Institute of Freshwater Ecology

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EFFECTS OF WATER QUALITY IN BASSENTHWAITE LAKE ON ANGLERS' CATCHES OF SALMON AND SEA-TROUT IN THE RIVER DERWENT

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SUMMARY

An analysis of the catch statistics for salmon and sea-trout in the Rivers Derwent and Cocker was undertaken in relation to available information on the algal water quality in Bassenthwaite Lake to test the hypothesis that poor catch returns were associated with a deterioration of water quality within the lake. A parallel analysis of the Windermere South Basin/Rivers Leven and Crake system, for which much better water quality records are available, was also undertaken.

The Rivers Derwent and Cocker provide the second-best salmon catches in the North West Region and the fifth best sea-trout catches. Annual catches of salmon show marked fluctuation but the overall trend for the period 1976-1991 has been upward. Sea-trout catches peaked in 1981, declined to a minimum in 1990 but then increased in 1991. There is no evidence to suggest that annual catches of salmon and sea-trout were fluctuating differently to those for other river systems in the North West. Analysis of the catch statistics on a monthly basis failed to reveal any correlation between water quality and catch returns for either species of fish and it is concluded that any water deterioration in Bassenthwaite Lake has not caused any major damage to the salmon and sea-trout fisheries of the Derwent/Cocker system. This conclusion is supported by the analysis of the Windermere/Leven and Crake system where, again, no correlation could be found between lake water quality and downstream catches of migratory salmonid fish.

However, the possibility still exists that the outflow of nutrient/algal-rich water from Bassenthwaite Lake could have a <u>local</u> effect on the River Derwent immediately downstream of the lake. Such an effect might be detected by further field work on the macroinvertebrates and on the composition of potential salmonid spawning gravels in the area.

1. INTRODUCTION

1.1 Background

Salmon anglers on the River Derwent (Cumbria) have complained that their catches are reduced during periods when Bassenthwaite Lake supports significant algal blooms. This complaint was relayed, via local MP, Mr Dale Campbell Savours, to the NRA NW Region General Manager, Dr C Harpley. Specific complaints were made with regard to the diatom *Asterionella*, as a causative agent. A subsequent exchange of information between Mr Bob Smeaton (a local angler) and Professor A D Pickering indicated that a further cause for concern was the excessive growth of diatoms (including *Asterionella*) and other organisms on the stony substratum of the River Derwent between Ouse Bridge and Cockermouth. The present investigation was designed to test the hypothesis that anglers' catches in the River Derwent are adversely affected by water quality deterioration in Bassenthwaite Lake. However, the catch statistics available for these analyses refer to the river system as a whole and are not sufficiently detailed to permit an investigation of regional variation in catches within the river system. Thus, the study will provide the NRA with an assessment, based on the best available data, of the state of the River Derwent/Cocker salmonid fishery in comparison with other salmonid rivers in the North West Region. For a more detailed investigation of possible regional variation within the Derwent/Cocker system, additional field work may be necessary.

The IFE has already undertaken some preliminary analyses of the Atlantic salmon (*Salmo salar*) and sea-trout (*Salmo trutta*) rod catch data for all NW Region Rivers, from the Ribble in the South of the Region to the border Esk in the North and already has access to most of these data. Analyses of the sea-trout data were part of a larger study on annual rod and commercial catch statistics for sixty-seven rivers in England and Wales (Elliott 1992 a,b). Additionally, the NRA has funded since 1990 an IFE monitoring programme of algal populations and water quality in Bassenthwaite Lake and the NRA has long-term data sets on lake levels and basic water chemistry (including suspended solids in the River Derwent). These data are used in the present investigation to determine whether the salmon and sea-trout catches in the River Derwent/Cocker system differ significantly from those of other rivers in the NW Region, to identify periods when catches are lower than might be expected and to see whether such periods are correlated with water quality in Bassenthwaite Lake or in the River Derwent. As the algal data from Bassenthwaite are available for only recent years (from 1990), earlier estimates of algal abundance have to be derived from the relationships between algal cell numbers, lake levels and suspended solids in the River Derwent. Such estimation is difficult because Bassenthwaite Lake is subject to periods of wind-mixing which adds to the suspended solids load in the River Derwent because of resuspension of lake sediments. In view of the somewhat fragmentary nature of the data relating to the Bassenthwaite/Derwent system, a parallel investigation has been made on the relationship between algal populations, water quality in Windermere South Basin and the salmonid catches in the River Leven. These data sets are the most extensive of their type in the UK, if not the world, and should indicate if any correlation exists between lake water quality (resulting from algal blooms) and rod-catches of salmonids. These data sets therefore provide the best opportunity to test the hypothesis that salmonid catches in a river are reduced when algal blooms are prevalent in any of the upstream lakes.

1.2 Objectives

These are summarised in the following terms of reference:

(i) To assess whether the annual pattern of salmon and sea-trout catches in the River Derwent/Cocker differs significantly from other river systems in the NW Region.

(ii) To determine, on a monthly basis, the relationship (if any) between anglers' catches in the river and algal water quality in Bassenthwaite Lake.

(iii) To run a parallel study on the Windermere South Basin/River Leven system where data sets are complete.

(iv) To advise the NRA on the evidence for or against the hypothesis that algal water quality in lakes influences salmonid catches in down-stream rivers.

2. SOURCES OF DATA

2.1 Fish

Information on rod catches of Atlantic salmon and sea-trout was obtained from annual reports of the North West Region of the National Rivers Authority and its predecessors. Both annual and monthly catches have been recorded over 16 years (1976-1991) from thirteen major rivers in the region (Ribble + Hodder, Wyre, Lune, Kent, Leven + Crake, Duddon, Esk, Irt, Ehen, Derwent + Cocker, Ellen, Eden, Border Esk). All 13 rivers were used for the comparisons of annual catches, but the comparisons of monthly catches were restricted to the Derwent + Cocker, and the Leven + Crake. It should be noted that the fishing season varies slightly between rivers. The close season for salmon is 15 October to 14 January on the Eden and 1 November to 31 January on the other rivers. That for sea-trout is usually 16 October to 30 April, but starts slightly later on 1 November for the Esk, Irt, Calder and Ehen. The catch statistics for the Derwent + Cocker and Leven + Crake are summarized in Tables 1 and 2.

The statistical methods used to analyze the catch data are described in the appropriate section of the results.

DERWENT + COCKER

MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	TOTAL
1976	0	0	0	0	0	25	59	32	82	18	216
1977	0	0	0	0	3	17	45	88	51	14	218
1978	0	0	0	0	0	6	39	49	23	7	124
1979	0	0	0	0	1	9	25	108	89	38	270
1980	0	0	0	0	8	48	143	87	33	14	333
1981	0	0	0	0	28	128	205	168	81	7	617
1982	0	0	0	0	9	57	144	102	62	20	394
1983	0	0	0	0	2	30	43	137	122	63	397
1984	0	0	0	0	11	76	96	88	56	25	352
1985	0	0	0	0	21	93	113	34	18	4	283
1986	0	0	0	0	3	31	18	50	89	27	218
1987	0	0	0	0	9	74	78	52	10	3	226
1988	0	0	0	0	11	59	37	23	8	4	142
1989	0	0	0	0	2	27	53	22	44	9	157
1990	0	0	0	0	0	20	15	22	26	6	89
1991	0	0	0	0	6	14	59	38	65	85	267
TOTAL	0	0	0	0	114	714	1172	1100	859	344	4303
%					2.6	16.6	27.2	25.6	20.0	8.0	100.0

LEVEN + CRAKE

MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	TOTAL
1976	0	0	0	0	2	16	143	63	196	112	532
1977	0	0	0	0	0	5	24	34	59	27	149
1978	0	0	0	0	0	3	16	60	32	13	124
1979	0	0	0	0	0	3	13	40	66	10	132
1980	0	0	0	0	3	38	127	219	103	27	517
1981	0	0	0	0	5	16	113	124	102	60	420
1982	0	0	0	0	5	9	75	77	51	20	237
1983	0	0	0	0	11	16	28	23	64	57	199
1984	0	0	0	0	0	0	15	19	62	43	139
1985	0	0	0	0	2	5	41	33	21	2	104
1986	0	0	0	0	0	8	40	92	20	12	172
1987	0	0	0	0	0	8	40	75	45	6	174
1988	0	0	0	0	6	3	101	63	47	14	234
1989	0	0	0	0	0	9	10	51	34	5	109
1990	0	0	0	0	7	9	20	13	41	11	101
1991	0	0	0	0	2	10	27	35	16	33	123
TOTAL	0	0	0	0	43	158	833	1021	959	452	3466
%					1.2	4.6	24.0	29.5	27.7	13.0	100.0

Table 1. Monthly catches of sea-trout in the Derwent + Cocker and Leven + Crake for the years 1976 to 1991.

DERWENT + COCKER

MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	TOTAL
1976	0	0	0	2	1	6	7	2	171	185	374
1977	0	0	0	4	3	7	53	79	358	242	746
1978	0	1	0	2	2	4	43	189	181	130	552
1979	0	0	0	1	1	3	14	116	212	198	545
1980	0	0	2	2	4	10	58	312	310	226	924
1981	0	1	2	2	2	34	88	93	200	239	661
1982	0	0	1	0	0	0	16	187	246	270	720
1983	0	1	2	1	2	2	0	4	189	144	345
1984	0	0	0	0	0	4	3	42	305	250	604
1985	0	0	1	1	0	6	62	310	433	270	1083
1986	0	0	0	1	2	4	17	246	123	164	557
1897	0	0	0	1	1	9	79	146	329	259	824
1988	0	0	0	0	0	1	103	446	567	344	1461
1989	0	0	0	0	0	4	8	207	297	452	968
1990	0	0	0	2	0	7	29	67	385	389	879
1991	0	1	3	1	0	11	23	101	321	604	1065
TOTAL	0	4	11	20	18	112	603	2547	4627	4366	12308
%		0.0	0.1	0.2	0.1	0.9	4.9	20.7	37.6	35.5	100.0

LEVEN + CRAKE

MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	TOTAL
1976	0	0	0	0	0	0	6	2	41	12	61
1977	0	0	0	1	0	2	2	6	36	26	73
1978	0	0	0	1	0	0	0	6	16	5	28
1979	0	0	0	0	0	6	5	8	10	10	39
1980	0	0	0	0	0	1	5	41	26	14	87
1981	0	0	0	5	0	4	6	1	14	18	48
1982	0	0	0	0	0	0	11	51	30	37	129
1983	0	0	0	2	0	0	0	1	27	22	52
1984	0	0	1	0	0	0	0	3	9	24	37
1985	0	0	0	0	2	0	5	19	25	6	57
1986	0	0	0	0	0	2	7	14	12	28	63
1987	0	0	0	0	0	4	5	12	24	23	68
1988	0	0	0	0	0	3	25	86	70	55	239
1989	0	4	0	0	0	0	1	9	19	43	76
1990	0	0	0	0	0	1	13	6	36	55	111
1991	0	0	0	1	2	5	11	13	39	107	178
TOTAL	0	4	1	10	4	28	102	278	434	485	1346
%		0.3	0.1	0.7	0.3	2.1	7.6	20.7	32.2	36.0	100.0

Table 2. Monthly catches of salmon in the Derwent + Cocker and Leven + Crake for the years 1976 to 1991.

2.2 Water quality and algal blooms

Details of the monthly maximum, minimum and mean lake levels for Bassenthwaite Lake were obtained from Shirley Hunt (NRA, Carlisle). The data sets covered the period 1976 to the present. Valerie Boyle (NRA, Carlisle) provided information on suspended solids in the River Derwent at Ouse Bridge. These data covered the period 1977 to the present but the sampling timetable was not totally consistent throughout this period. Sampling frequency varied between once every two months in 1977 to fortnightly sampling in 1992. Wind speed data (Sellafield site) were provided to the IFE by BNF plc and daily mean wind speeds were then abstracted (D P Hewitt, IFE). This information was used in an attempt to assess the contribution of wind-induced resuspension of sedimented material to the suspended solids in the outflow from Bassenthwaite Lake. Chlorophyll *a* values for Bassenthwaite Lake (August 1990 to the present) and for Windermere South Basin (1976 to the present) were provided, in digital form, by J V Roscoe (IFE) from the Institute's algal data base. Sampling frequency was fortnightly for Bassenthwaite Lake and fortnightly during the winter months but weekly during the summer months for Windermere South Basin.

