at the river margins.

Also in 1970, the analysis of variance showed significant differences (at 0.1% level) between the total catches of Ephemeroptera per visit at 70/1 (upstream) and 70/4 (downstream) – See Appendix A. The total catch in 70/4 was in fact *three* times that in 70/1 over the whole emergence period (Table IV).

In 1971, although the results suggested lower average (Table VI) catches per visit at the downstream location, the analysis of variance showed that, for the Ephemeroptera, this was not significant.

For the Trichoptera, however, the average catches were lower at D/E than at U/A (Table VI), in both 1970 and 1971, though the analysis showed that in 1971 the ratio of upstream to downstream catches from visit to visit was not significantly different. A separate analysis, based on the total catch of each trap, showed that there were, however, significantly fewer Trichoptera caught downstream than upstream over the whole sampling period in 1971. A similar analysis on the total catch of Ephemeroptera showed no significant differences between actual numbers caught upstream and downstream in 1971.

(*ii*) *Numbers of species caught*

The number of species caught in both groups varied with year and location (Table 7). In 1971 the increased trapping effort was probably responsible for the capture of more species than in the previous years. There were fewer species of Ephemeroptera caught at the downstream location D/E in both 1970 and 1971. In 1970 fewer species of Trichoptera were caught at D/E than at U/A, though in 1971, the same number of species were caught at both locations. The larger number of Ephemeroptera species caught at U/A was as a result of species from the slow backwater at the margin of the stony run.

(*iii*) *Comparisons of species composition*

To assess the relative similarities of trap catches, a simple coefficient of similarity between pairs of traps was calculated, using the Jaccard equation:

$$C_s = \frac{j}{a + b - j}$$

where C_s = coefficient of similarity expressed as a %
j = the number of species common to both traps, a and b are the numbers of species present in each trap.

Although this method of comparing catches exaggerates the importance of the rarer species, it provides a simple qualitative guide as a basis for more detailed analysis. Fig. 7 and 8 show the percentage-composition by species in each trap and at each location. In Fig. 9 and 10, the C_s for each pair of traps is shown. The Ephemeroptera and Trichoptera are treated separately. There is obviously considerable variation in the coefficients of similarity between pairs of traps, irrespective of location. By far the majority of coefficients for the Ephemeroptera are over 50% (Fig. 9), suggesting that most traps generally caught the same species. The mean C_s for the upstream traps in 1971 was 65.8, with a range of 58—79. For the downstream traps the mean was 74.6 with a range of 58—89. This suggests that the individual upstream strap showed less similarity in their catches of Ephemeroptera species than those downstream. The C_s results *between* upstream and downstream *groups* of traps showed a mean of 63.8%, and a range of 43—100. Thus although there appears on average to be less similarity between traps at the two locations, than between pairs of traps at each location, the range is so wide that the difference is not significant.

The list of *most* and *least* similar pairs (Fig. 9) shows that some of the most similar results were obtained by pairs consisting of an upstream and a downstream trap. On the other hand, the two *least* similar pairs were also made up of an upstream and downstream trap. A C_s of 82% for 70/1 v 70/4 shows very similar qualitative catches at both locations in 1970.

The coefficients of similarity for the Trichoptera species were generally lower than for the Ephemeroptera (Fig. 10). The mean similarity between catches of upstream traps was 57.7% with a range of 46—75%. Downstream, the mean degree of similarity was again less, i.e. 55.6%, again with a wider range (36—83%) than upstream. As with the Ephemeroptera, the mean Cs for Trichoptera catches between upstream and downstream traps (53.2%) was slightly, though not significantly, less than those for traps within each location. The range of similarities was also very wide, i.e. 33—75%. 'Most similar' pairs included 71/1B: 71/7, i.e. an upstream and downstream trap, and the 'least similar' pairs included two downstream traps (Fig. 10). From this analysis of similarities, it is apparent that there were no differences in the qualitative composi-

	70/1	70/4	71/1A	71/1C	71/1B	71/2	71/3	71/6A	71/6C	71/6B	71/7	71/8
70/1												
70/4	82											
71/1A	58	70										
71/1C	67	80	70									
71/B	57	54	58	67								
71/2	60	69	62	69	60							
71/3	53	62	67	62	64	79						
71/6A	67	64	70	50	43	47	62					
71/6C	58	70	100	69	67	69	75	64				
71/6B	54	64	89	62	58	62	54	70	89			
71/7	50	73	64	64	50	53	57	58	73	64		
71/8	58	70	78	62	58	62	67	70	89	78	80	

Fig. 9. Coefficients of similarity for *Ephemeroptera* catches in emergence traps, upstream and downstream of ironbridge power station (1970/1971).

No. pairs	% Sim.	Most similar pairs	% Sim.
20	70+	71/1A: 71/6C	100
44	50+	71/1A: 71/6B	89
2	40+	71/6C: 71/6B	89
0	25+	70/1: 70/4	82
0	25—		
		Least similar pairs	
		71/1B: 71/6A	43
		71/2: 71/6A	47

tion of the emergence-trap catches which can be related to the power station's discharge, and there was no significant difference in the species composition of the total adult Ephemeroptera and Trichoptera emergence during 1971, which can be related to the different locations. In 1970, the coefficients of similarity between 70/1 and 70/4 showed that, during the year catches of species upstream and

	70/1	70/4	71/1A	71/1C	71/1B	71/2	71/3	71/6A	71/6C	71/6B	71/7	71/8
70/1												
70/4	53											
71/1A	41	40										
71/1C	44	35	64									
71/B	50	50	60	50								
71/2	50	41	46	46	75							
71/3	75	47	54	67	62	53						
71/6A	33	31	45	33	64	46	43					
71/6C	59	60	46	58	50	47	64	36				
71/6B	50	60	58	58	62	38	53	58	57			
71/7	59	50	58	58	75	57	64	46	69	83		
71/8	50	50	46	46	50	57	53	36	57	57	57	

Fig. 10. Coefficients of similarity for *Trichoptera* catches in emergence traps, upstream and downstream of ironbridge power station (1970/1971).

