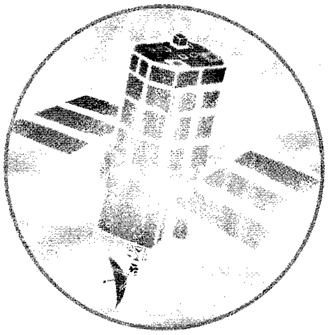
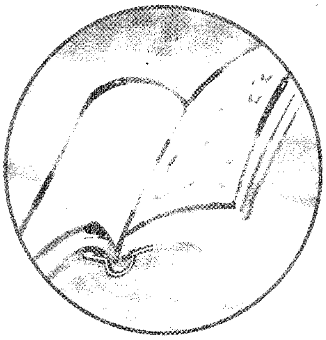
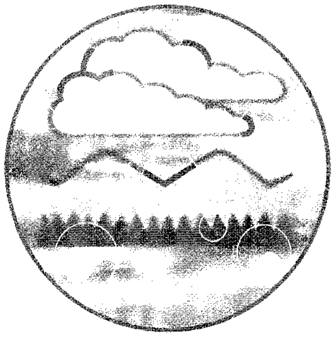
The Use of Catch Statistics to Monitor Fishery Change

Migratory Salmonid Study

Research and Development

Technical Report
W27

ENVIRONMENT AGENCY

APPENDIX 3: Worked example of ANCOVA analysis with salmon rod catch data for the River Ribble

An example of the use of the Analysis of Covariance and "Minitab" to demonstrate the effect of flow on Salmon rod catches in the R. Ribble

For ANOVA and ANCOVA procedures Minitab requires a worksheet in the following coded form. It will allow intuitive coding as shown. Preparation of the worksheet may be carried out according to taste or knowledge of suitable spreadsheet programs. In this case the worksheet was prepared on Excel and simply copied and pasted into the Minitab worksheet

salmon	month	year	flow
0	1	1978	52.926
0	1	1979	32.25
0	1	1980	54.136
0	1	1981	71.898
0	1	1982	61.558
0	1	1983	80.078
0	1	1984	79.672
0	1	1985	28.577
0	1	1986	82.514
0	1	1987	35.401
0	1	1988	75.486
0	1	1989	26.566
0	1	1990	81.162
0	1	1991	40.823
1	2	1978	32.456
0	2	1979	22.288
1	2	1980	56.46
0	2	1981	34.262
2	2	1982	24.456
0	2	1983	25.693
0	2	1984	49.331
0	2	1985	16.493
2	2	1986	10.672
0	2	1987	31.678
0	2	1988	50.709
0	2	1989	49.709
1	2	1990	71.604
1	2	1991	45.381
8	3	1978	48.93
etc	etc	etc	etc

It was known that in some months the numbers of salmon caught were insignificant and likely to cause more problems by invalidating the normality assumptions than their inclusion was worth so the following basic examination was carried out on the data in order to establish which months to delete:- (In practice this knowledge is likely to be already at hand from the spreadsheet or database file on which it is customarily stored.)

MTB > Describe 'salmon';
SUBC> By 'month'.

	month	N	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN
salmon	1	14	0.00000	0.00000	0.00000	0.00000	0.00000
	2	14	0.571	0.000	0.500	0.756	0.202
	3	14	3.286	3.000	3.167	2.494	0.667
	4	14	5.64	4.50	5.25	4.25	1.14
	5	14	8.79	7.50	8.25	7.14	1.91
	6	14	12.14	9.00	10.33	11.91	3.18
	7	14	21.79	13.00	19.25	21.82	5.83
	8	14	60.6	55.5	55.2	47.6	12.7
	9	14	116.5	105.5	113.7	59.2	15.8
	10	14	147.7	44.0	149.7	45.3	12.1

month		MIN	MAX	Q1	Q3
salmon	1	0.00000	0.00000	0.00000	0.00000
	2	0.000	2.000	0.000	1.000
	3	0.000	8.000	1.750	4.250
	4	0.00	16.00	3.50	7.75
	5	0.00	24.00	3.50	12.50
	6	2.00	44.00	4.50	16.00
	7	2.00	72.00	9.00	25.75
	8	12.0	174.0	18.5	80.0
	9	23.0	244.0	69.3	149.5
	10	52.0	219.0	123.7	188.0

MTB > Describe 'salmon';
SUBC> By 'year'.