3. RESULTS

3.1 Comparisons of annual salmon and sea-trout catches between rivers

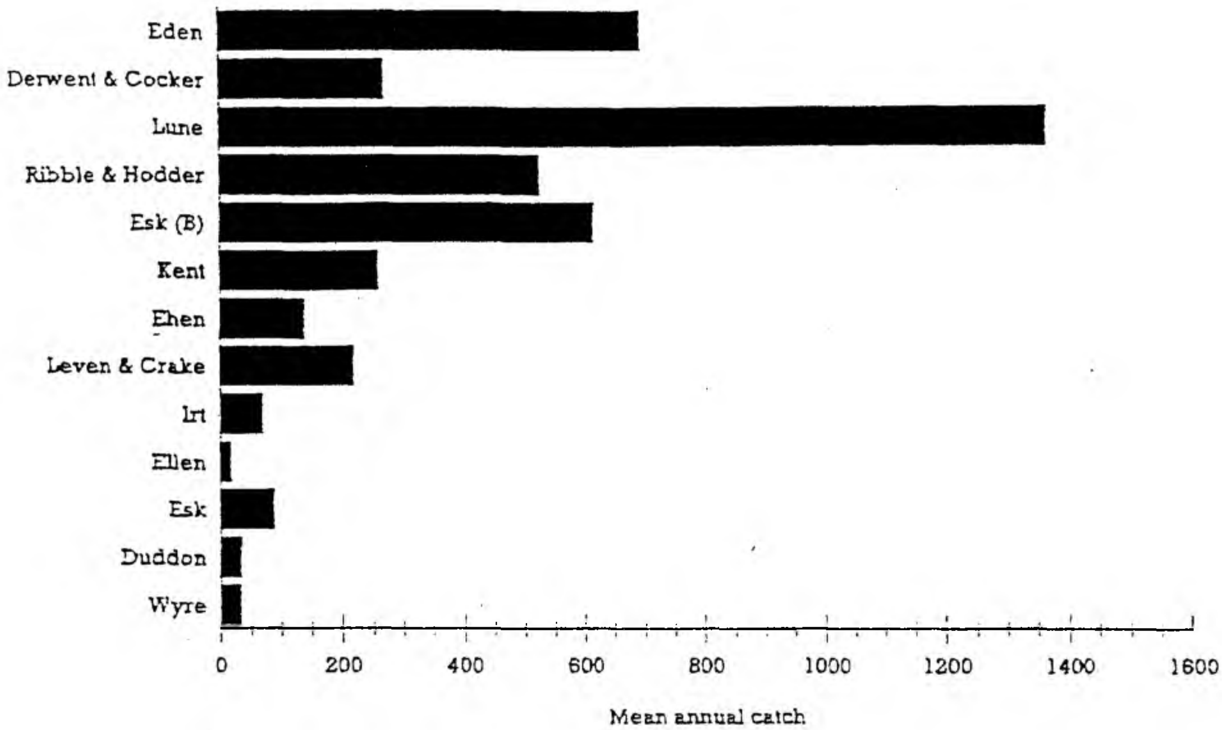
Mean annual catches (for period 1976-1991) for the thirteen major rivers in the North West region are compared in Fig. 1. The average annual catch of Atlantic salmon in the Derwent + Cocker is exceptionally high and is surpassed by that in only one river, the Eden. In comparison, catches of salmon in the Leven + Crake are very low. Catches of sea-trout in the Derwent + Cocker are much lower than those for salmon and are exceeded by those in four other rivers in the region. Catches of sea-trout in the Leven + Crake are higher than those for salmon and are only slightly below those in the Derwent + Cocker.

In summary, the Derwent + Cocker provides the second best salmon catches in the region, but only the fifth best sea-trout catches. The latter catches are similar to those for the Leven + Crake, but the latter is a much poorer salmon river.

Annual catches of salmon in the Derwent + Cocker fluctuate markedly between years but the overall trend has been upward over the years 1976-1991 (Fig. 2). The lower annual catches of sea-trout attained their maximum in 1981 but have since declined steadily to their minimum in 1990 (Fig. 2). The increase in 1991 to the highest value for the last six years is encouraging, especially if it heralds a return to former levels.

These fluctuations in annual catches could be due to some unique changes in the Derwent + Cocker or Bassenthwaite Lake, or they could simply reflect more general fluctuations in catches

Sea-trout



Salmon

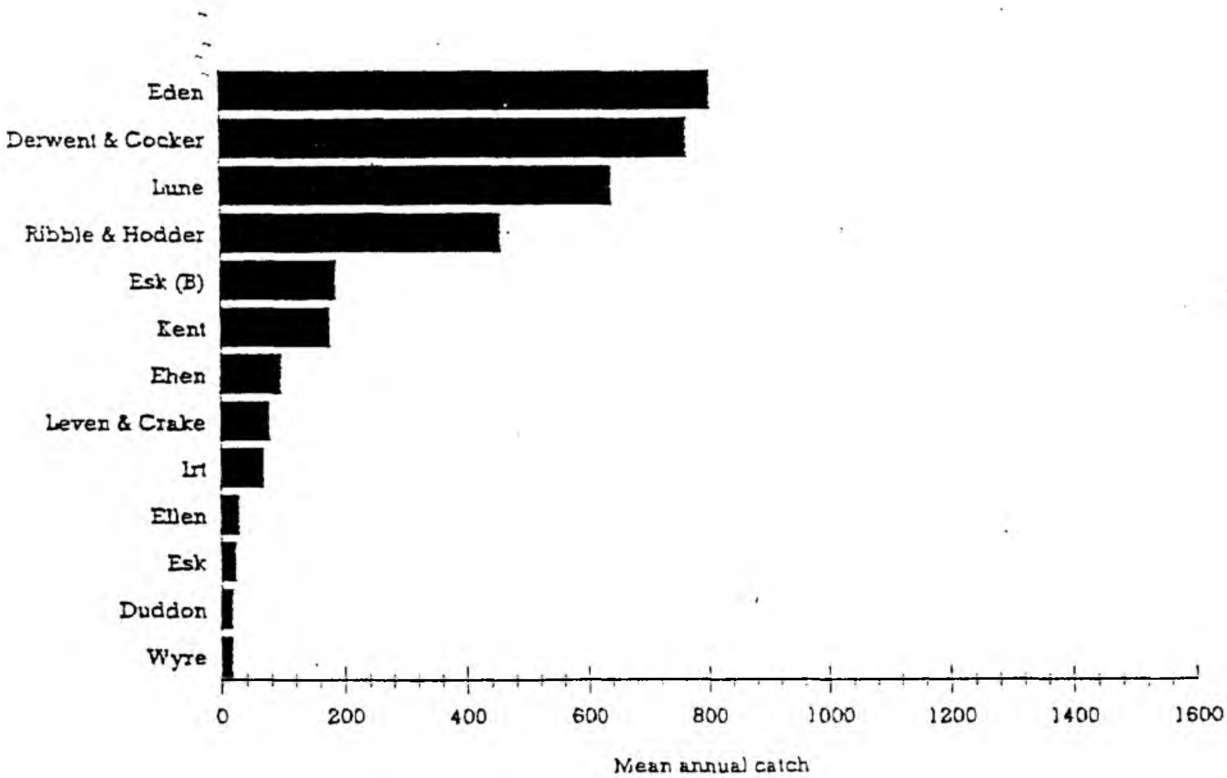


Fig. 1. Mean annual catches for 13 rivers over 16 years (1976-1991); rivers ranked from highest to lowest salmon catch.

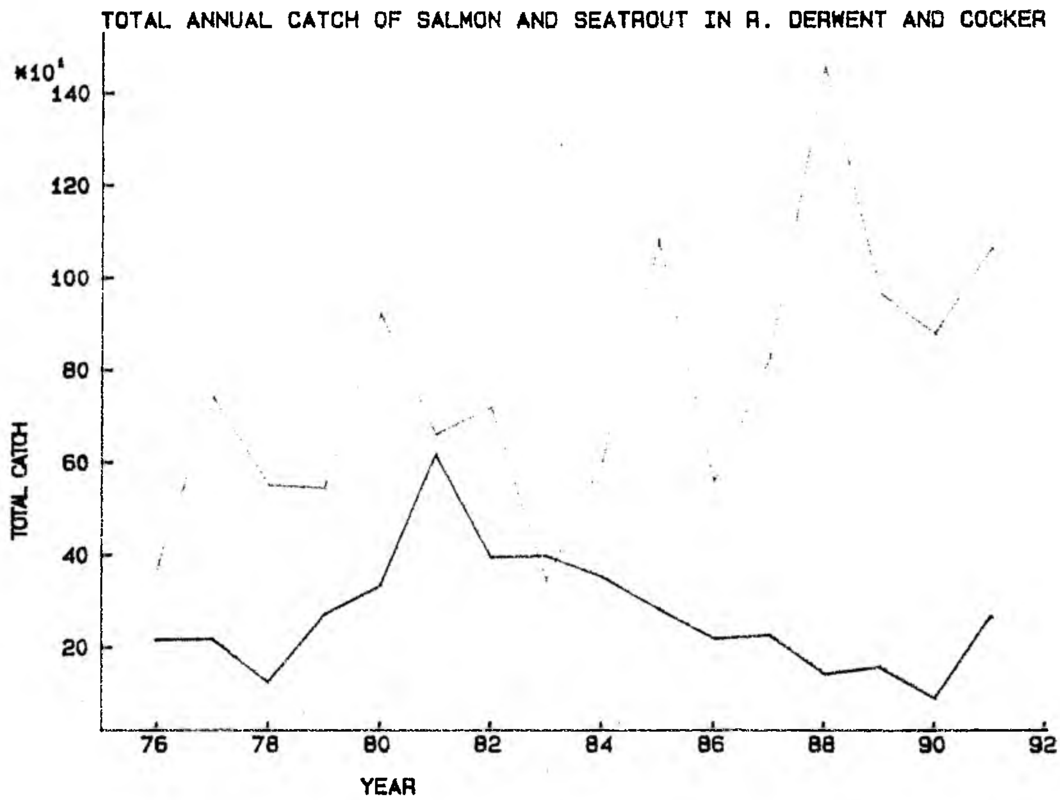


Fig. 2. Annual catches of Atlantic salmon and sea-trout in the Derwent + Cocker for the period 1976 to 1991.

River.

Year	1	2	3	. . .	13.	
1976	y_{11}	y_{12}	y_{13}	. . . —	$y_{1,13}$.	$y_{1\cdot}$
1977						
⋮						
1991						
Overall M.	$\bar{y}_{\cdot 1}$ S_1^2	$\bar{y}_{\cdot 2}$ S_2^2	$\bar{y}_{\cdot 3}$			$\bar{y}_{\cdot\cdot}$

$y_{i,j}$ = annual catch in year i - from river j

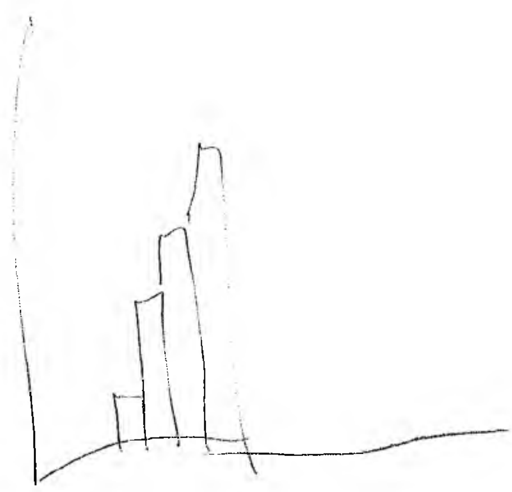
1. Std.

$$\tilde{y}_{ij} = \frac{100 * (\text{annual catch} - \bar{y}_{\cdot j})}{\bar{y}_{\cdot j}}$$

S_j^2 = variance in annual catches between years within a river.