No. pairs	% Sim.	Most similar pairs	% Sim.
4	70+	71/6C: 71/7	83
39	50+	71/1B: 71/7	75
16	40+	71/1B: 71/3	75
9	25+	71/1B: 71/2	75
0	25—		

Least similar pairs	
70/4: 70/6A	31
70/1: 70/6A	33
71/1C: 71/6A	33
71/1B: 70/4	35
71/6A: 70/6C	36

downstream were also relatively similar, though the results for Ephermeroptera showed more similarity than those for Trichoptera. Fig. 7 and 8 show also that the percentage composition of the catch was basically similar in all traps, both upstream and downstream of the power stations, except for 70/2 and 70/3. The same species tended to predominate in the catches at both U/A and D/E in 1970 and 1971, though there were minor changes in relative abundance. For example, in 1971 *Agapetus ochripes* was generally more abundant at U/A than at D/E and *Baetis buceratus* more abundant at D/E.

The reason for the larger number of Ephemeroptera species at U/A in 1970 and 1971 was mainly the presence of the 'slow-water' species, i.e. *Cloëon dipterum*, *Centroptilum* spp., and *Procloëon* so. in these upstream traps. These probably originated from marginal grasses (LANGFORD, in press) and the slow backwater at U/A. There was no obvious reason for the lower number of species of Trichoptera at D/E in 1970, but the species not recorded downstream represented only a very small proportion of the total catch in the upstream trap U/A. These were probably not sampled as effectively by the single traps as by the larger groupings in 1971. The predominant species of Ephemeroptera in all locations seemed to be *Ephemerella ignita*, *Heptagenia sulphurea* and *Baetis spp.*, though in 1970 adult *Baetis spp.* were much less common than in 1971. In 70/2, the 'slow-water' species, *Cloëon dipterum*, dominated the total catch, though this was relatively small. 70/3 caught no adults of this species. Of the Trichoptera, *Psychomyia pusilla*, *Hydropsyche spp.* and *Rhyacophila dorsalis* were most abundant in the total catches of 1969 and 1970, though in 1971, *Agapetus ochripes* was also very common.

Seasonal variations in total emergence

The seasonal variations in total emergence are probably related to a number of factors, including river conditions, time of year and the emergence pattern of each species (LANGFORD, in press). It is difficult in a field study to relate separately the effects of temperature, flow and time on emergence though the relative importance of each factor may be assessed by careful examination of the data for a number of years. There were slight variations in the emergence period for both Ephemeroptera and Trichoptera during 1970 and 1971. In 1970, emergence of Ephemeroptera began about May 20, at U/A and May 28 at D/E. At U/A, the numbers of adults caught were much lower than at D/E during the period from June 5 to about July 20, though the patterns were reasonably similar. From July 20 numbers were low at both locations and catches ceased after August 20 at D/E and September 7 at U/A. Thus the total emergence of Ephemeroptera occurred over a longer period at U/A than at D/E, though the rate of capture at D/E was considerably higher than at U/A during June and July.

In 1971, adult Ephemeroptera were first collected on May 12 at both U/A and D/E. At U/A there was a marked peak in captures on

June 5—7, which was not as obvious downstream of the power station. A second peak period of emergence occurred both upstream and downstream between July 20 and August 2, but again this second peak was not as marked at the downstream station. A smaller peak emergence occurred in September at both locations, but this time catches were much larger at the downstream location.

There was a considerable difference in the extension of the emergence period during autumn, from year to year. In both 1969 and 1970, catches of Ephemeroptera were low in September. In 1970, emergence appeared to cease before mid-September, while in 1969, a few adults were captured in mid-October. In 1971, on the other hand, emergence continued at a high rate throughout the whole of September, but ceased before October 10.

Catches of adult Trichoptera were first recorded on May 12 1970, at U/A and May 26 at D/E. Upstream catches reached a peak on June 24. Downstream a similar peak occurred on June 21, more or less at the same time. A second peak occurred upstream on August 7 but this was not very obvious downstream. The last catches of Trichoptera in 1970 were on September 10 at both locations. In 1969, Trichoptera were captured in traps as late as October 21.

In 1971, adult Trichoptera were first recorded at about the same time as in 1970, with peaks occurring during late May and early June, and again during July. After a break in August some Trichoptera were caught during September and small numbers were collected as late as October 7 at U/A.

In both groups, there were obvious differences in the extension of the emergence periods into autumn in different years. There were, however, no significant differences between the total emergence periods upstream and downstream of the power stations.

Seasonal variations in catches from individual traps

Individual traps showed slight variations in catches which are obviously important to further work of this nature (Fig. 11, 12 and 13). For example in 69/1 (Fig. 11) captures of Trichoptera remained fairly constant during the late summer, but 69/2 showed two distinct peaks. In 1971, seasonal patterns of Ephemeropteran emergence were obviously different in Mark 1 (float) and Mark 3 (outrigged) traps, at the upstream location. In June all five traps showed a peak in captures, though a second peak, during late July and early August, only occurred in all the Mark 1 traps. At D/E all traps showed similar patterns but the capture-rate in Mark 1 traps was consistently higher than in Mark 3 traps.

