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Mass mortalities of adult salmon *(Salmo salar* L.) in the R. Wye, 1976

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Abstract

The physical, biological and chemical conditions leading to a mass mortality of adult salmon *(Salmo salar* L.) in the lower reaches of the R. Wye are described. As a result of sunny and low flow conditions during late June, 1976, water temperatures increased to a maximum of 27.6°C and accelerated the decay of substantial plant stands, the growth of which had been enhanced by the prevailing conditions: this resulted in severe de-oxygenation of the water. It is concluded that the low oxygen concentration in the water at this time was the principal factor in causing mass mortalities of fish and was probably accentuated by high water temperatures.

I Introduction

The R. Wye, which is 250km long and drains an area of 4183 km^2, rises at Plynlimon (677m O.D.) in Powys, Wales and enters the Severn Estuary at Chepstow (Fig. 1). The river supports a substantial rod and net salmon fishery: during the period 1945 – 1975 annual rod catches of salmon averaged 4072 (2056 – 7864) with an average annual total weight of 25659 (13493 – 56561) kg (Wye River Division 1975). Edwards (*pers. comm.*) has estimated that the recreational fishery of this catchment (including other species) with associated activities generates an actual expenditure of approximately £5 million.

Although fish mortalities resulting from episodes of pollution have been the subject of much investigation, there are few reports of fish deaths resulting from natural changes in water quality. During 1976 a massive mortality of salmon occurred in one region of the R. Wye where routine observations relating to a wider and long-term biological and chemical study of the river were being made: this paper describes those routine observations of river conditions.

II Salmon Deaths

Reports of salmon deaths were generally restricted to those reaches of the river below Hampton Bishop (Fig. 1.). Some mortalities were recorded on 24 and 25 June 1976 but it seems likely that the major 'kill' occurred on the night of 28 June (Staite *pers. comm.*). During the period 29 June – 2 July, 426 adult corpses were recorded by Wye River Division staff between Hampton Bishop and Bigsweir (Fig. 1).

Observations by U.W.I.S.T. (University of Wales Institute of Science and Technology) staff, from a boat, on 29 and 30 June recorded 93 salmon corpses between Ross and Monmouth (Figs 1 & 2a). In this survey the greatest density, 4.5 corpses/ha of river, was observed in a 0.9 km reach 3.0 km downstream of

Kerne Bridge (Figs 1 & 2a). Comparison of counts between Ross and Monmouth from the above sources indicated substantial differences (Table 1). Despite these differences it is clear that substantial mortalities of adult salmon did occur in late June, Staite *(pers. comm.)* estimated that total deaths were probably in the region of 1000.

III Rainfall

Comparison of rainfall in the Wye catchment in 1975 and 1976 indicates that in both years precipitation was much lower than the long term average (1916 – 1950) (Table II). In 1976 rainfall (January to July inclusive) at stations in the upper (Cefn Brywn), middle (Erwood) and lower (Ross-on-Wye) catchment was always less than 50% of the long term average. The 18-month period beginning February 1975 can be regarded as the driest period recorded in the Wye catchment (Tillotson *pers. comm.*).

IV River Flow

As a result of the very low rainfall during 1976, river flows in the R. Wye have been the lowest on record (Tillotson *pers. comm.)* (Table III). The flow at Kerne Bridge (Fig. 1), where substantial numbers of salmon corpses were recorded, was generally below 10 cumec for most of June (Fig. 3, Table III) and during the period 21-30 June, when the major fish 'kill' occurred, flows fell from 9.0 to 5.5 cumec (Fig. 3a). Average flows during June and July were less than 30% of the long term average (Table III).

V Sunshine and Temperature

The general meteorological conditions during the summer of 1976 were characterised not only by low rainfall but long periods of sunshine and high air temperatures, particularly during the period 23 June – 7 July (Table IV). During the final week in June, when fish deaths occurred, maximum air temperature ranged from 25.8 to 31.5^{o}C, considerably greater than during the same period in 1975 (15.0 to 24.4^{o}C) (Table IV). Water temperatures, measured continuously in the R. Wye at Kerne Bridge by a submersible temperature and oxygen recorder were also considerably elevated during this period (Fig. 3b). Average daily water temperature increased steadily from 23 June (21.4^{o}C) to 28 June (26.3^{o}C) (Fig. 3b). The highest temperature recorded (28.0^{o}C) was on 4 July: the maximum temperature on 28 June, the day prior to the massive 'kill' of salmon was 27.6^{o}C recorded at 16.00 hours BST (Table V). Minimum water temperatures on 29 and 30 June were 25.2 (at 06.00 hours BST) and 24.1^{o}C (at 04.00 hours BST) respectively. Limited records of water temperature at Kerne Bridge in 1975 indicate that maximum temperatures during the periods 24 June – 2 July and 8 July – 18 July did not exceed 23.0^{o}C.