S_j^2 = ~~exp(... β~~ $a\bar{y}_{\cdot j}^{\,b}$.

River. ln.Var. ln.Mean.



from other northwest rivers. To examine the latter possibility, catches were standardized by simply expressing them as the percentage difference from the overall mean annual catch for each river:

$$\% \text{ difference from overall mean} = \frac{100(\text{actual catch} - \text{overall mean})}{(\text{overall mean})}$$

The standardized values show clearly that the salmon catches for the Derwent + Cocker are centrally placed in comparison with other northwest rivers (Fig. 3). This is also generally true for the sea-trout catches from the Derwent + Cocker, apart from the exceptionally low values in 1978 and 1988 (Fig. 3).

Although this simple standardization is relatively easy to interpret, it corrects for only differences in the magnitude of annual fluctuations in catch between rivers. The variability in annual catch was therefore next standardized using a fractional power function that has already been shown to be a good model (Elliott 1992 a,b) for the relationship between the variance in annual catches between years within a river (s^2) and the mean annual catch for that river ($\bar{x}$): $s^2 = a\,\bar{x}^{\,b}$ where a and b are constants. This equation was fitted in its logarithmic form, using linear regression:

$$\ln s^2 = \ln a + b \ln \bar{x}$$

This model was a highly significant fit ($P<0.001$) to the data for both salmon and sea-trout from the thirteen rivers, and the proportion of the variations in s^2 between rivers that could be explained by variations in $\bar{x}$ was 95.8% for sea-trout and 96.4% for salmon. A new standardized catch was then calculated for each river in each year thus:

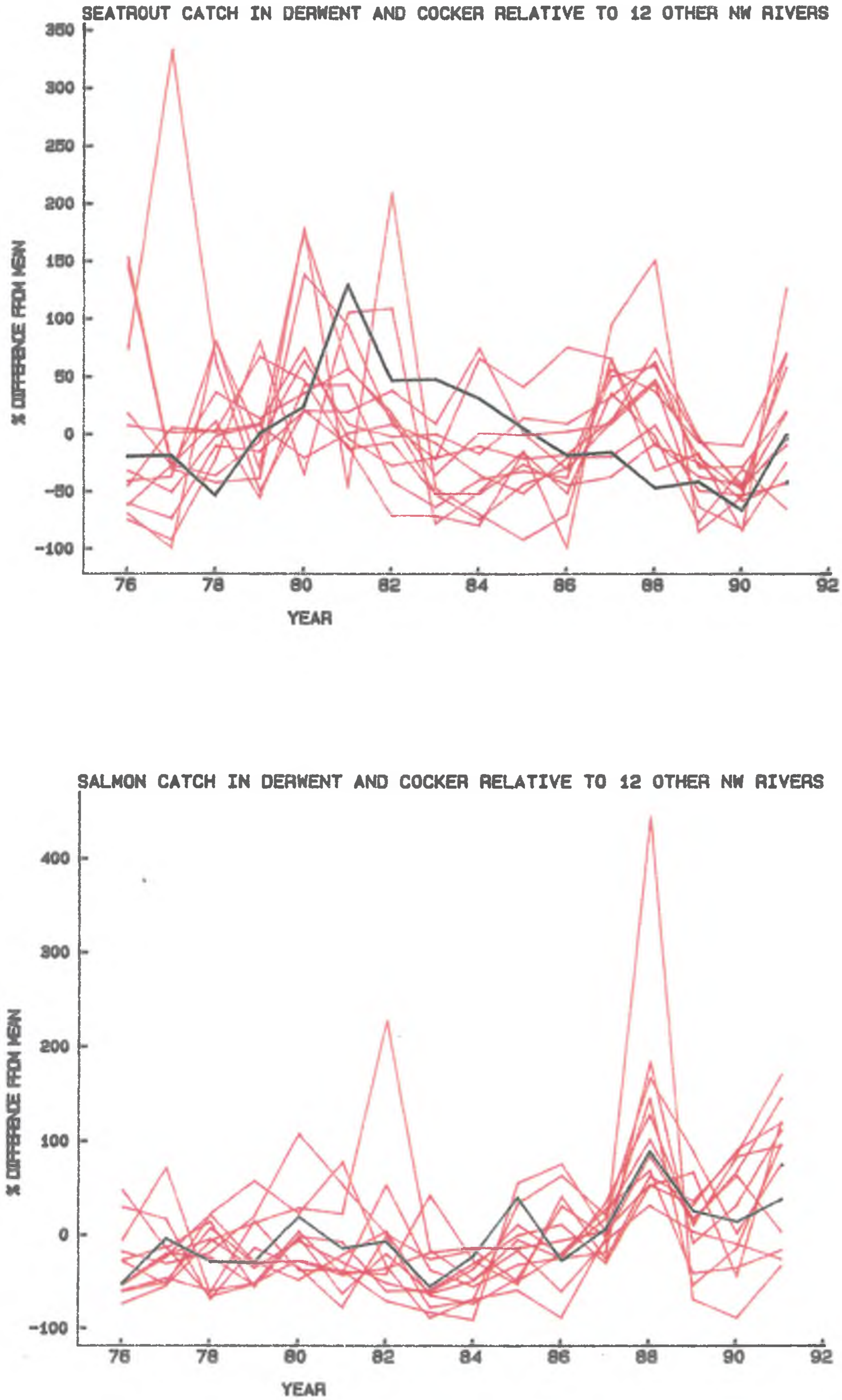


Fig. 3. **Comparison of annual catches of salmon and sea-trout in the Derwent + Cocker (green line) with annual catches from the other twelve rivers in the north west (red lines); catches have been standardized by expressing them as the percentage difference from the overall mean annual catch for each river.**

$$\text{Standardized annual catch} = \frac{\text{(actual catch - mean catch)}}{\text{(standard deviation of catch)}}$$

where the standard deviation of catch (SD) is given by:

$$\ln SD^2 = \ln a + b \ln (\text{mean catch})$$

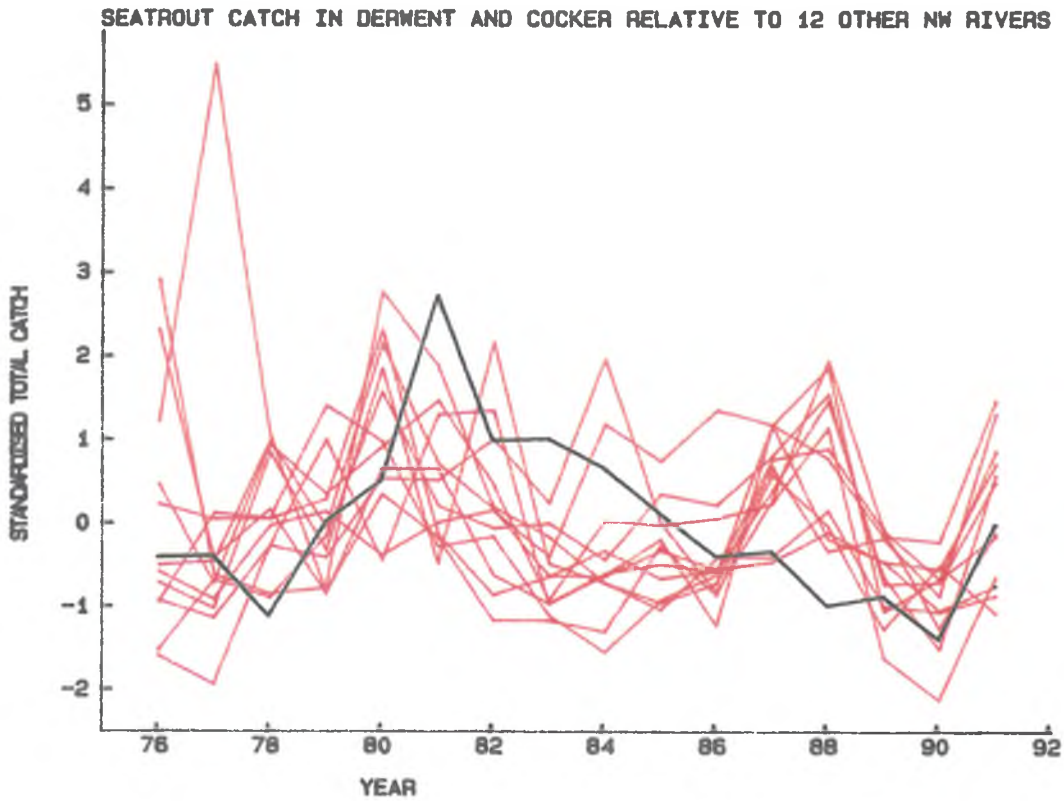
where parameter estimates (with standard error in parenthesis) are a = 1.16 (0.48), b = 1.53 (0.09) for sea-trout and a = 0.36 (0.47), b = 1.71 (0.09) for salmon.

The new standardized values are compared in Fig. 4 and again show that values for the Derwent + Cocker are centrally placed, the only exceptions being the relatively low values for sea-trout in 1978 and 1988. Although these comparisons convey a similar impression to those illustrated in Fig. 3, they are more statistically correct.

It can therefore be concluded that there is no evidence to suggest that annual catches of salmon and sea-trout for the Derwent + Cocker were fluctuating differently to those for other northwest rivers. Whatever was responsible for these fluctuations, it was not unique to the Derwent + Cocker system and therefore could not be associated with water quality changes in Bassenthwaite Lake.

3.2 Comparisons of monthly rod catches

Although annual catches in the Derwent system appear to be unaffected by local changes in water quality, it is possible that monthly catches could change in years of poor water quality even



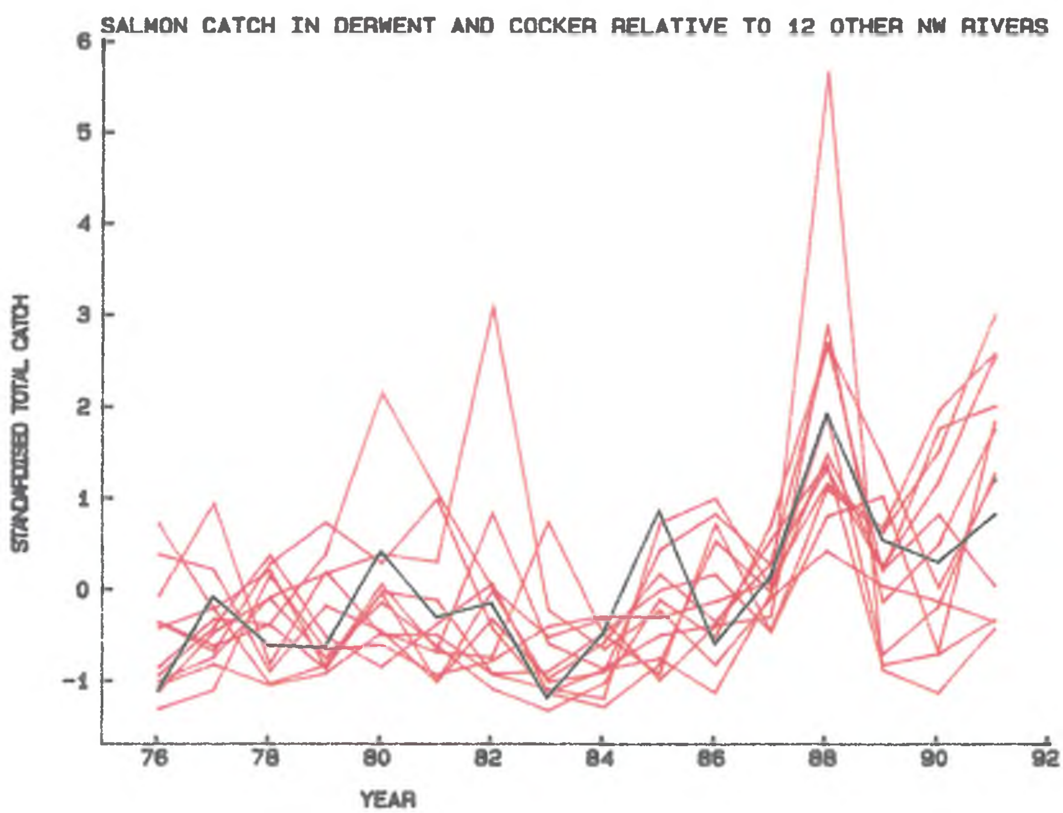


Fig. 4. Comparison of standardized annual catches of salmon and sea-trout in the Derwent + Cocker (green line) with those from the other twelve rivers in the North West (red lines).

though the annual catch was relatively unaffected, i.e. monthly catches in some years could be lower than expected from the average catches for the same months. Although monthly catches for the Derwent + Cocker are available for the years 1976 to 1991, the corresponding data for water quality in Bassenthwaite Lake are available for the latter part of 1990 and 1991. Therefore, as mentioned in the introduction (section 1.1), monthly catches have also been examined for the River Leven system. The Leven is the outflow of Windermere and extensive data are available to document the increasing eutrophication of the lake, especially the south basin. If river catches of salmon and sea-trout are affected by changes in water quality in a lake supplying the river, then these effects should be most readily detected in the Windermere catchment that includes the River Leven.