There were not such obvious differences in trap performance as far as Trichoptera catches were concerned (Fig. 13). Where in-

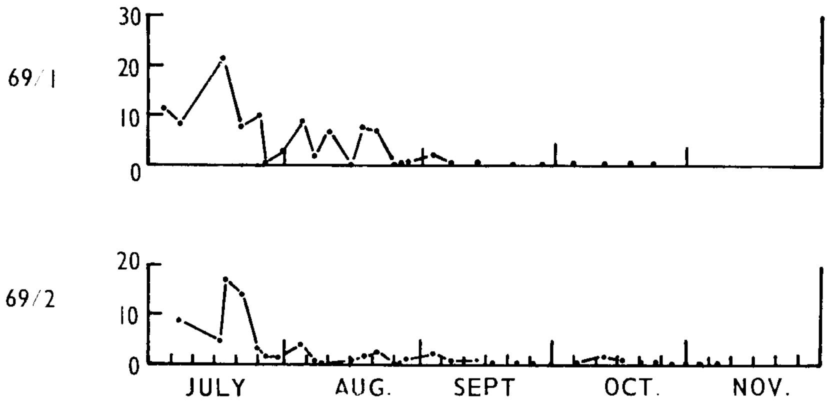


Fig. 11. Numbers of *Ephemeroptera* collected from each trap on each visit in 1969.

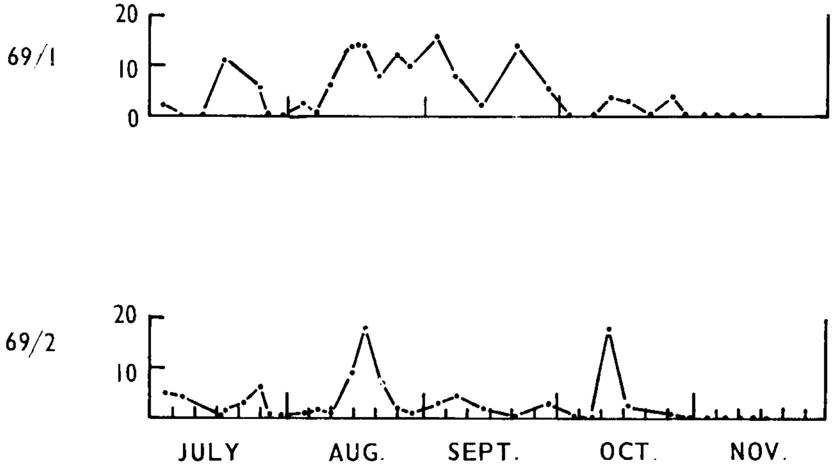


Fig. 12. Numbers of *Trichoptera* collected from each trap on each visit in 1699.

consistencies did occur, they were not related to the *type* of trap. For example, catches reached a peak during late May (1971) in all traps at U/A, but only in three of the traps at D/E, viz. 71/6A, 6B and 6C. In the two separate Mark 1 traps, 71/7 and 71/8, the peak occurred some two weeks later. The reason for this is not clear, though as the first three traps with similar peaks were very close together, distribution or larvae on the river bed may be an important factor.

Total emergence in relation to water temperature and river level

It is evident from all the data so far that there are few differences between the total emergence at locations upstream and downstream

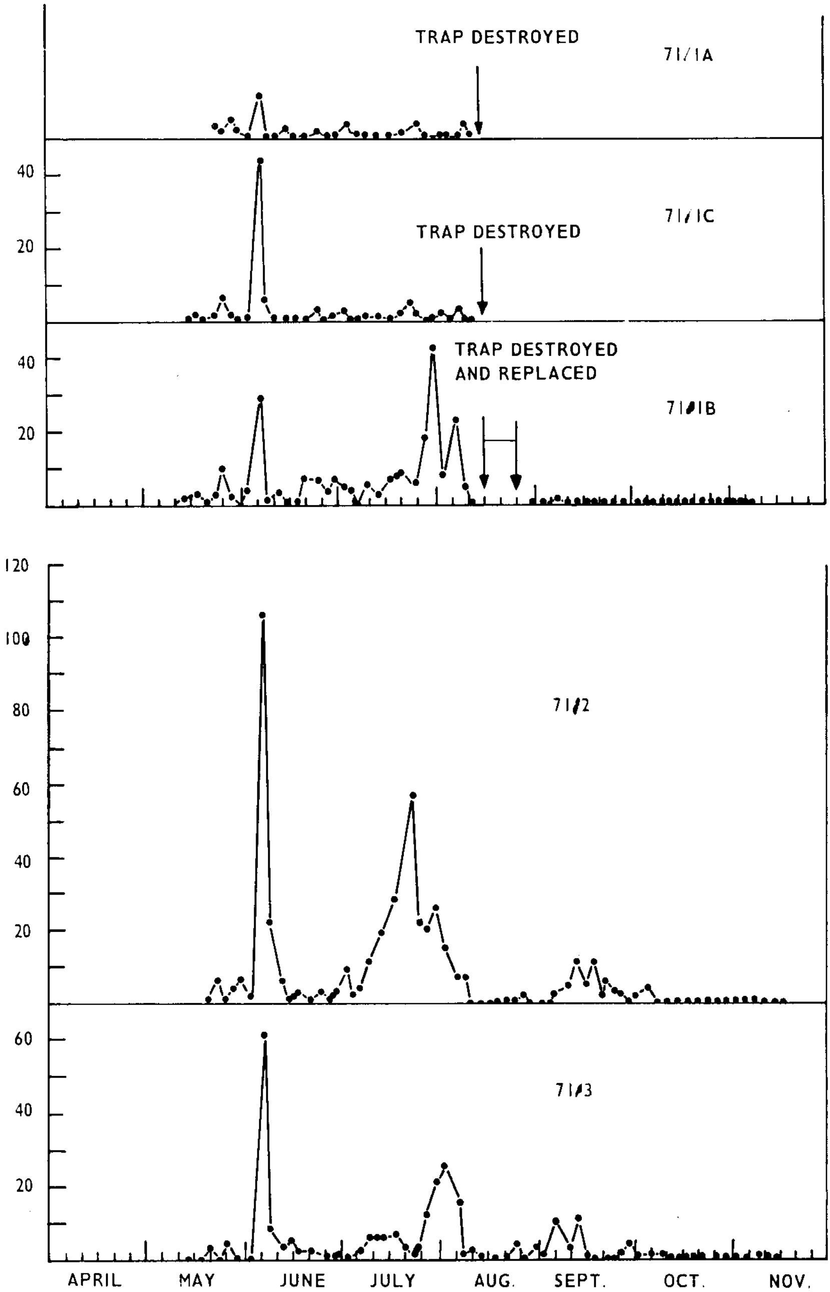


Fig. 13. Number of *Ephemeroptera* collected on each visit from each trap at U/A (1971).