VI Aquatic Plants and Water Quality

The lower reaches (below Hereford, Fig. 1) of the R. Wye are characterised by substantial summer growths of the submerged macrophyte *Ranunculus fluitans* (long-leaved water crowfoot). Surveys in 1975 and 1976 between Ross and

Monmouth (Fig. 1) along reaches of variable length (0.6 – 3.0 km) indicated that the average cover (expressed as a percentage of river surface) was substantially greater in 1976 (36%) THAN IN 1975 (17%) (Fig. 2b).

Supplementary studies designed to describe the growth characteristics of *R. fluitans* in representative stands were undertaken, using an optical technique (Owens *et al* 1967), at Kerne Bridge (220m long and 55m wide) and Huntsham Bridge (230m long and 50m wide) (Fig. 1). IN both years the pattern of growth was similar with peak biomasses being recorded in mid-June: death and decay in both years occurred at the end of June and the beginning of July (Fig. 3c). At both sides peak mean biomass in 1976 was some four times the value recorded in 1975 (Table VI). Assuming these quantitative estimates of plant biomass were representative of plant stands between Ross and Monmouth and using cover estimates shown in Fig. 2, it can be calculated that the river supported about eight times as much organic material, an aquatic macrophyte, in 1976 compared with 1975.

Following the death and decay of *R. fluitans* in early July substantial growths of the filamentous algae *Oedogonium* sp. developed at Kerne Bridge: on 28 July the mean biomass was estimated as 8.8g dry wt.m^2.

Chlorophyll a concentrations (used as an estimate of 'phytoplankton' density) measured at Korne Bridge were generally higher in 1976 than 1975 with peak concentrations occurring during July (Table VII).

Some changes in water quality were associated with the photosynthetic activity of the plant community. Marked diel fluctuations in oxygen concentrations were recorded at Kerne Bridge by the submersible temperature and dissolved oxygen recorder in both 1975 and 1976 (Fig. 3d). the amplitude of these changes was related to sunlight in a general way. In 1975 records at Kerne Bridge were incomplete but during the periods 24 June – 2 July and 8 July – 18 July oxygen concentrations ranged between 5.9 and 15.6 mg/l. During the critical period of June 1976 there were distinct trends, other than those associated with daily rhythms of plant activity, in the oxygen status of the R. Wye at Kerne Bridge (Fig. 3d). There was a rapid decline in the maximum and minimum dissolved oxygen concentrations during the period 25 – 30 June (Fig. 3d): only 0.5 mg/l dissolved oxygen was recorded at 04.00 hours BST on 30 June. This followed a period when the aquatic macrophyte, *R. fluitans,* had become increasingly moribund and when water temperatures were increasing rapidly (Fig 3b). Subsequently the minimum oxygen concentration increased to 2.0 mg/l and there was a substantial increase in the diel amplitude of oxygen concentration at the time when growths of *Oedongonium* were developing. Dissolved oxygen concentrations again fell to 0.5 mg/l during the period 10 – 14 July.

On 28 July, at a time when the submersible temperature and oxygen recorder was not functioning, a survey of temperature and oxygen was undertaken at Kerne Bridge in order to assess the spatial variability of these water quality characteristics in the reach under observation. Temperature varied between 22 and 25^{o}C (coefficient of variation, 5.1%) and dissolved oxygen concentration from 10.3 to 22.9 (coefficient of variation, 21.3%). Temperature and oxygen were highest in

those areas of the reach which were shallow and contained growths of *Oedongonium*.

Other chemical characteristics were monitored at Kerne Bridge on a more limited basis, analyses generally being undertaken fortnightly (Table VII). These data indicate that pH and free CO_2 fluctuated more in 1976 than in 1975. Highest pH was recorded in mid-June in each year, at the time that *R. fluitans* was at maximum biomass; in 1976 at the end of June, when *R. fluitans* was decaying, a pH of 7.6 was recorded. Dissolved solids and soluble organic carbon show no distinct trends.

VII Discussion

Quantitative estimates of the size of fish 'kills' are always difficult to undertake because of the problem of observing corpses and the efficiency of the count depends on a variety of factors including visibility and the extent of plant growths. Snyder (1969) reported that only 2.7% of 1169 adult Chinook salmon carcasses released on the Columbia River were recovered by special teams assigned to daily searches. Clearly with the conditions pertaining in the R. Wye in 1976 only a small proportion of dead fish were observed.