Monthly catches for both river systems during the years 1976 to 1991 show that all sea-trout and nearly all salmon were caught in the period May to October (Tables 1, 2). A few salmon were caught earlier in the year but the catches were negligible compared with those later in the year (Table 2). Total monthly catches for the sixteen years were used to illustrate the general distribution of catches through the fishing season with the monthly catches expressed as a percentage of the annual catch (Fig. 5). It can be seen that the general distribution of catches was similar in the two river systems apart from the slightly higher percentages for sea-trout in the Derwent + Cocker in June and the Leven + Crake in October.

Assuming that this percentage distribution of monthly catches represents the long-term normal pattern, expected catches were calculated for each month (expected catch = monthly percentage × annual catch / 100) for the years 1976 to 1991 (Tables 3, 4). The negligible catches for salmon in February, March and April were ignored in the calculation of expected catches. To identify months in which the observed catch was significantly lower or higher than expected, the residual

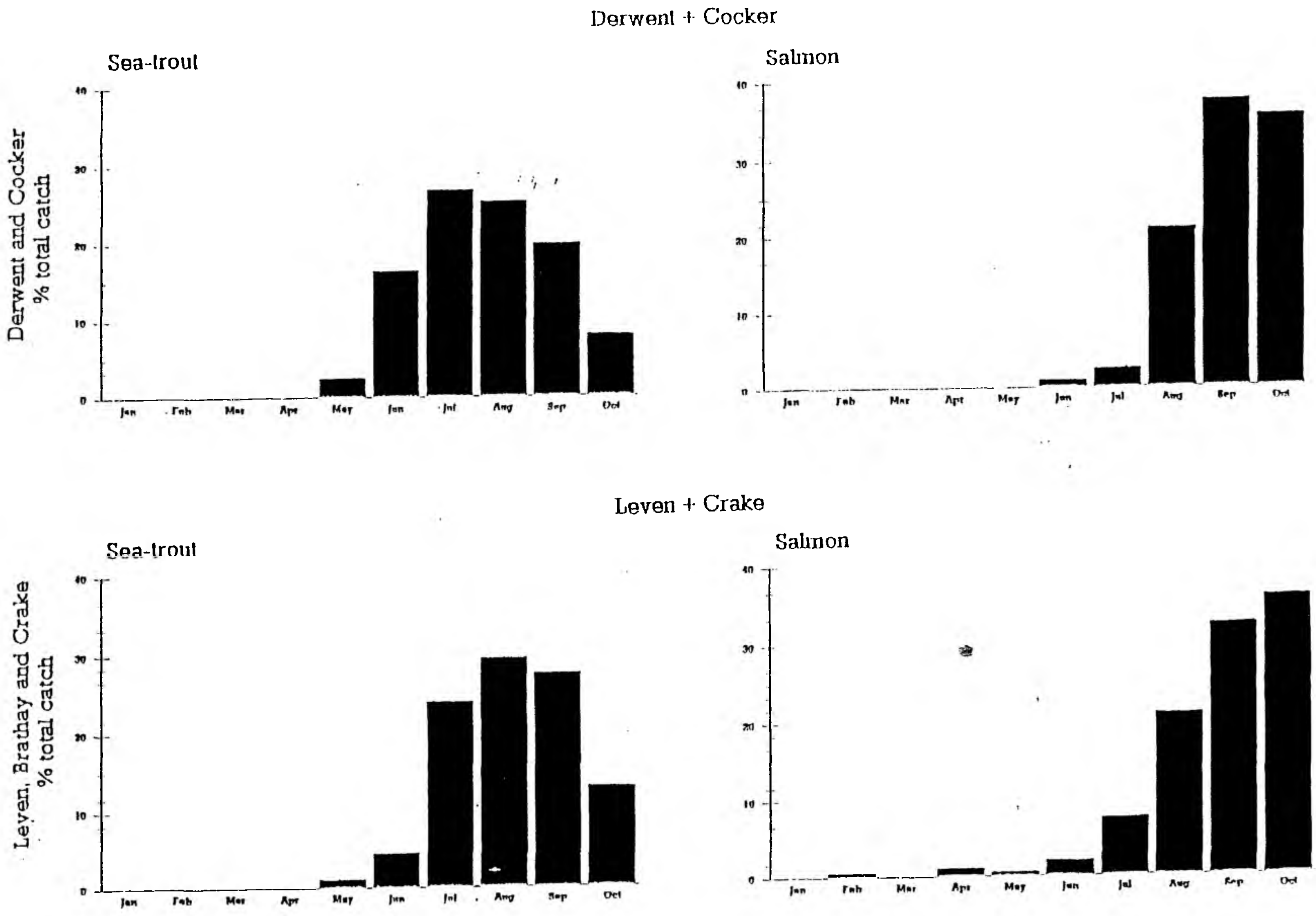


Fig 5. **Frequency distribution of monthly catches of sea-trout and salmon in the Derwent + Cocker and Leven + Crake.**

DERWENT + COCKER

MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1976	*	*	*	*	6	36	59	55	43	17
1977	*	*	*	*	6	36	59	56	44	17
1978	*	*	*	*	3	21	34	32	25	10
1979	*	*	*	*	7	45	74	69	54	22
1980	*	*	*	*	9	55	91	85	66	27
1981	*	*	*	*	16	102	168	158	123	49
1982	*	*	*	*	10	65	107	101	79	31
1983	*	*	*	*	11	66	108	101	79	32
1984	*	*	*	*	9	58	96	90	70	28
1985	*	*	*	*	7	47	77	72	56	23
1986	*	*	*	*	6	36	59	56	44	17
1987	*	*	*	*	6	38	62	58	45	18
1988	*	*	*	*	4	24	39	36	28	11
1989	*	*	*	*	4	26	43	40	31	13
1990	*	*	*	*	2	15	24	23	18	7
1991	*	*	*	*	7	44	73	68	53	21

LEVEN + CRAKE

MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1976	*	*	*	*	7	24	128	157	147	69
1977	*	*	*	*	2	7	36	44	41	19
1978	*	*	*	*	2	6	30	37	34	16
1979	*	*	*	*	2	6	32	39	37	17
1980	*	*	*	*	6	24	124	152	143	67
1981	*	*	*	*	5	19	101	124	116	55
1982	*	*	*	*	3	11	57	70	66	31
1983	*	*	*	*	2	9	48	59	55	26
1984	*	*	*	*	2	6	33	41	38	18
1985	*	*	*	*	1	5	25	31	29	14
1986	*	*	*	*	2	8	41	51	48	22
1987	*	*	*	*	2	8	42	51	48	23
1988	*	*	*	*	3	11	56	69	65	31
1989	*	*	*	*	1	5	26	32	30	14
1990	*	*	*	*	1	5	24	30	28	13
1991	*	*	*	*	2	6	30	36	34	16

Table 3. Expected monthly catches of sea-trout in the Derwent + Cocker and Leven + Crake for the years 1976 to 1991.

DERWENT + COCKER

MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1976	*	*	*	*	1	3	18	77	140	132
1977	*	*	*	*	1	7	36	154	280	264
1978	*	*	*	*	1	5	27	114	207	195
1979	*	*	*	*	1	5	27	113	205	194
1980	*	*	*	*	1	8	45	191	347	327
1981	*	*	*	*	1	6	32	136	247	233
1982	*	*	*	*	1	7	35	149	271	256
1983	*	*	*	*	1	3	17	71	129	121
1984	*	*	*	*	1	6	30	125	228	215
1985	*	*	*	*	2	10	53	224	408	385
1986	*	*	*	*	1	5	27	115	210	198
1987	*	*	*	*	1	8	40	171	310	293
1988	*	*	*	*	2	13	72	303	551	520
1989	*	*	*	*	1	9	48	201	365	344
1990	*	*	*	*	1	8	43	182	331	312
1991	*	*	*	*	2	10	52	220	400	377

LEVEN + CRAKE

MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1976	*	*	*	*	0	1	5	13	20	22
1977	*	*	*	*	0	2	6	15	23	26
1978	*	*	*	*	0	1	2	6	9	10
1979	*	*	*	*	0	1	3	8	13	14
1980	*	*	*	*	0	2	7	18	28	32
1981	*	*	*	*	0	1	3	9	14	16
1982	*	*	*	*	0	3	10	27	42	47
1983	*	*	*	*	0	1	4	10	16	18
1984	*	*	*	*	0	1	3	8	12	13
1985	*	*	*	*	0	1	4	12	19	21
1986	*	*	*	*	0	1	5	13	21	23
1987	*	*	*	*	0	1	5	14	22	25
1988	*	*	*	*	1	5	18	50	78	87
1989	*	*	*	*	0	2	6	15	23	26
1990	*	*	*	*	0	2	9	23	36	40
1991	*	*	*	*	1	4	14	37	58	64

Table 4. Expected monthly catches of salmon in the Derwent + Cocker and Leven + Crake for the years 1976 to 1991.

catch was obtained and standardized by an appropriate estimate of its standard error. It was assumed that observed monthly catches were distributed in a "super-Poisson" manner so that the variance of a catch is proportional to the expected catch. $V(y) = \lambda E(y)$.

$$\text{Standardized residual} = \frac{(O - E)}{\{\lambda\, E\, (1 - \text{leverage})\}^{0.5}}$$

where O and E are the observed and expected catches respectively, λ is the coefficient of proportionality and the leverage term corrects for the fact that expected catches are estimated quantities. All computations were made by the generalized linear model procedures of GENSTAT.