of the power stations, which can readily be related to the effects of the discharges. It is, however, also evident (Fig. 14 to 19) that most emergence of both Ephemeroptera and Trichoptera takes place at low river levels, i.e. below 120′ (O.D.N.) and water temperatures over 15°C, though these are by no means limiting values.

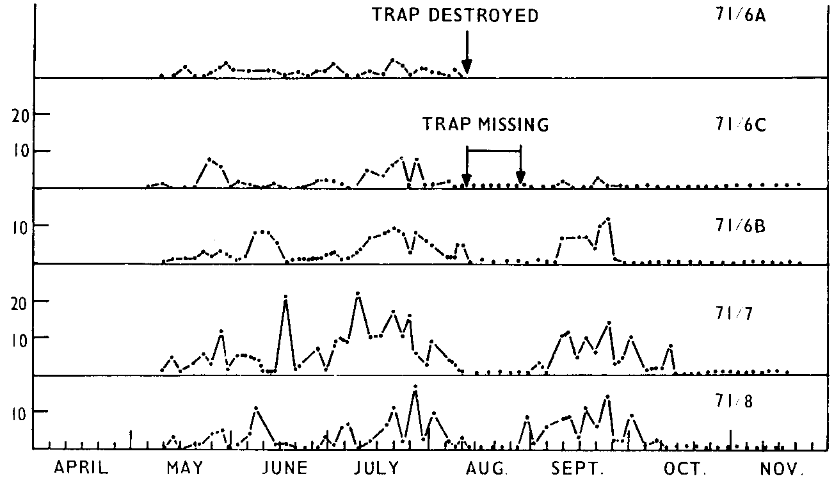


Fig. 14. Numbers of *Ephemeroptera* collected on each visit from each trap at D/E (1971).

a. Ephemeroptera

In 1970, when the first adult Ephemeroptera were captured, river temperatures upstream were around 14°C and downstream around 20°C. The higher temperatures at D/E during May did not result in any obvious advance in emergence. The highest capture-rate at U/A in 1970 coincided with the June period of high river temperatures. Catches did, however, fall off sharply when river temperatures dropped to 14.5°C in early July. Even when temperatures rose again, emergence continued at a low rate at U/A. At D/E, however, Ephemeroptera catches reached a peak when river temperatures rose to 26°C and then remained at a high level during the period of very high downstream temperatures in June. A small decrease in captures occurred during early July, when downstream temperature dropped to 18°C, but captures increased again as river temperatures rose to 24—26°C. Careful examination of Fig. 15 shows that catches again decreased at D/E, before temperatures fell below 22°C, though at U/A they had been at a low level since mid-July, when temperatures stayed below 20°C.

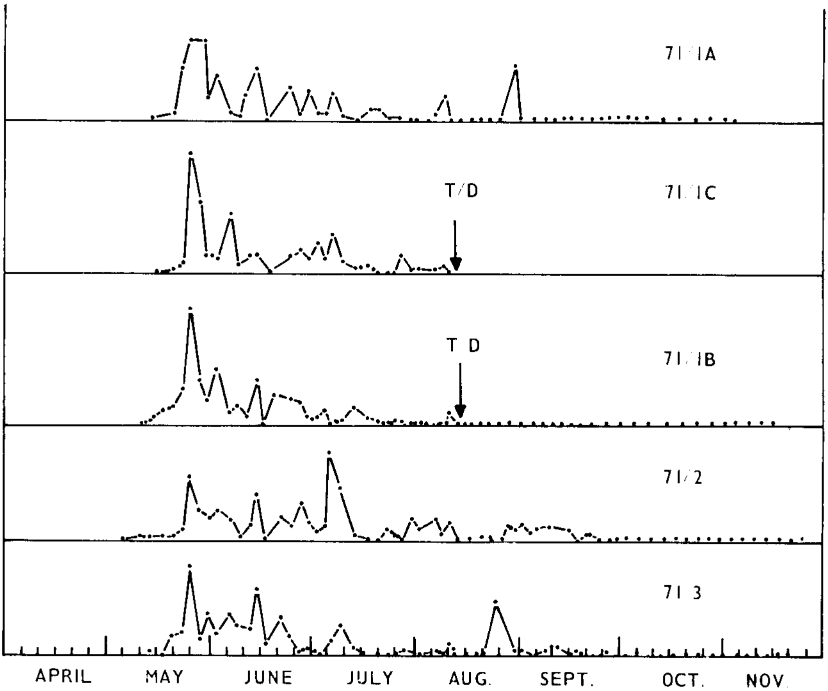


Fig. 15. Numbers of *Trichoptera* collected from each trap at U/A on each visit (1971).

Although the fall in river temperature in July did not coincide with a spate, the fall in temperature in late August did. During and after this spate, very few adult Ephemeroptera were taken either upstream or downstream even though temperatures at D/E did rise to 19.5°C between the autumn spates, and to 18°C during late September. Upstream, some adults were collected from traps when river temperatures were around 14—16°C in early September.