The importance of the loss of these fish is also difficult to ascertain both in terms of their amenity or commercial value and in terms of their significance to the population as spawning fish. Very simply the loss of 500 fish of average weight 20 kg represents a retail value of about £10,000. This is likely to be a gross underestimate of the recreational value of these fish in economic terms.

Although it was not possible to ascertain the proportion of the spawning run of salmon which was lost in this fish kill it can be noted that in 1968 and 1969 it was estimated that 2831 and 1168 adult salmon (albeit many of them kelts on spawning beds) were killed by ulcerative dermal necrosis (U.D.N.) with little effect on subsequent rod catches in 1972 – 1974 (Wye River Authority* Fisheries Reports 1968 – 1974).

** Now Wye River Division, Welsh National Water Development Authority.*

Few data from large rivers in the U.K. are available for comparison with the high water temperatures recorded in the R. Wye in 1976. Langford (1970) reported that over the period 1957 – 1966 water temperatures upstream of Ironbridge power station on the adjacent Severn catchment ranged from 12.2 – 22.8 and 14.4 – 22.8 during June and July respectively, substantially lower than the maximum of 27.6^{o}C (daily average 26.3^{o}C) recorded at Kerne Bridge the day before substantial fish kills were reported. Between 24 June and 8 July, North *(pers. comm.)* reported that water temperatures in the R. Severn ranged from 25.2 – 28.0^{o}C. At Ddol Farm (Fig. 1) in the upper reaches of the R. Wye maximum temperatures in the period 22 June – 2 July did not exceed 23.9 ^{o}C (unpublished data). Pomfret *(pers comm.)* recorded temperatures as high as 28.5^{o}C at Kerne Bridge on 1 July 1976.

Huntsman (1942) recorded deaths of adult Atlantic salmon in Nova Scotia which he attributed to high water temperature in conditions of 'very low water.' Huntsman

(1942) concluded that larger salmon died before grilse and that fresh run grilse died at 29.5°C and resident grilse at 30.5°C. Clearly the lethal temperature for any individual will vary with its thermal history and Alabaster (1962) reported that 50% of trout acclimated at 20°c survived for 1000 min at 26.4°C but only 100 min at 28.2°C: acclimation at 15°C reduced these temperatures to 26.0 and 27.4°C respectively. However, Landford *(pers. comm.)* observed that brown trout *(Salmo trutta)* subjected to temperatures between 28-30°C for several days in the R. Severn below a power station outfall were not distressed: such temperatures are higher than those generally accepted as being lethal to this species (Hawkes, 1969).

It is clear that the death and subsequent decay of *R. fluitans* during the period 23 June – 5 July, considerably modified the chemical characteristics of the R. Wye and such changes were enhanced by the low flow conditions prevailing. Although the high temperatures at this time are unlikely to have initiated the death of *R. fluitans* (Anderson, 1969) decay processes would have been accelerated and the changes in the pH-carbon dioxide-oxygen equilibrium were similar to those observed in closed water bodies following the use of herbicides to control growths of aquatic plants (Edwards, 1968; Brooker and Edwards, 1975). The low oxygen concentrations (0.5 mg/l recorded at Kerne Bridge clearly resulted from the decay of substantial amounts of *R. fluitans*: a survey conducted by the Wye River Division on 30 June – 1 July in the lower reaches of the R. Wye recorded minimum oxygen concentrations ranging from 1.8 to 4.5 mg/l (Pomfret, *pers. comm.)*. Using data of plant biomass and plant cover collected in 1976 it was calculated, using the method of Jewell (1970), that such low oxygen conditions could have been predicted. Similar calculations using plant data collected in 1975 indicated that the decay of *R. fluitans* in 1975 would have been unlikely to have resulted in low oxygen concentrations. In addition a small flood in early July (see Fig. 3a) effectively removed moribund *R. fluitans* downstream to the estuary and prevented 'in situ' decomposition.