salmon

year	N	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN
1978	10	30.8	11.0	26.2	37.6	11.9
1979	10	41.5	13.0	33.6	56.6	17.9
1980	10	75.1	25.0	63.4	92.3	29.2
1981	10	49.5	33.5	38.5	63.4	20.0
1982	10	35.9	8.5	28.4	50.5	16.0
1983	10	23.6	5.5	13.8	41.2	13.0
1984	10	26.6	2.5	15.5	51.3	16.2
1985	10	22.9	6.5	18.0	30.24	9.5
1986	10	36.8	9.0	27.6	54.6	17.3
1987	10	49.2	6.5	35.2	81.3	25.7
1988	10	62.5	4.5	50.8	87.6	27.7
1989	10	19.9	3.5	7.1	43.6	13.8
1990	10	23.3	5.0	14.5	38.0	12.0
1991	10	30.2	8.5	17.1	51.8	16.4

year	MIN	MAX	Q1	Q3
salmon				
1978	0.0	98.0	6.2	66.5
1979	0.0	146.0	1.5	95.0
1980	0.0	244.0	2.5	178.3
1981	0.0	187.0	2.2	73.7
1982	0.0	132.0	3.5	86.5
1983	0.0	126.0	1.5	29.5
1984	0.0	142.0	0.8	34.5
1985	0.0	85.00	0.00	53.00
1986	0.0	147.0	3.5	76.7
1987	0.0	210.0	0.0	88.8
1988	0.0	219.0	0.8	152.8
1989	0.0	142.0	0.0	17.0
1990	0.0	117.0	1.8	30.2
1991	0.0	165.0	0.8	36.2

MTB > Table 'year' 'month';
SUBC> Frequencies 'salmon';
SUBC> Counts.

ROWS: year COLUMNS: month

	1	2	3	4	5	6	7	8	9	10	ALL
1978	0	1	8	11	9	11	20	58	96	92	308
1979	0	0	2	10	17	15	11	83	131	146	415
1980	0	1	3	16	20	30	72	174	244	191	751
1981	0	0	3	5	24	44	43	53	136	187	495
1982	0	2	4	5	8	9	11	79	109	132	369
1983	0	0	2	6	11	5	2	17	67	126	236
1984	0	0	1	1	2	3	3	12	102	142	266
1985	0	0	0	7	6	6	17	56	85	52	229
1986	0	2	4	4	9	10	9	62	121	147	368
1987	0	0	0	4	4	9	20	55	190	210	495
1988	0	0	2	4	1	5	63	140	191	219	625
1989	0	0	5	2	0	2	10	15	23	142	199
1990	0	1	4	4	7	2	15	19	64	117	233
1991	0	1	8	0	5	19	9	25	70	165	302
ALL	0	8	46	79	123	170	305	848	1631	2068	5278

CELL CONTENTS -- COUNT

Clearly January and February provided catches of inconsequential size so were deleted from the worksheet and Minitab automatically noted the fact.

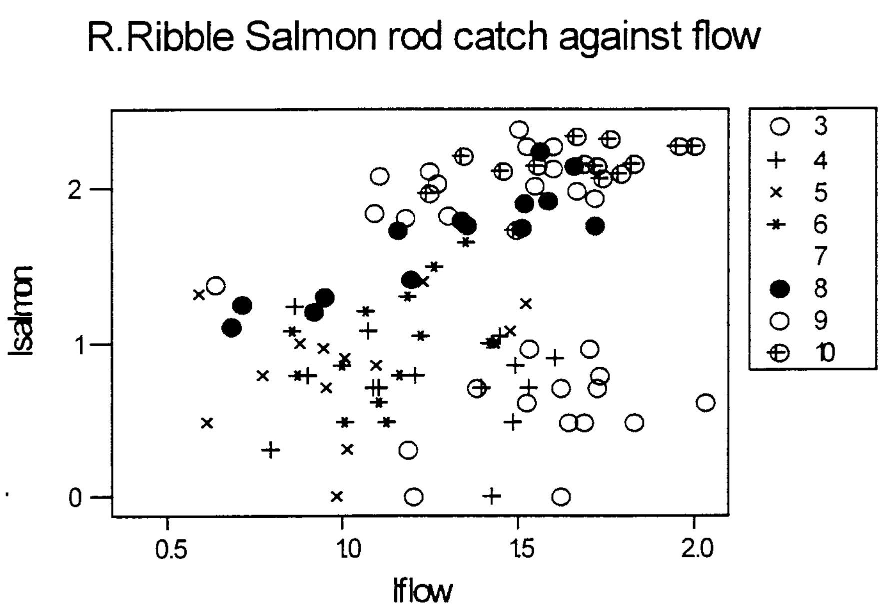
NOTE *** Data window was used to change the worksheet