The standardized residuals are presented in Tables 5 and 6. Monthly catches that are lower (negative sign) or higher (no sign) than expected were identified as those which exceeded 1.96, 2.58 or 3.29, the 5%, 1% and 0.1% tails of the normal distribution. No values for sea-trout in the Derwent + Cocker were lower than expected, but three higher than expected values were obtained in September 1986 (5%), June 1988 (5%) and October 1991 (0.1%). Only one value (August 1976) for sea-trout in the Leven + Crake was lower (1%) than expected, but five higher than expected values were obtained in August 1980 (5%), October 1983 (5%), October 1984 (5%), August 1986 (5%) and July 1988 (5%). Only two values (October 1988, August 1990) for salmon in the Derwent + Cocker were lower (5%) than expected, but six higher than expected values were obtained in August 1980 (5%), June 1981 (5%), July 1981 (5%), August 1986 (5%), August 1988 (5%) and October 1991 (1%). Only two values (October 1988, August 1991) for salmon in the Leven + Crake were lower (5%) than expected, but six higher than expected values were obtained in September 1976 (5%), June 1979 (5%), August 1980 (1%), August 1982 (5%), August 1988 (1%) and October 1991 (1%). The available evidence therefore indicates that

DERWENT + COCKER

MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1976	*	*	*	*	-0.63	-0.51	0.01	-0.94	1.71	0.05
1977	*	*	*	*	-0.30	-0.90	-0.57	1.30	0.33	-0.22
1978	*	*	*	*	-0.47	-0.90	0.27	0.91	-0.10	-0.25
1979	*	*	*	*	-0.61	-1.53	-1.73	1.42	1.39	0.96
1980	*	*	*	*	-0.07	-0.28	1.69	0.06	-1.20	-0.67
1981	*	*	*	*	0.80	0.76	0.91	0.26	-1.16	-1.71
1982	*	*	*	*	-0.12	-0.30	1.10	0.04	-0.56	-0.56
1983	*	*	*	*	-0.70	-1.28	-1.94	1.08	1.42	1.53
1984	*	*	*	*	0.15	0.66	0.00	-0.06	-0.50	-0.16
1985	*	*	*	*	1.30	1.92	1.25	-1.36	-1.49	-1.06
1986	*	*	*	*	-0.30	-0.24	-1.63	-0.23	1.99*	0.62
1987	*	*	*	*	0.32	1.69	0.64	-0.23	-1.51	-0.96
1988	*	*	*	*	0.97	2.05*	-0.08	-0.66	-1.10	-0.58
1989	*	*	*	*	-0.28	0.05	0.47	-0.85	0.65	-0.27
1990	*	*	*	*	-0.40	0.38	-0.56	-0.05	0.56	-0.11
1991	*	*	*	*	-0.11	-1.30	-0.49	-1.10	0.47	3.74*

LEVEN + CRAKE

MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1976	*	*	*	*	-0.62	-0.59	0.53	-3.07*	1.63	1.89
1977	*	*	*	*	-0.44	-0.23	-0.73	-0.58	1.06	0.60
1978	*	*	*	*	-0.40	-0.37	-0.94	1.49	-0.15	-0.27
1979	*	*	*	*	-0.42	-0.41	-1.23	0.07	1.86	-0.60
1980	*	*	*	*	-0.47	1.05	0.10	2.21*	-1.35	-1.82
1981	*	*	*	*	-0.03	-0.25	0.47	0.01	-0.52	0.26
1982	*	*	*	*	0.40	-0.18	0.90	0.34	-0.70	-0.69
1983	*	*	*	*	1.79	0.77	-1.07	-1.81	0.46	2.14*
1984	*	*	*	*	-0.43	-0.83	-1.18	-1.32	1.45	2.03*
1985	*	*	*	*	0.20	0.04	1.18	0.16	-0.55	-1.08
1986	*	*	*	*	-0.48	0.02	-0.08	2.25*	-1.53	-0.77
1987	*	*	*	*	-0.48	0.01	-0.11	1.29	-0.17	-1.22
1988	*	*	*	*	0.60	-0.79	2.25*	-0.28	-0.85	-1.05
1989	*	*	*	*	-0.38	0.60	-1.17	1.28	0.27	-0.84
1990	*	*	*	*	1.66	0.68	-0.32	-1.18	0.94	-0.21
1991	*	*	*	*	0.12	0.61	-0.17	-0.08	-1.17	1.47

Table 5. **Standardized Pearson residuals for comparisons between observed and expected monthly catches of sea-trout in the Derwent + Cocker and Leven + Crake for the years 1976 to 1991. Asterisks denote those months which exceeded 1.96, 2.58 or 3.29, the 5%, 1% and 0.1% tails of the normal distribution.** Negative values indicate lower-than-expected catches, positive values indicate higher-than-expected catches.

DERWENT + COCKER

MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1976	*	*	*	*	0.13	0.29	-0.55	-1.96	0.67	1.16
1977	*	*	*	*	0.38	0.02	0.58	-1.40	1.22	-0.35
1978	*	*	*	*	0.27	-0.09	0.65	1.62	-0.47	-1.19
1979	*	*	*	*	0.05	-0.18	-0.52	0.07	0.13	0.08
1980	*	*	*	*	0.48	0.12	0.41	2.05 *	-0.52	-1.45
1981	*	*	*	*	0.22	2.37 *	2.07 *	-0.86	-0.78	0.09
1982	*	*	*	*	-0.21	-0.53	-0.69	0.72	-0.40	0.23
1983	*	*	*	*	0.43	-0.13	-0.85	-1.81	1.37	0.52
1984	*	*	*	*	-0.19	-0.13	-1.03	-1.72	1.33	0.61
1985	*	*	*	*	-0.26	-0.26	0.26	1.35	0.34	-1.53
1986	*	*	*	*	0.27	-0.10	-0.41	2.80 *	-1.55	-0.61
1987	*	*	*	*	-0.04	0.11	1.29	-0.44	0.28	-0.51
1988	*	*	*	*	-0.31	-0.72	0.81	1.97 *	0.19	-2.05 *
1989	*	*	*	*	-0.25	-0.34	-1.23	0.10	-0.94	1.51
1990	*	*	*	*	-0.24	-0.07	-0.46	-1.99 *	0.79	1.13
1991	*	*	*	*	-0.26	0.09	-0.87	-1.89	-1.04	3.05 *

LEVEN + CRAKE

MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1976	*	*	*	*	-0.19	-0.51	0.28	-1.49	2.54 *	-1.20
1977	*	*	*	*	-0.21	0.18	-0.69	-1.16	1.40	-0.03
1978	*	*	*	*	-0.12	-0.33	-0.65	0.07	1.29	-0.84
1979	*	*	*	*	-0.15	2.53 *	0.53	-0.03	-0.41	-0.61
1980	*	*	*	*	-0.23	-0.28	-0.30	2.69 *	-0.24	-1.76
1981	*	*	*	*	-0.16	1.44	0.68	-1.31	0.00	0.32
1982	*	*	*	*	-0.28	-0.76	0.17	2.36 *	-1.03	-0.83
1983	*	*	*	*	-0.17	-0.46	-0.90	-1.44	1.42	0.49
1984	*	*	*	*	-0.14	-0.38	-0.76	-0.81	-0.43	1.65
1985	*	*	*	*	1.95	-0.49	0.14	1.02	0.80	-1.79
1986	*	*	*	*	-0.19	0.26	0.45	0.12	-1.01	0.58
1987	*	*	*	*	-0.20	0.96	-0.04	-0.29	0.21	-0.20
1988	*	*	*	*	-0.40	-0.44	0.77	2.73 *	-0.52	-2.05 *
1989	*	*	*	*	-0.21	-0.55	-0.89	-0.78	-0.50	1.82
1990	*	*	*	*	-0.26	-0.40	0.72	-1.81	-0.02	1.29
1991	*	*	*	*	0.93	0.31	-0.34	-2.05 *	-1.39	3.07 *

Table 6. **Standardized Pearson residuals for comparisons between observed and expected monthly catches of salmon in the Derwent + Cocker and Leven + Crake for the years 1976 to 1991.** Asterisks denote those months which exceeded 1.96, 2.58 or 3.29, the 5%, 1% and 0.1% tails of the normal distribution. Negative values indicate lower-than-expected catches, positive values indicate higher-than-expected catches.

although several higher than expected catches were obtained for both sea-trout and salmon in both river systems, much lower than expected monthly catches were rare. There was only one for sea-trout in the Leven + Crake, none for sea-trout in the Derwent + Cocker, only two for salmon in the Leven + Crake, and only two for salmon in the Derwent + Cocker. Finally, it should be stressed that each table contains 96 residual values and therefore, by pure chance, the expected number of significant values should be about five at a 5% probability level and about one at a 1% probability level. It must be therefore concluded that there is no strong evidence to support the hypothesis of abnormally low monthly catches of salmon or sea-trout in either river system, except for the five occasions detailed above.

3.3 Water quality in Bassenthwaite Lake

Chlorophyll *a* data were available from August 1990 to the present, with one, two or three observations per calendar month. Maximum, minimum and mean lake levels were available on a monthly basis and suspended solids in the lake outflow (River Derwent at Ouse Bridge) were provided as spot readings (quarterly prior to 1991, bimonthly in 1991 and monthly in 1992). Windspeeds for the Sellafield area were provided as daily means.

The finest temporal resolution for the salmonid catch data was monthly and, therefore, it was appropriate to convert all the environmental variables outlined above to monthly means (see Table 7). For windspeed, the data were also expressed as the square of the speed (calculated on a monthly basis as the mean of the squared daily windspeed) because windstress is proportional to the square of the windspeed and, therefore, the squared data may provide a better indication of the relative efficiency of wind-induced mixing of the lake water.

All of the variables are likely to exhibit seasonal changes during the year and in order that this pattern should not obscure possible underlying relationships between chlorophyll *a* and potential predictor variables, residual plots were produced for inspection. Chlorophyll *a* residuals (x axis) were plotted, separately, against the residuals for maximum lake level, minimum lake level, mean lake level, range (maximum - minimum), suspended solids, windspeed and squared wind speed (y axis). It is clear from inspection of these plots (Fig. 6) that there is little predictive power in any of the seven variables. Simple linear regression of chlorophyll *a* on month of the year and then, additionally, on each of the seven variables gave non-significant F-tests for all the variables. This approach was then repeated on a restricted data set comprising the salmonid fishing season only (May to October inclusive). Fig. 7 presents the plots from this second series of analyses and again, it was concluded that the variables have little predictive power.

If there was a more sophisticated model involving these seven variables (eg. a non-linear equation and/or interactions between variables) capable of predicting chlorophyll *a* better than monthly pattern alone, it is most unlikely that parts of it would not be indicated in the residual plots or in the regressions. It is concluded that, with the short data sets available, it is not possible to predict chlorophyll *a* levels in Bassenthwaite Lake from the other environmental data available.

3.4 Comparison of rod-catches with water quality - Bassenthwaite Lake

Despite this inability to predict chlorophyll *a* levels from other environmental variables (see above) a visual inspection was made of the suspended solids/ chlorophyll *a* data for Bassenthwaite Lake for those months when salmonid catches in the Derwent + Cocker were markedly higher or lower than expected (see Section 3.2). Table 8 summarizes this information and, from a visual inspection, there is little to suggest that lower than expected catches were associated with high chlorophyll *a*/suspended solids or, vice versa, that higher than expected catches were associated with low chlorophyll *a*/suspended solids.

Month	Year	Max Lake Level	Min Lake Level	Mean Lake Level	Suspended solids	Chlorophyll *a*	Windspeed Mean	Windspeed Mean of Squares
		cm above station zero			mg l^{-1}	µg l^{-1}	knots	$knots^2$
1	90	2235	988	1610	*	*	14.210	228.6
2	90	2533	1585	2084	8	*	17.282	334.6
3	90	2072	840	1196	*	*	11.952	164.1
4	90	1159	817	959	*	*	9.790	114.6
5	90	902	701	804	1	*	5.935	39.0
6	90	1136	695	857	*	*	8.400	83.1
7	90	1208	675	888	*	*	8.158	89.5
8	90	1017	639	768	5	11.425	8.490	90.8
9	90	1289	767	968	*	10.750	9.172	114.8
10	90	2498	897	1399	*	10.580	10.313	128.6
11	90	1689	942	1239	2	5.925	8.060	84.6
12	90	2514	846	1366	*	2.630	11.035	175.8
1	91	2506	898	1517	2	1.320	11.100	168.7
2	91	2627	734	1115	*	1.370	6.818	57.8
3	91	2392	957	1446	4	6.460	5.826	42.8
4	91	1962	721	1195	*	9.920	9.773	108.7
5	91	731	614	683	1	15.145	6.377	46.7
6	91	1090	603	859	*	12.930	8.680	87.0
7	91	896	712	833	2	15.375	7.845	71.3
8	91	1056	679	833	*	13.220	7.042	61.3
9	91	1050	619	789	3	10.823	7.887	85.9
10	91	1763	853	1186	4	14.435	8.874	130.2
11	91	2731	1030	1788	4	3.270	11.293	154.0
12	91	2853	762	1325	*	2.700	7.752	95.4
1	92	1429	735	1016	3	1.380	7.045	81.6
2	92	1943	724	1198	2	4.985	8.575	86.3
3	92	2165	1094	1524	3	8.937	10.506	129.3
4	92	1356	992	1138	3	20.760	10.330	118.9
5	92	1573	700	1065	8	15.290	9.140	99.3
6	92	711	579	641	3	20.605	6.547	48.7
7	92	950	593	745	1	15.380	8.650	86.8
8	92	1637	818	1037	2	18.985	10.532	134.1
9	92	1628	928	1327	5	41.005	10.043	131.1
10	92	1562	784	979	3	25.915	8.145	80.8
11	92	1902	1206	1569	3	3.810	*	*
12	92	2575	884	1514	6	1.920	*	*

Table 7. Mean monthly environmental data for Bassenthwaite Lake during the period January 1990 to December 1992. Asterisks denote missing values.