Oxygen concentrations recorded in 1976 were considerably below the recommended lower limits for salmonid fish. Davis (1975), reviewing the oxygen requirements of aquatic organisms, reported that the critical oxygen response threshold for salmonids at 15°C is 4.16 mg/l, some eight times greater than the 0.5 mg/l recorded on 29 June, the day of the major fish kill. Temperature has a direct effect on the oxygen requirements of many fish (Van Dam, 1938; Erichson-Jones, 1952) and the effect of the low oxygen concentrations in the R. Wye would have been accentuated by the high water temperatures prevailing. Consideration of these two factors in detail over the period 24-29 June illustrates that the major fish kills reported on 29 June were precipitated by rapidly increasing temperatures associated with rapidly decreasing oxygen concentrations (Fig. 4); it seems likely, however, that the oxygen status of the water was the dominating factor in producing this mass mortality of adult salmon. Certainly a complex matrix of interacting factors was responsible for the condition leading to these salmon mortalities and the decay of substantial amounts of aquatic plants, the growth of which had been enhanced by sunny low-flow conditions during 1976, exerted a maximal effect on water quality because of these low-flows. Nevertheless, the biomass of plant material in 1976 was not particularly high when compared with

that found in other rivers (Owens and Edwards, 1962; Dawson, 1976) and, though the future regulation of the R. Wye may prevent the recurrence of such low flows, the margin of safety in the protection of this fishery resource seems far from adequate. The cropping of plants in such a river would be difficult and control using aquatic herbicides is, at the current stage of application technology, unlikely to be feasible. Other speculative alternatives, such as controlled freshets to remove maturing plant stands or artificial injections of oxygen during critical conditions, might need to be explored.

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Table 1

Comparison of counts of salmon corpses between Ross and Monmouth by Wye River Division (W.R.D.) staff and U.W.I.S.T. Staff.

Reach	Corpses counted		Corpses density No./ha.	
	W.R.D.	U.W.I.S.T	W.R.D.	U.W.I.S.T
Ross to Kerne Bridge	66	40	1.60	0.80
Kerne Bridge to Courtfield	98	42	6.50	2.80
Courtfield to Welsh Bicknor	70	4	9.30	0.50
Welsh Bicknor to Huntsham	9	0	1.20	0
Huntsham to Symonds Yat	4	4	0.41	0.40
Symonds Yat to Martins Pool	24	1	1.20	0.04
Martins Pool to Monmouth	11	2	0.40	0.07

Table II

Rainfall (mm) in the Wye Catchment in 1975 and 1976* compared with long-term average (L.T.A.).

Data from Wye River Division

Reach	1975		1976*	
	Total rainfall	% of L.T.A.	Total rainfall	% of L.T.A.
Cefn Brywn	1934	92	637	49
Erwood	829	75	582	46
Ross-on-Wye	543	77	185	49

* January – July Inclusive.

Table III

Long term average (L.T.A.) monthly flows (cumec) at Kerne Bridge compared with 1975 and 1976. Data from Wye River Division.

Month	L.T.A.*	1975	1976
April	47.8	42.0	20.3
May	35.9	24.7	13.2
June	28.5	12.3	8.2
July	21.5	12.6	5.3

* 1933 – 1975 inclusive.

Table IV

Daily sunshine hours and average air temperatures in June and July 1975 and 1976. Records from Preston Wynne (Fig. 1).

Week	Average sunshine hours		Average air temperature (^{o}C)	
	1975	1976	1975	1976
June 1-8	9.6	7.2	12.6	14.2
June 8-16	10.1	3.6	15.1	15.2
June 16-23	7.0	5.0	15.0	15.1
June 23-30	9.8	14.6	15.0	21.0
July 1-7	10.7	11.4*	16.6	22.9

* 3 days missing data

Table V

Average maximum and minimum weekly water temperatures (^{o}C) at Kerne Bridge, 1976

Week	Average	Minimum	Maximum
June 1-8	18.1	15.7	21.5
June 8-16	20.5	18.8	21.9
June 16-23	19.7	18.0	22.6
June 23-30	24.6	21.7	27.6
July 1-7	26.0	23.6	28.0

Table VI

Peak mean biomass (g fresh wt / m^2) of *R. fluitans* at Kerne Bridge and Huntsham Bridge 1975 and 1976

Site	Peak mean biomass	
	1975	1976
Kerne Bridge	0.47	1.99
Huntsham Bridge	0.41	1.59

Table VII

Water quality characteristics at Kerne Bridge, 1975 and 1976

Date		Chlorophyll a (mg/l)		pH		Free CO_2 (mg/l)		Dissolved solids (mg/l)		Soluble carbon (mg/l)	
1975	**1976**	**1975**	**1976**	**1975**	**1976**	**1975**	**1976**	**1975**	**1976**	**1975**	**1976**
28 April	**26 April**	6.3	5.4	8.4	7.9	0.9	3.1	179	189	2.8	2.3
12 May	**10 May**	4.5	25.7	8.4	7.0	0.8	4.4	186	184	2.3	2.0
27 May	**-**	7.5	-	8.7	-	0.5	-	211	-	2.2	-
16 June	**7 June**	71.4	117.2	8.8	9.1	0.5	0.1	251	178	2.9	2.2
30 June	**21 June**	18.8	44.4	8.4	7.6	1.2	4.8	259	208	2.4	2.3
14 July	**5 July**	49.3	121.7	8.2	7.5	1.8	5.8	206	223	2.8	2.5
30 July	**19 July**	9.4	127.6	7.8	7.4	3.1	8.6	187	209	-	2.4