Emergence continued during June, even when river temperature reached 27.8°C on June 12, and there was no evidence of a subsequent suppression of total emergence.

In 1971, the first Ephemeroptera adults were trapped when river temperatures were 12°C upstream and downstream of the power station (Fig. 16). The first peak occurred when water temperatures were about 16°C and river levels at 119′. Catches were reduced upstream when the small June spate coincided with river temperatures as low as 11°C, but emergence did not cease either upstream or downstream. The second peak of Ephemeroptera captures coincided at both locations with river levels of about 119′ and river temperatures of 18—20°C. The September emergence occurred

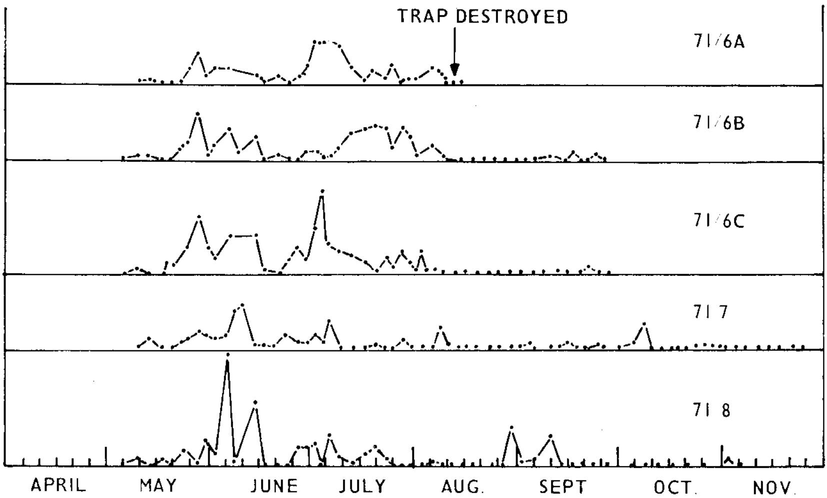


Fig. 16. Numbers of *Trichoptera* collected on each visit from each trap at D/E (1971).

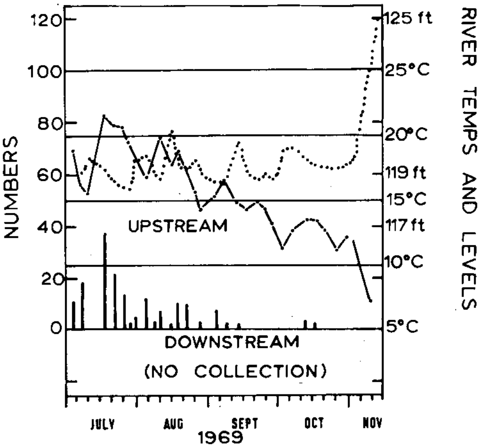
again at low river levels, but at water temperatures (upstream) of 12—16°C. Downstream temperatures were 16°—20°C and the emergence rate was somewhat higher than upstream. The break in captures during August coincided with a heavy spate. It is important to note, however, that although water temperatures were stable around 15—16°C, in late August, catches did not recommence until river levels were well below 121′. Peak captures again occurred at river levels around 119′.

It is evident therefore that there is some relationship between river level, water temperature and trap captures. River level, and therefore flow, appears to be a major factor limiting captures of Ephemeroptera. The evidence shows clearly that emergence continued during water temperatures of up to 27.8°C in 1970 and down to 11°C in 1971, both without obvious drastic effects on later emergence. Some adults were emerging at temperatures of 11—12°C in the autumn.

b. Trichoptera

In both 1970 and 1971, catches of adult Trichoptera first occurred at about the same time as the first Ephemeroptera captures. Water temperatures were then 14°C upstream and 21°C downstream in 1970, and 12°C and 13°C in 1971. Again, first captures were recorded at or around the same data in both locations.

In both years, there was apparently less relationship between captures of Trichoptera, water level and temperature than for the



Key applies to fig. 17, 18, & 19
Temperature .—.—.
River level ....
(River level at surface on feet above ordnance datum Newlyn)
Months are sub-divided into 5 day intervals

Fig. 17. Total number of *Ephemeroptera* collected f om all traps on each visit.

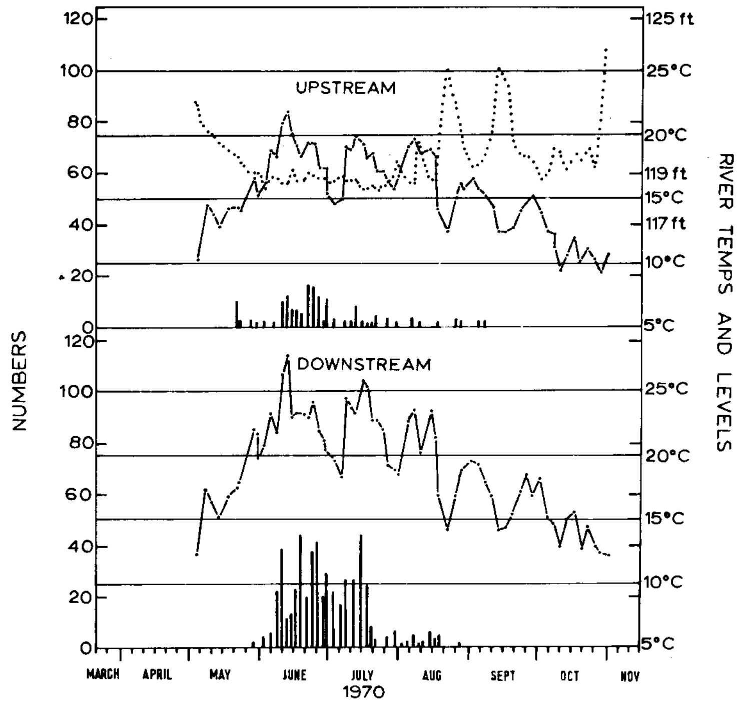


Fig. 18. Total number of *Ephemeroptera* collected frım all traps on each visit.