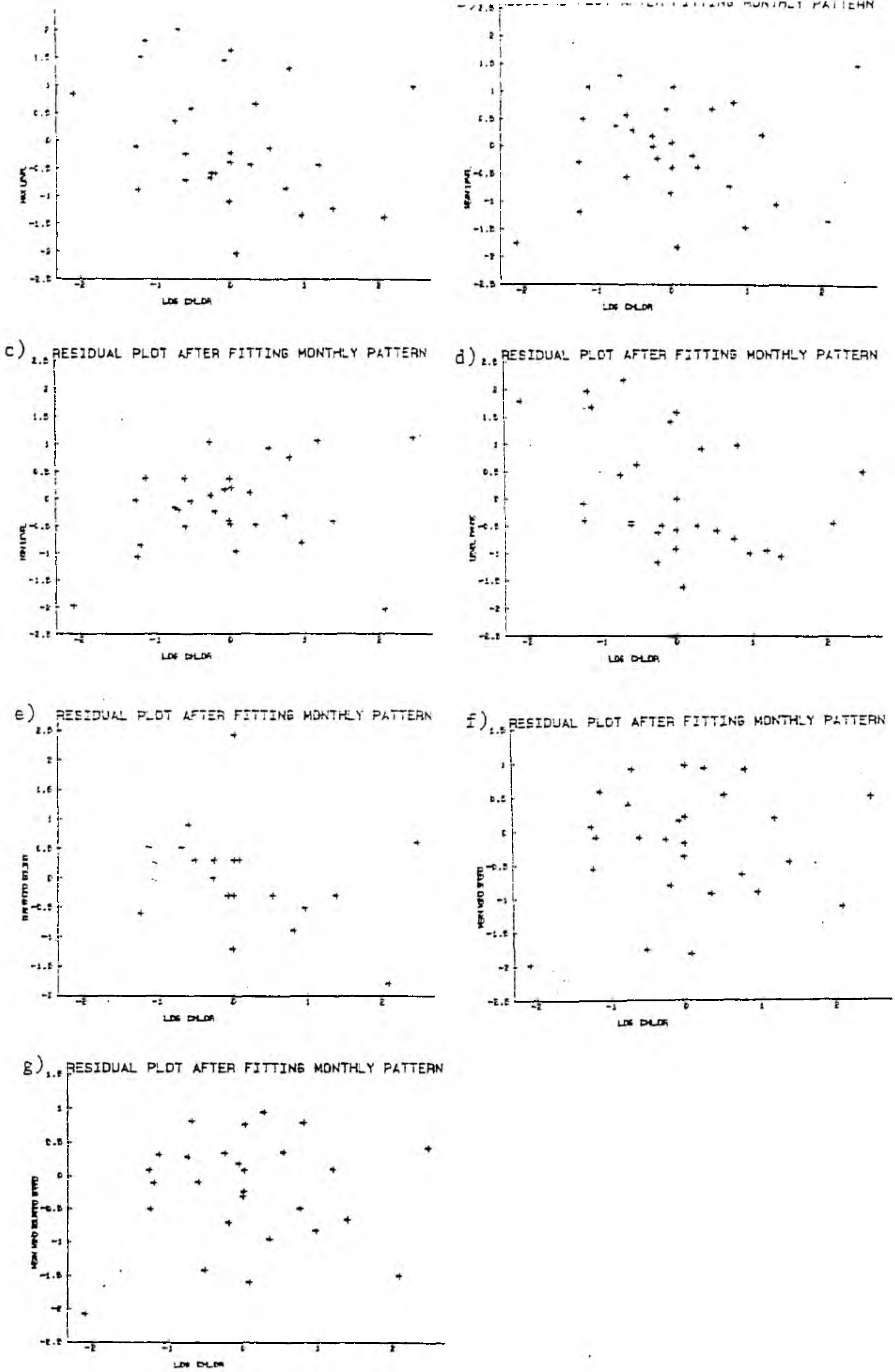


Fig. 6. Plots of residuals for chlorophyll *a* (x axis) against residuals for a) maximum lake level, b) mean lake level, c) minimum lake level, d) lake level range, e) suspended solids, f) wind speed, g) squared wind speed for Bassenthwaite Lake 1990-1992, all months.

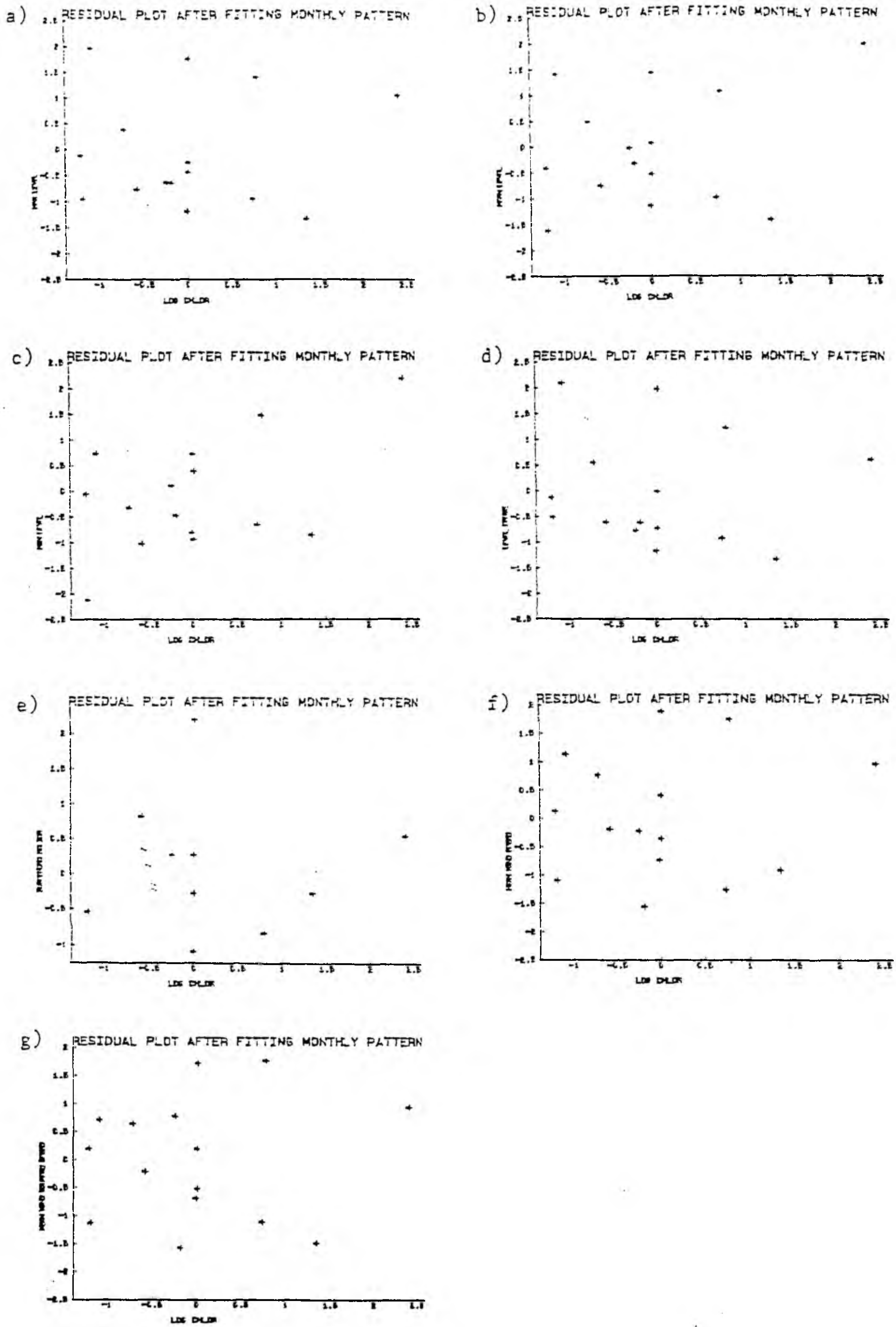


Fig. 7. Plots of residuals for chlorophyll *a* (x axis) against residuals for a) maximum lake level, b) mean lake level, c) minimum lake level, d) lake level range, e) suspended solids, f) wind speed, g) squared wind speed for Bassenthwaite Lake 1990-1992, data restricted to May-October (inclusive).

Species	Date	Standardized Residual (from Tables 5 and 6)	Suspended Solids mg l^{-1}	Chlorophyll *a* µg l^{-1}
Catches lower than expected				
Salmon	October 1988	-2.05	6	*
	August 1990	-1.99	5	11.4
Catches higher than expected				
Sea-trout	Sept. 1986	1.99	2	*
	June 1988	2.05	5	*
	October 1991	3.74	4	14.4
Salmon	August 1990	2.05	4	*
	June 1981	2.37	4	*
	July 1981	2.07	5	*
	August 1986	2.80	5	*
	August 1988	1.97	5	*
	October 1991	3.05	4	14.4

Table 8. Water quality variables in Bassenthwaite Lake when salmonid catches in the Derwent/Cocker system were higher or lower than expected. Asterisks denote missing values.

3.5 Water quality in Windermere South Basin

Full data sets for chlorophyll *a* (and algal counts, if necessary) are already available for Windermere South Basin and it is unnecessary, therefore, to attempt any prediction from other environmental variables. Table 9 presents the mean monthly chlorophyll *a* concentrations for Windermere South Basin during the period 1976 to 1991. These data are presented in graphical form in Fig. 8.

3.6 Comparison of rod-catches with water quality - Windermere South Basin

A monthly pattern was fitted to the logarithm of chlorophyll *a* measurements in Windermere South Basin and the residuals obtained. The standardized catch residuals (see Section 3.2, Tables 5 and 6) were then plotted against the chlorophyll *a* residuals (Figs. 9 and 10). No correlations were apparent from visual inspection but further analyses of monthly catches were then made by fitting a 'super-Poisson' model for monthly catch which assumes that the common monthly percentage catch can be modified by the deviation of the chlorophyll *a* level from its average monthly pattern. A further assumption was made that the influence of chlorophyll *a* would be the same in all months (May to October) but the single modification parameter was not significant for either sea-trout or salmon. In the light of this information, a second assumption was made that the influence of chlorophyll *a* may be different in each month. Figs. 10 and 11 show the monthly residual plots for sea-trout and salmon respectively. Using F-value test statistics, it was concluded that there was no significant influence of chlorophyll *a* on catches of either species at any month during the salmonid fishing season.

MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1976	1.35	1.33	4.72	11.94	7.45	4.13	19.45	27.87	20.24	4.82	1.28	1.23
1977	1.23	1.65	3.11	8.07	8.57	5.07	8.52	14.04	11.32	5.23	1.98	1.38
1978	1.20	1.52	2.98	6.97	25.08	10.37	12.77	10.13	24.19	7.24	2.37	1.62
1979	1.39	2.00	3.28	8.63	18.10	9.00	9.90	20.86	28.28	6.81	3.66	1.66
1980	1.21	1.58	2.99	15.19	7.49	5.79	14.00	22.66	13.60	6.83	3.22	1.85
1981	1.04	1.25	2.75	18.42	10.26	12.10	16.92	11.20	11.68	4.37	3.16	1.39
1982	1.51	1.14	3.24	10.21	14.27	12.92	9.66	15.86	17.69	5.67	1.17	0.79
1983	0.63	0.92	3.75	8.09	13.41	4.60	9.70	20.26	9.47	4.98	1.99	2.05
1984	1.30	1.80	4.65	8.15	15.07	12.75	12.98	12.80	16.80	10.28	2.32	1.57
1985	0.78	1.30	4.90	12.06	10.31	15.29	19.13	25.06	13.37	5.60	2.89	2.42
1986	1.84	2.05	6.47	11.22	10.15	7.13	6.19	11.33	16.00	8.02	2.42	1.10
1987	1.13	1.34	4.21	15.73	20.23	7.03	16.55	27.83	28.43	10.46	2.13	1.56
1988	1.06	0.89	2.56	12.91	11.74	9.34	22.47	24.97	20.11	6.58	2.74	1.44
1989	1.59	1.85	3.10	11.41	20.93	19.20	7.30	9.98	10.33	7.64	2.90	1.76
1990	1.72	3.00	8.64	15.76	8.10	8.46	18.60	22.80	20.52	4.18	2.62	2.32
1991	1.84	4.28	13.57	20.32	12.14	7.99	17.30	28.83	11.85	5.38	2.10	1.97

Table 9. Mean monthly chlorophyll a concentration (μg l^{-1}) in Windermere South Basin for the period 1976 to 1991.

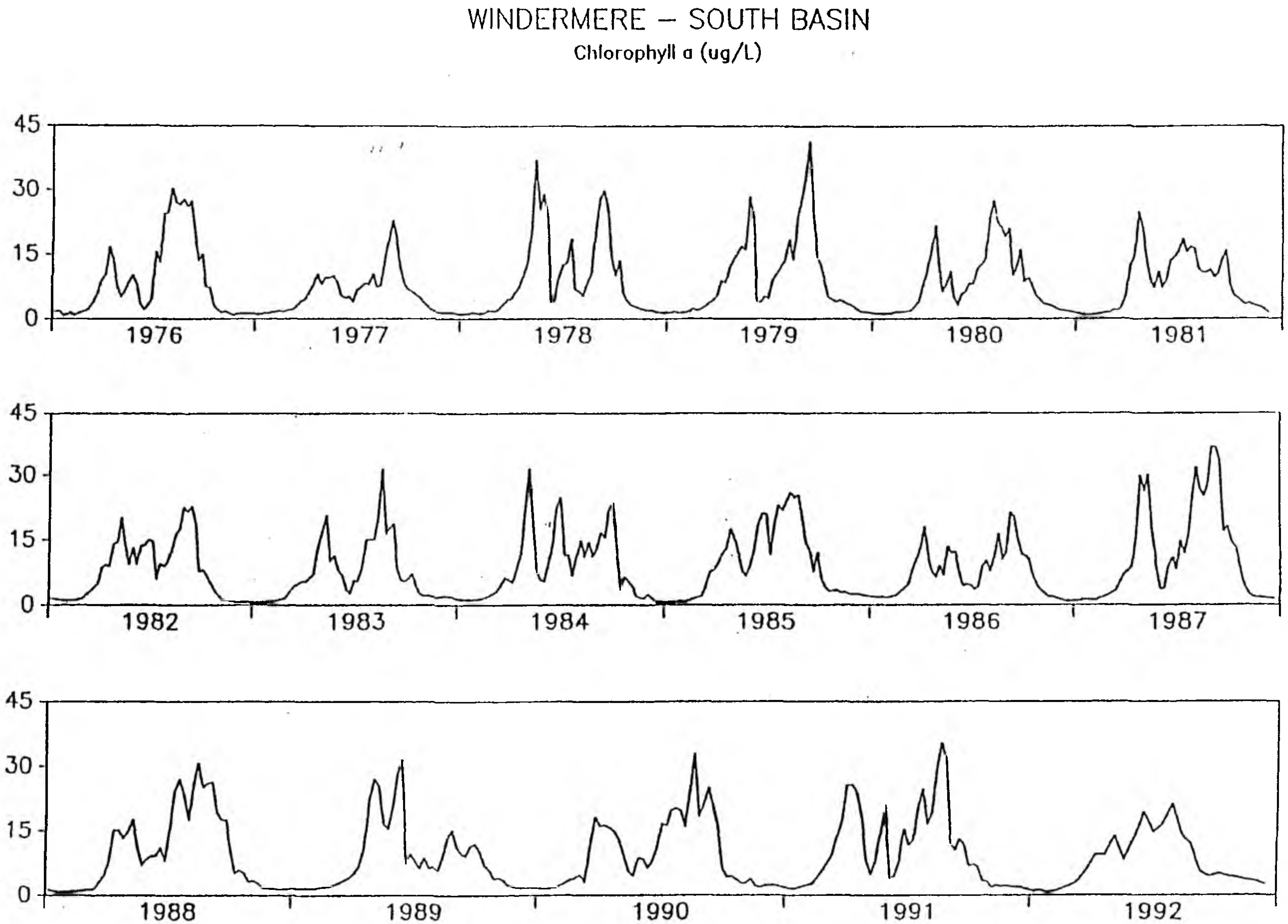


Fig. 8. Fluctuation in chlorophyll *a* concentration in Windermere South Basin during the period 1976 to 1992.

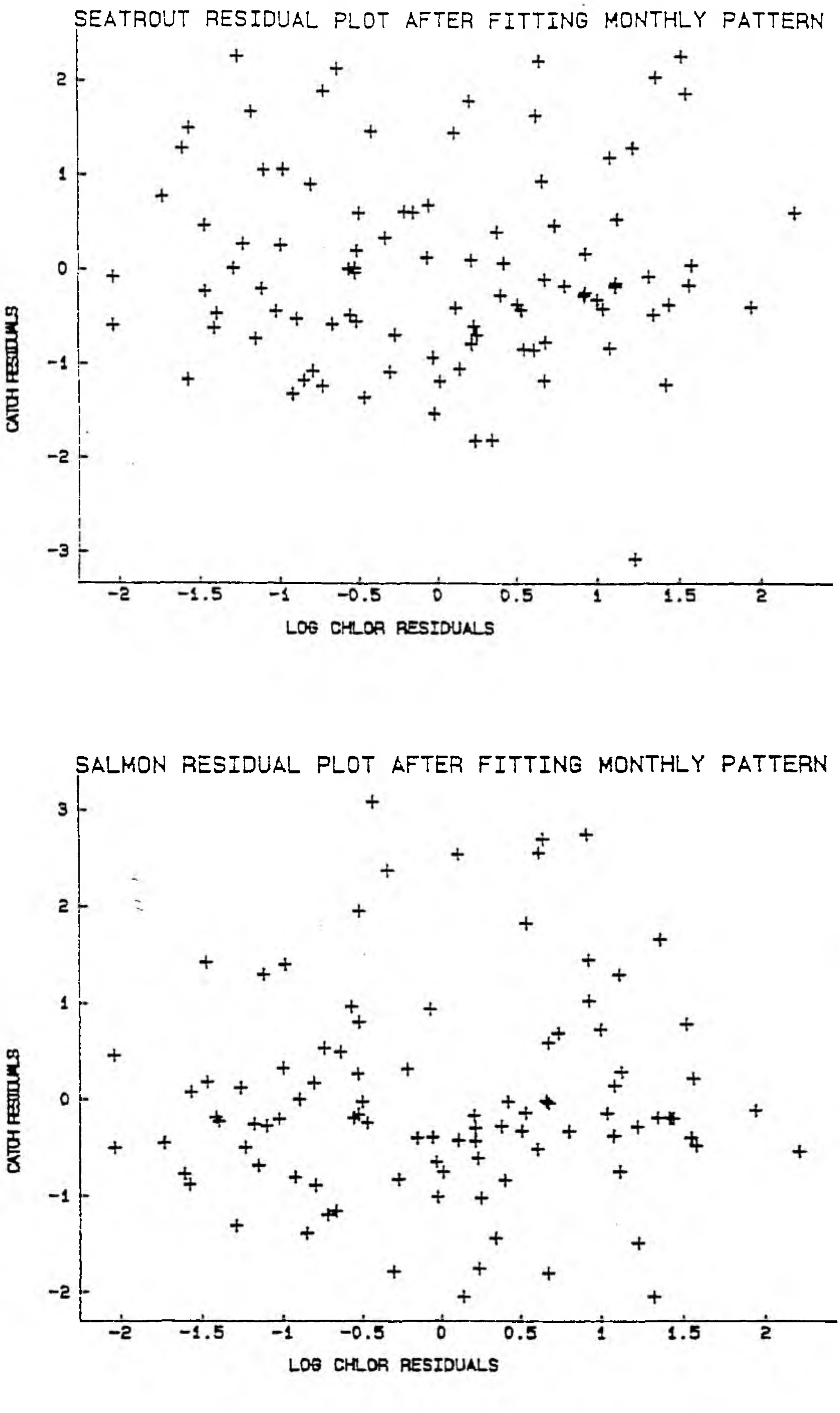


Fig. 9 Plot of catch residuals against Windermere South Basin chlorophyll *a* residuals for sea-trout and salmon in the River Leven/Crake system.

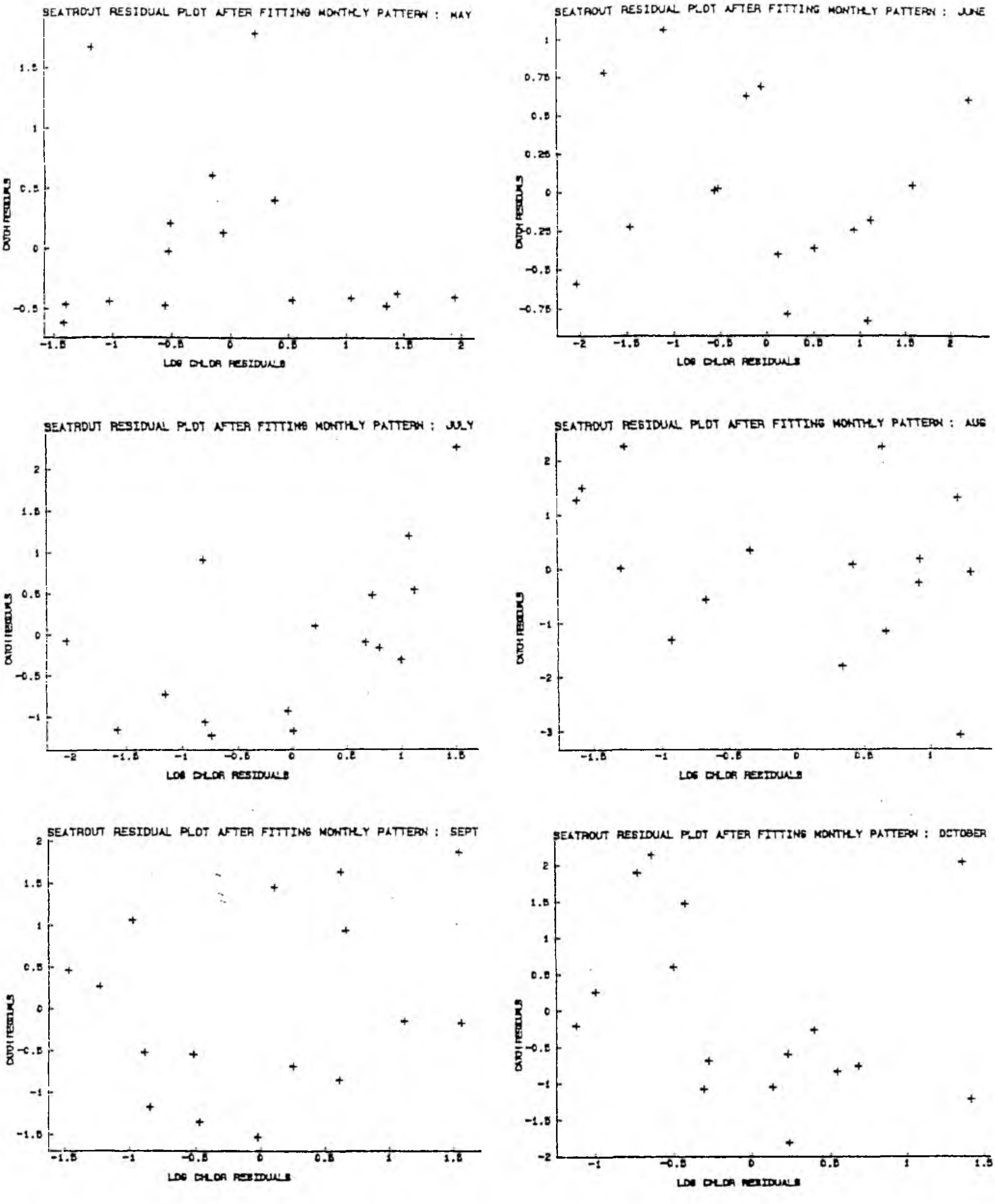


Fig. 10. Plots of catch residuals against Windermere South Basin chlorophyll *a* residuals for sea-trout in the River Leven/Crake system. The data are analysed on a month by month basis during the sea-trout fishing season.