Figures

Figure 1 Location map of the R. Wye

Fig. 2 (a) Distribution of salmon corpses in the R. Wye between Ross and Monmouth, 29 and 30 June 1976, and

(b) The proportion of plant cover in the R. Wye between Ross and Monmouth 1975 and 1976.

Fig. 3 (a) Flow in the R. Wye at Kerne Bridge, 1975 and 1976,

(b) Changes in water temperature of the R. Wye at Kerne Bridge, 1976.

(c) Changes in the biomass of *R. fluitans* at Kerne Bridge and Huntsham Bridge, 1975 and 1976, and

(d) Changes in the concentration of dissolved oxygen of the R. Wye at Kerne Bridge.

Fig. 4 Changes in water temperature and dissolved oxygen concentration at Kerne Bridge during the period 24-30 June.

Figure 1

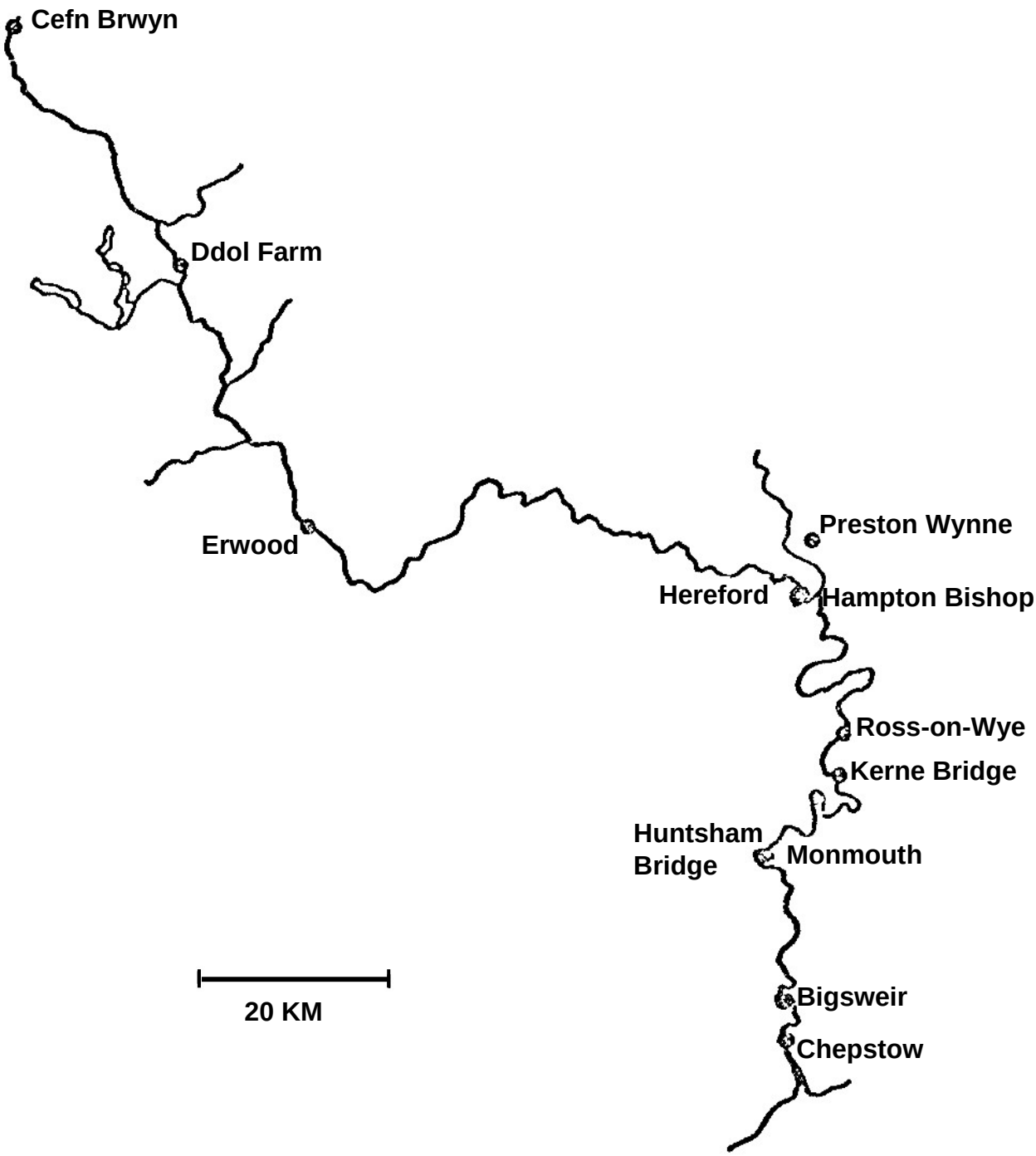

Cefn Brwyn
Ddol Farm
Erwood
Preston Wynne
Hereford
Hampton Bishop
Ross-on-Wye
Kerne Bridge
Huntsham Bridge
Monmouth
Bigsweir
Chepstow
20 KM

Figure 2

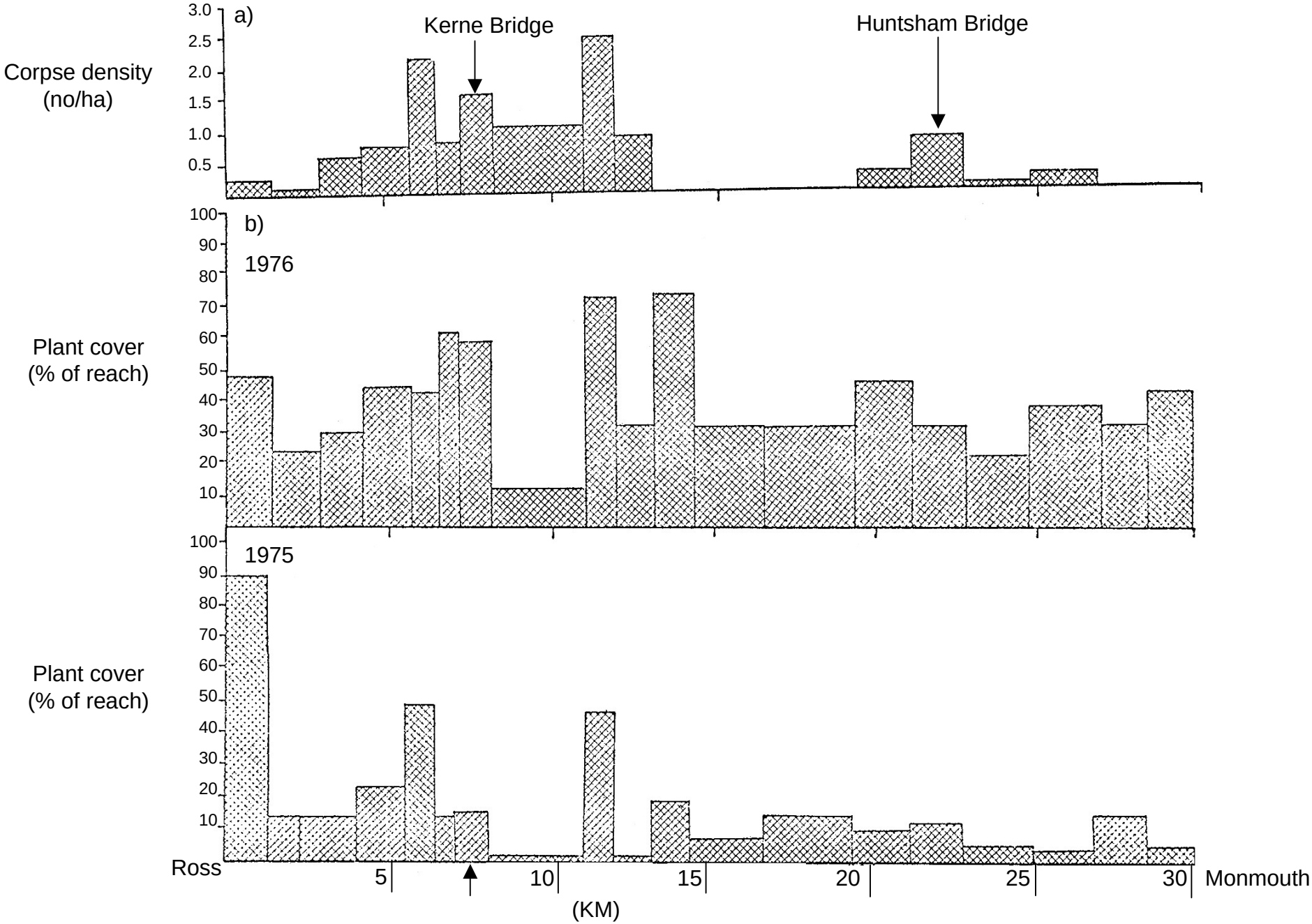

a)
Kerne Bridge
Huntsham Bridge
Corpse density (no/ha)
3.0
2.5
2.0
1.5
1.0
0.5
b)
1976
Plant cover (% of reach)
100
90
80
70
60
50
40
30
20
10
1975
Plant cover (% of reach)
Ross
5
10
15
20
25
30
Monmouth
(KM)