Ephemeroptera (Fig. 17 and 19). In 1970, the first large peak occurred at U/A in late June, some ten or twelve days after the peak water temperatures. Also, emergence appeared to continue through the first heavy August spate, but not through the second spate. No captures were recorded in late September and October, even though

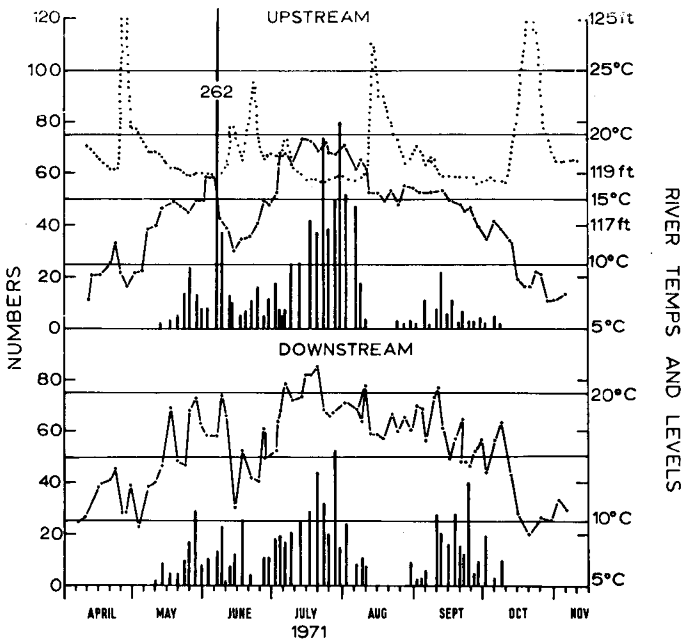
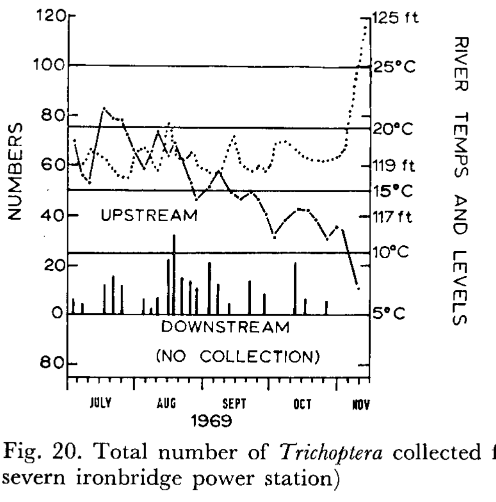


Fig. 19. Total number of *Ephemeroptera* collected from all traps on each visit·



Key applies to fig. 20, 21 & 22
Temperature .—.—.
River level ....
(River level at surface level in feet above ordnance datum level)
Months are sub-divided into 5 day intervals

Fig. 20. Total number of *Trichoptera* collected from all traps on each visit (R. severn ironbridge power station)

water temperature was a little higher than in 1969 or 1971 at the beginning of the month, and river levels were quite low.

In 1971, the first peak captures coincided with a period of rising temperature and low flows, but emergence continued at an apparently high rate through the small June spate, when water temperatures dropped to 11°C both upstream and downstream, As with the Ephemeroptera, there was a break in captures during the heavy August spate, but these increased again during September. There was no real peak emergence during the 'low river level/high temperature' period in July and early August, and capture-rate was consistently low both upstream and downstream.

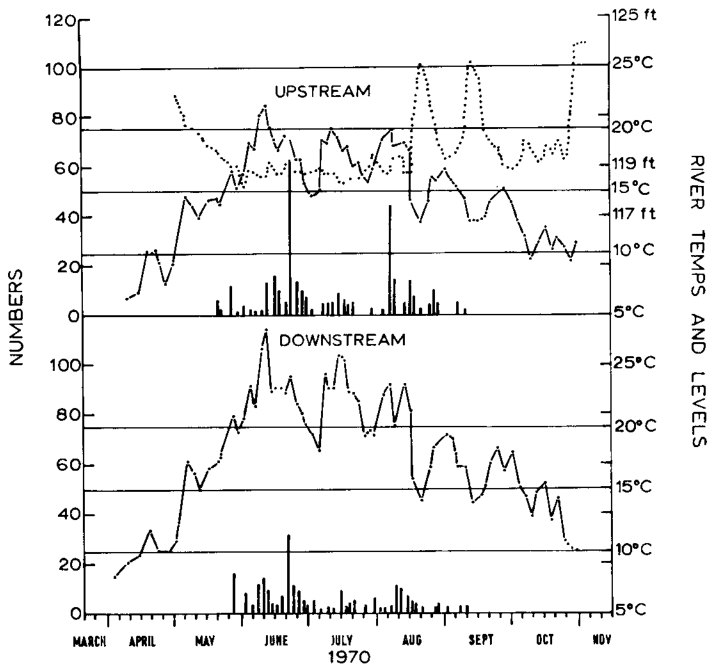


Fig. 21. Total number of *Trichoptera* collected from all traps on each visit (R. severn ironbridge power station)

There was no prolongation of the emergence period at the downstream stations during either 1970 or 1971.