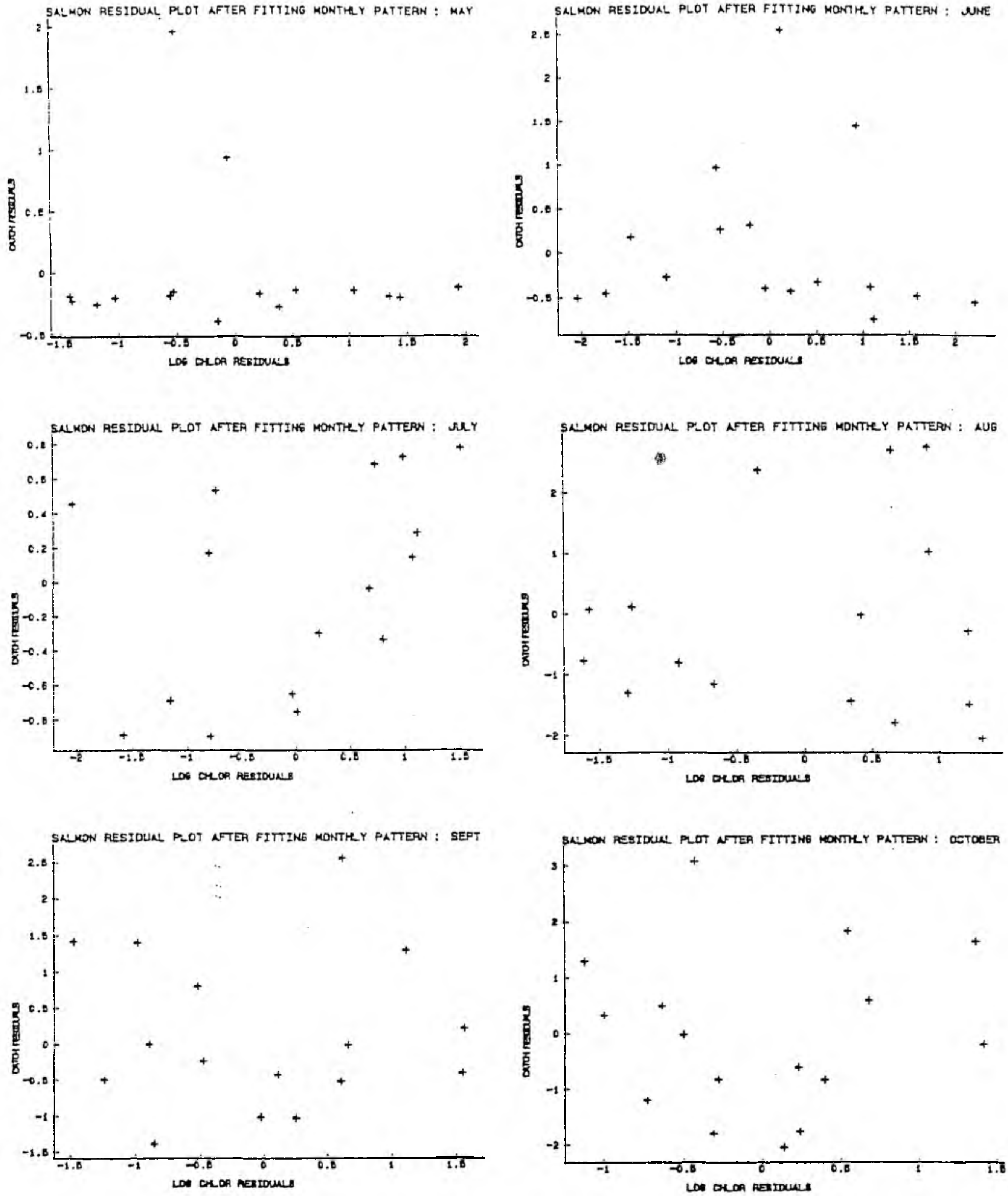


Fig. 11. Plots of catch residuals against Windermere South Basin chlorophyll *a* residuals for salmon in the River Leven/Crake system. These data are analysed on a month by month basis during the salmon fishing season.

4. DISCUSSION

The present investigation produced no evidence to support the hypothesis that changes in water quality in Bassenthwaite Lake, resulting from algal blooms, have had any adverse impact on the overall catches of salmon and sea-trout in the Rivers Derwent + Cocker. Thus, all the changes observed in the catches were within those normally expected for fisheries of this type and were similar to those of other salmonid rivers in the North West Region. It is concluded, therefore, that any deterioration of water quality in Bassenthwaite Lake has not caused major damage to the salmon and sea-trout fisheries of the Rivers Derwent and Cocker. This conclusion is supported by examination of another lake/river system in the area, vis the Windermere South Basin and the Rivers Leven and Crake, for which continuous records of water quality have been maintained during a well-known and documented period of lake enrichment resulting primarily from the increasing sewage-borne load of soluble reactive phosphorus (see Atkinson et al 1989). Again, no evidence could be found linking poor catch returns for salmon and/or sea-trout in the river system with water quality in Windermere South Basin.

Lake enrichment, or eutrophication as it is usually called, is known to have both beneficial and harmful effects on fish populations. One of the most marked effects of eutrophication on the fisheries resource of a water body is a general tendency for increased fish stock with increased levels of primary production. In North America, investigations in several lakes have established a positive relationship between fish yield as catch data, or fish biomass, and annual production of planktonic algae, or summer chlorophyll levels, or epilimnetic total phosphorus concentration (eg Oglesby 1977; Hanson & Leggett 1982; Jones & Hoyer 1982). It has even been suggested that mean summer chlorophyll concentration can be used to predict sportfish harvest from a Lake (Jones & Hoyer 1982).

The harmful effect of algae on fish catches has a long history. Although fish biomass in a lake may increase, the species may change, usually from salmonids to non-salmonids such as perch, roach and carp. Algal blooms, especially blue-greens (or cyanobacteria), may also affect catches. As long ago as 1937, Rosenberg (1937) showed that poor catches of brown trout in several Scottish lochs in one summer were associated with exceptionally large blooms of blue-green algae (cyanobacteria) such as *Anabaena* and *Oscillatoria*. The trout were present and alive in most of the lochs and rose to the fly in usual numbers as soon as the "algal" growth died down. However in one loch the decomposition of the dead blue-greens led to rapid deoxygenation of the water and a fish-kill of 640 trout in one night. Taylor (1978) made a detailed analysis of trout catches in relation to various factors in a eutrophic reservoir. He found that trout fishing was generally unaffected by the presence of large numbers of algae, including blue-greens. Rainbow trout fishing was good at all times but brown trout catches decreased markedly during two exceptionally large blooms of blue-greens or the dinoflagellate, *Ceratium*. In the South Basin of Windermere, poor catches of Arctic charr have been associated with exceptional blooms of *Oscillatoria* (Elliott & Baroudy 1992).

There is, therefore, some evidence for poor fish catches during exceptional phytoplankton blooms in lakes and the next question is whether or not such blooms affect catches in the river downstream from the lake. Mass fish-kills due to a "red-tide", a golden alga *Prymnesium parvum*, have been recorded in the USA (Pecos River, Texas; Rhodes & Hubbs 1992), but there are no similar records for a British or European river. It is unlikely that algae washed out of a lake travel far down the outflow river. There are large populations of specialized, filter-feeding, invertebrates living in the outflow biozone and several studies have shown that these animals are responsible for the rapid removal of plankton leaving a lake (eg Chandler 1937; Muller 1956; Cushing 1963; Carlsson et al 1977).

There may, however, be indirect effects on the river when the water leaving the lake is rich in nutrients. A detailed study in a Montana river showed that nutrient-rich water from a reservoir increased the productivity and diversity of periphyton in the river (Marcus 1980). Some workers have concluded that such river enrichment and increased algal production within the river leads to increased density of pre-smolt, streamdwelling salmon (eg Huntsman 1948). The withdrawal of nutrient-rich water from Bighorn Lake (USA) resulted in algal growths in the outflow river and increased fish production downstream (Soltero et al 1974). The opposite effect has been found in regulated rivers in Norway. One of the effects of eutrophication in these rivers is an increased growth of benthic algae, and this has been reported as having a harmful effect on spawning grounds and growth of juveniles of salmonid fish (Skulberg 1984).

It can be seen from the above that the local effects can occur in a river immediately downstream from a nutrient-rich supply of water. A general review of environmental and biological features of Bassenthwaite Lake came to the conclusion that it always was, and still is, one of the most productive of the Cumbrian lakes (Atkinson et al 1989). Unlike most of the other lakes, it has a short retention time of only about 24 days. This short retention time is likely to lead to 'episodic' wash-out effects, and to favour the predominance of rapidly growing phytoplankton species (eg diatoms) rather than slow growing ones (eg larger blue-greens). It also means that nutrient inputs to the lake could be mostly washed out rather than stored in the lake, but more work is required on the nutrient pathways in the lake. It is possible, however, that the outflow of nutrient-rich water could affect the River Derwent immediately below the lake. This could be confirmed by future surveys of the river flora and fauna at selected sites.

5. CONCLUSIONS

1 The Rivers Derwent and Cocker provide the second best salmon catches in the North West Region but only the fifth best sea-trout catches.

2 Annual catches of salmon fluctuate markedly but the trend has been upward for the period 1976-1991.

3 Sea-trout catches have declined since 1981 to a minimum in 1990 but then increased in 1991.

4 There is no evidence to suggest that annual catches of salmon and sea-trout for the Rivers Derwent and Cocker were fluctuating differently to those for other North West Region rivers.

5 When the data were analysed on a monthly basis, there were no obvious correlations between lower-than-expected catches and poor water quality (based on chlorophyll *a* or suspended solids) in Bassenthwaite Lake. Similarly, higher-than-expected catches could not be related to good water quality.

6 A parallel examination of the data for Windermere South Basin (for which complete data sets are available) and the salmonid catches in the Rivers Leven and Crake came to a similar conclusion:- there is no evidence in the data to link poor catch returns with water quality deterioration within the lake.

7 The possibility still exists that the outflow of nutrient/algal-rich water could affect the River Derwent immediately downstream of Bassenthwaite Lake with a resultant local impact on the fishery in this area.

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