Figure 3

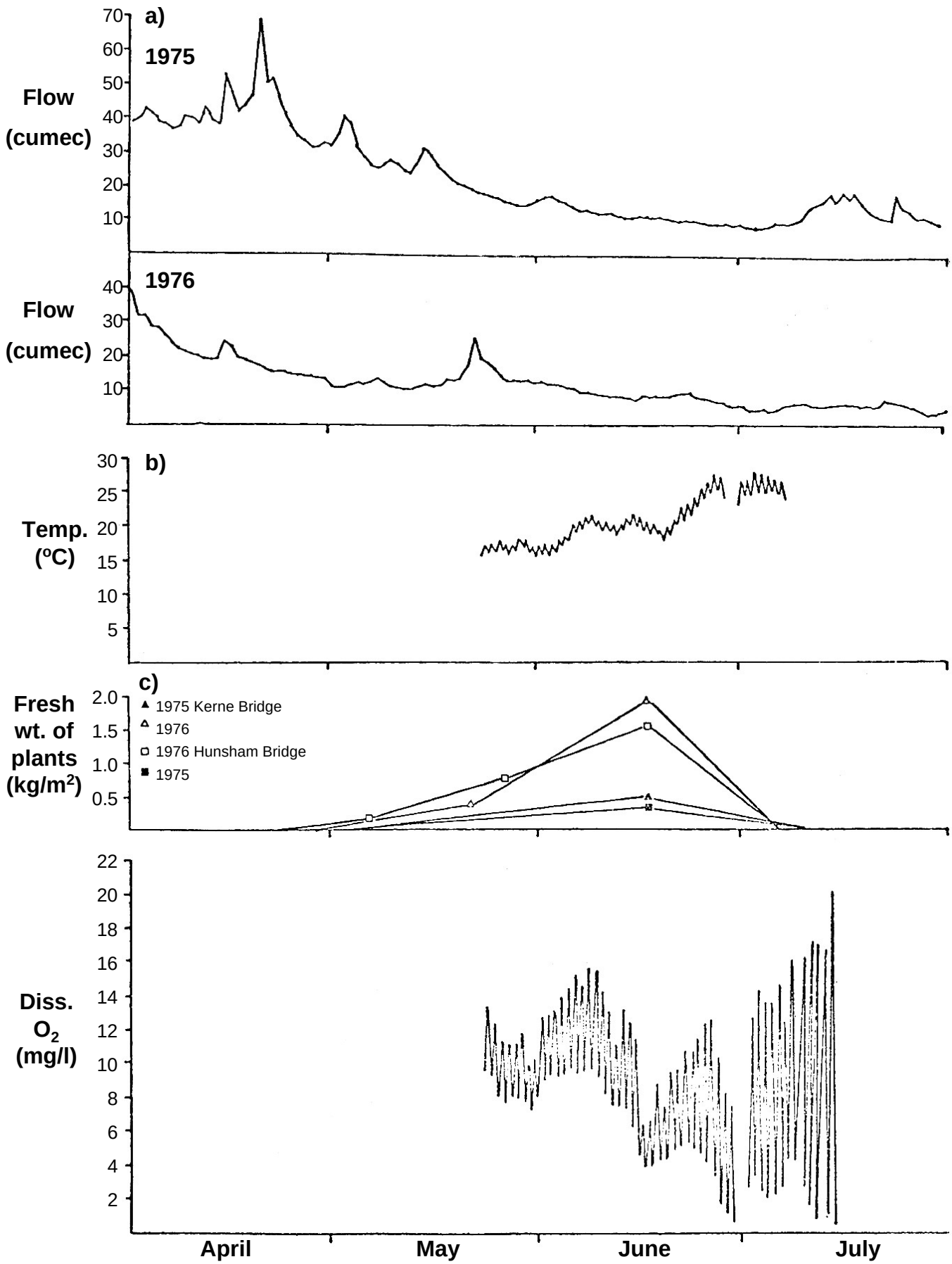
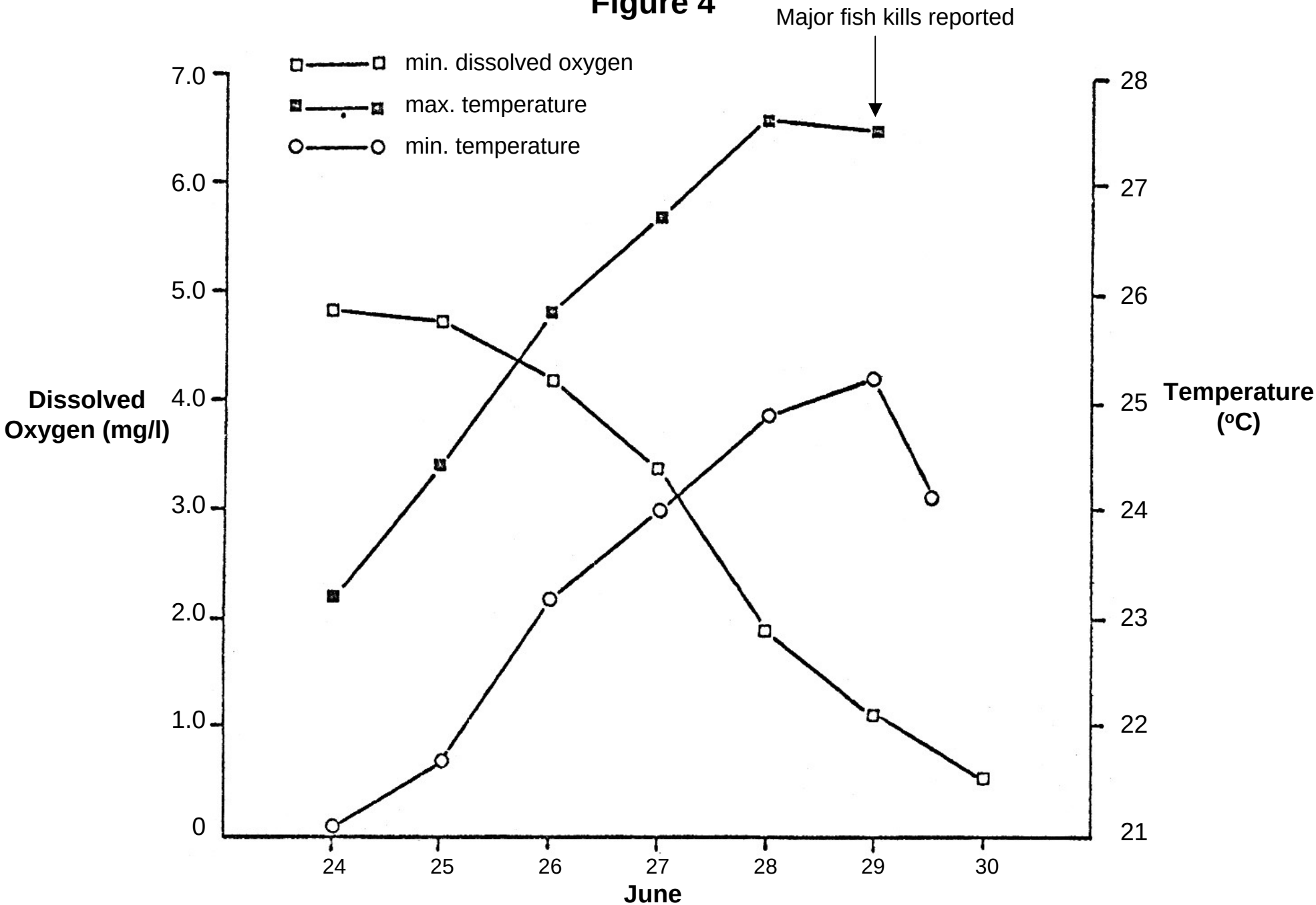

a)
1975
Flow (cumec)
70
60
50
40
30
20
10
1976
Flow (cumec)
40
30
20
10
b)
Temp. (°C)
30
25
20
15
10
5
c)
Fresh wt. of plants (kg/m²)
2.0
1.5
1.0
0.5
1975 Kerne Bridge
1976
1976 Hunsham Bridge
1975
Diss. O₂ (mg/l)
22
20
18
16
14
12
10
8
6
4
2
April
May
June
July

Figure 4


Major fish kills reported
min. dissolved oxygen
max. temperature
min. temperature
Dissolved Oxygen (mg/l)
Temperature (°C)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
28
27
26
25
24
23
22
21
24
25
26
27
28
29
30
June