Discussion

One of the main points for discussion, as a result of the data presented here, is whether the variation of trap catches (capture-rate)

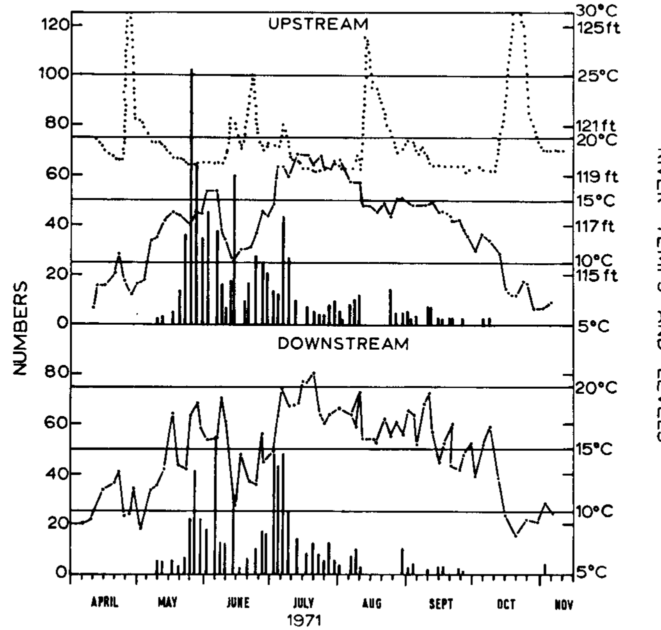


Fig. 22. Total number of *Trichoptera* collected from all traps on each visit. (R. severn ironbridge power station).

with river level and water temperature is caused by an actual variation in the emergence patterns of the insects or to a change in the efficiency of the traps, irrespective of these emergence patterns. There is little doubt that catches of Trichoptera varied independently of trap type. The presence of absence of a large float for colonization had little effect on their capture-rate. If these insects were emerging at a constant rate during different river conditions, catches in the outrigged traps, which relied on insects emerging directly from the water for captures, should have been unchanged during these conditions. The fact that total captures tended to fall in all traps during low temperatures and high-water levels suggests that this was owing to changes in actual emergence rate, though for some specimens emergence continued at a steady rate even during spates (LANGFORD – in press).

The effects of trap type on Ephemeroptera catches are not as conclusive. In June, the presence of a large peak in all five traps upstream suggests that emergence rate was high, irrespective of colonization of the float-traps by immature stages. Similarly, the reduction in captures in *all* traps during mid to late June suggests an actual reduction in emergence rate. The August peak captures, occurring only in the Mark 1 (float) traps, suggests an effect of trap-type on captures which may then have been affected differently by the August spates. In this case there may be a trap effect rather than an effect on emergence. Further analysis (LANGFORD, in press) shows that the June peak and August peak were due to emergence of different species and the lack of a peak in 71/1A and 71/1C may also have been due to different pre-emergence behaviour of the later species. It is reasonable to conclude, however, that the major emergence takes place during periods of low flow, and higher water temperatures.

COUTANT (1967) concluded that a 1°C temperature rise in the Columbia river caused a significant two-week advance in the emergence date of Hydropsychid caddis-flies. Although the emergence patterns of individual species are not shown here, it is obvious that there was no total advance in the Severn, even during 1970, when May temperatures downstream were relatively high. The direct effects of temperature on the emergence of adult insects are not easy to determine in a field study. GLEDHILL (1960) concluded that onset of emergence was not related to temperature in a Lake District stream. PLESKOT (1953) on the other hand suggested that emergence occurred so that the insects could avoid periods of high water temperature and low oxygen levels. MACAN AND MAUDDESLEY (1966) showed that the onset of emergence in some Odonata was related to the first date on which certain water temperatures were reached.

It is apparent that, in the Severn, the temperature increment at D/E during the winter and early spring has no effect on the onset of total emergence, though different species may be found to respond differently (LANGFORD, in press). Also, there is no apparent extension of emergence into the autumn in the heated reaches.

Similar work on a heated lake (ROTHWELL 1971) showed that although species of Chironomidae could be induced experimentally to emerge as adults earlier than normal at 25°C, there was no advance in their emergence periods in the lake itself, although there was evidence that some Trichoptera emerged relatively early.

Recent work by NEBEKER et al. (1971) has shown that some species of stone-fly can be induced experimentally to emerge early, if fully grown numphs are transferred from winter temperatures around 2°C, to spring or summer temperatures around 16°C. The implications of this work are discussed in relation to whole insect populations in streams in the second paper (LANGFORD, in press).

Although the conclusion from the work on the Severn suggest that there are no changes in total emergence above and below the power station discharge, it is not possible to conclude that increased temperature will never have any effect, only that the type of temperature increases experienced at Ironbridge are not significant. However, during 1970 and 1971, river temperatures varied sufficiently during the summers to show that total emergence was not arrested by either very high or very low temperatures, once the emergence period has begun.

Day-length (photo-period) is known to affect various stages in insect life-histories (DANILIEVSKII 1965) and there is no doubt that it has some effect on the onset of emergence in aquatic insects (BECK 1968). The fact that captures began on certain dates both upstream and downstream of the power stations, irrespective of temperature or of the date of installation of the trap, suggests that some relatively constant factor may be the major controlling factor for onset of emergence, though this can be confirmed only by experiment.

MACAN (1958) has suggested that short emergence periods in some insects were related to warmer spring and summer water and air temperatures. From the work on the Severn, it is evident that the total emergence season in 1970 at both upstream and downstream of the power stations was shorter than in 1971 or probably 1969. There was no exaggeration of this at the downstream station even though water temperatures were much higher, and on close analysis it appears that the shorter emergence period may have been more related to the two, large spates in August and September, than to temperature.

ACKNOWLEDGEMENTS

This paper is published by permission of the Central Electricity Generating Board. The authors wish to thank Mr. K. Johnson for statistical analyses and R. S. A. Beauchamps for editing manuscript.

REFERENCES

BECK, STANLEY D. - 1968 - Insect Photoperiodism. Academic Press N.Y. and Lond. (273 pp).

BREGMAN, JACOB - 1969 - Keynote Address to National Symposium on Thermal Pollution – in: Engineering Aspects of Thermal Pollution. (Ed.) KRENKEL, P. A. & PARKER, F. L. Vanderbuilt Press (1969) pp. 3—14.

DANILIEVSKII, A. A. - 1965 - Photoperiodism and Seasonal Development in Insects – OLIVER & BOYD (Lond. 1—178) (Translation of 1961 Book).

GLEDHILL, T. - 1960 - The Ephemeroptera, Plecoptera and Trichoptera caught by emergence traps in two streams during 1958 – *Hydrobiologia* XV: 179—188.

HAWKES, H. A. - 1969 - Ecological Changes of Applied Significance Induced by the Discharge of Heated Waters – in engineering aspects of thermal pollution – PARKER, F. L. & KRENKEL, P. A. (eds). Vanderbuilt Univ. Press Nashville Tenn. 15.

LANGFORD, T. E. - 1970 - The Temperature of a British River upstream and downstream of a heated discharge from a Power Station. *Hydrobiologia* 35: 353—375.

LANGFORD, T. E. - 1971 - The Distribution, Abundance and Life-Histories of Stoneflies (Plecoptera) and Mayflies (Ephemeroptera) in a British River, Warmed by Cooling Water from a Power Station. Hydrobiologia 38: 339—376.

LANGFORD, T. E. - in press - The Emergence Patterns of some Ephemeroptera and Trichoptera in relation to the cooling-water discharge from Ironbridge Power Station (1969—1971).

LANGFORD, T. E. & ASTON, R. J. - 1972 - The Ecology of Some British Rivers in Relation to warm water discharges from Power Stations. *Proc. R. Soc. Lond.* 180: 407—419.

LEMKE, A. E. & MATTSON, U. R. - 1969 - An Emergence Trap for Aquatic Insects – *The Michigan Entomologist* 2. No. 1—2: 19—21.

MACAN, T. T. - 1957 - The Ephemeroptera of a stony stream. *J. Anim. Ecol.* 26: 317—342.

MACAN, T. T. - 1958b - Causes and Effects of short emergence periods in insects. *Verh. int. Ver. Limnol.* 13: 845—849.

MACAN, T. T. - 1964 - Emergence Traps and the Investigation of stream faunas. *Riv. di Idrobiol*: Vol III. 75—92.

MACAN, T. T. & MAUDDESLEY, R. - 1966 - The Temperature of a Moorland Fishpond. *Hydrobiol.* 27: 1—22.

MORGAN, N. C., WADDELL, A. B. & HALL, W. B. - 1963 - A comparison of the catches of emerging insects in floating box and submerged funnel traps. *J. Ecol.* 203—218.

MUNDIE, J. H. - 1956 - Emergence Traps for Aquatic Insects. *Mitt. int. Ver. Limnol.* 7: 1—13.

NEBEKER, A. V. - 1971 - Effect of High Water temperatures on adult emergence of aquatic insects. *Wat. Res.* 5: 777—783.

PLESKOT, G. - 1953 - Zur Ökologie der Leptophlebiiden. (Ins. Ephemeroptera), *Öst. Zool. Z.* 4: 45—107.

Severn river authority annual reports - 1970, 1971.

SOUTHWOOD, T. R. E. - 1966 - Ecological Methods. Methuen & Co. Ltd. Lond. 391 pp.

SPRULES, W. M. - 1947 - An ecological investigation of stream insects in Algonquin Park. Ontario. *Univ. Toronto. Stud. Biol.* 56: 1—181.

Appendix A

Ephemeroptera

Table A1

Source of variation	S.S.	D.F.	M.S.	V.R.	Whether Significant
Visits	24.4538	35	0.70	7	***
Traps	11.2429	9	1.25	12.5	***
Visits × Traps	32.0154	315	0.102		
Total	67.7121	359			

Table A2

Source of variation	S.S.	D.F.	M.S.	V.R.	Whether Significant
Upstream v. Downstream	0.0989	1	0.0989	.25	
Mk. 1 v. Mk. 3	8.4848	1	8.4848	21.2	**
Type × Location	0.2401	1	0.2401	0.6	
Within types of locations	2.4191	6	0.403	4	***
Total Traps	11.2429	9			

Table A3

Source of variation	S.S.	D.F.	M.S.	V.R.	Whether Significant
Location × Visits	6.8986	35	0.197	2.2	***
Within Upstream × Visits	14.8583	140	0.106		
Within Downstream × Visits	10.2585	140	0.073		
Total Traps × Visits	32.0154	315			

***Significant at 0.1% level
**Significant at 1% level

Trichoptera

Table B1

Source of Variation	S.S.	D.F.	M.S.	V.R.	Whether Significant
Visits	30.3341	35	0.87	9	***
Traps	1.1800	9	0.13	1.4	
Visits × Traps	29.5604	315	0.094		
Total	61.0745	359			

Table B2

Source of Variation	S.S.	D.F.	M.S.	V.R.	Whether Significant
Upstream v. Downstream	0.3826	1	0.3826	4.0	
Mk. 1 v. Mk. 3	0.0001	1	0.0001	0.001	
Type × Location	0.2183	1	0.2183	2.3	
Within types of locations	0.5790	6	0.0965		
Total Traps	1.1800	9			

Table B3

Source of Variation	S.S.	D.F.	M.S.	V.R.	Whether Significant
Location × Visits	6.1101	35	0.175	2.08	**
Within Upstream × Visits	12.4782	140	0.089		
Within Downstream × Visits	10.9721	140	0.078		
Total, Traps × Visits	29.5604	315			

***Significant at 0.1% level
**Significant at 1% level