The variables "salmon" and "flow" were then transformed to stabilise the variance.

```
MTB > Name c5 = 'lsalmon'
MTB > Let 'lsalmon' = logten(1+ 'salmon')
MTB > Name c6 = 'lflow'
MTB > Let 'lflow' = logten( 'flow' )
```

Minitab is then used to plot lsalmon against lflow to give some indication of the shape of the relationship.

```
MTB > Plot 'lsalmon'*'lflow';
SUBC>   Symbol 'month';
SUBC>   Title "R.Ribble Salmon rod catch against flow".
```



There is clearly a relationship between catch and flow for July, August and September but if the other months were considered on their own such a relationship would be doubtful however, the basic assumption in ANCOVA is that there are a number of parallel regression lines of lsalmon on lflow and that the monthly and annual effects account for the difference in intercept between them so the apparent lack of fit for the other months may be due to the effects of these factors. It also appears that the slope of the line may decrease at high flows so prior to carrying out the ANCOVA procedure a further variable ((Log10 (flow))^2) was added to the list in order to provide a second covariate and thus a second order relationship between logcatch and logflow.

```
MTB > Name c7 = 'lflowsq'
MTB > Let 'lflowsq' =  'lflow'**2
```

The ANCOVA procedure and printout follows.

```
MTB > Name c8 = 'FITS1' c9 = 'RESI1'
MTB > GLM 'lsalmon' = month year;
SUBC>   Covariates lflow lflowsq;
SUBC>   Means month year;
SUBC>   Fits 'FITS1';
SUBC>   Residuals 'RESI1'.
```

Factor	Levels	Values
month	**8**	3 4 5 6 7 8 9 10
year	**14**	1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991

Analysis of Variance for lsalmon

Source	DF	Seq SS	Adj SS	Adj MS	F	P
lflow	1	6.2729	0.4531	0.4531	8.32	0.005
lflowsq	1	0.0005	0.2065	0.2065	3.79	0.055
month	7	32.0572	32.3115	4.6159	84.77	0.000
year	13	3.3339	3.3339	0.2565	4.71	0.000
Error	89	4.8465	4.8465	0.0545		
Total	111	46.5109				

Term	Coeff	Stdev	t-value	P
Constant	0.1208	0.2992	0.40	0.687
lflow	1.4179	0.4915	2.88	0.005
lflowsq	-0.3829	0.1966	-1.95	0.055

Unusual Observations for lsalmon

Obs.	lsalmon	Fit	Stdev.	Fit Residual	St.Resid
10	0.00000	0.48029	0.10193	-0.48029	-2.29R
12	0.77815	0.32225	0.10446	0.45590	2.18R
14	0.95424	0.49565	0.10118	0.45859	2.18R
28	0.00000	0.77134	0.10476	-0.77134	-3.70R
39	0.30103	0.91424	0.10290	-0.61321	-2.93R
40	0.00000	0.58409	0.10193	-0.58409	-2.78R

R denotes an obs. with a large st. resid.

Nothing unusual here. With 112 observations a few with large standardised residuals can be expected.

Means for Covariates

Covariate	Mean	Stdev
lflow	1.288	0.3422
lflowsq	1.775	0.8709

Adjusted Means for lsalmon

month	Mean	Stdev
3	0.4305	0.06959
4	0.7337	0.06332
5	0.9774	0.06684
6	1.0173	0.06589
7	1.3166	0.06684
8	1.6733	0.06242
9	1.9745	0.06279
10	2.0155	0.07402
year		
1978	1.4250	0.08297
1979	1.3540	0.08350
1980	1.6959	0.08317
1981	1.4705	0.08427
1982	1.3335	0.08273
1983	1.1201	0.08265
1984	1.1240	0.08951
1985	1.0965	0.08328
1986	1.2658	0.08316
1987	1.1740	0.08400
1988	1.3067	0.08313
1989	0.9997	0.08331
1990	1.1688	0.08382
1991	1.2084	0.08412

In view of the apparently small contribution of the lflowsq covariate to the model the procedure was repeated using only lflow.

```
MTB > Name c10 = 'FITS2' c11 = 'RESI2'
MTB > GLM 'lsalmon' = month year;
SUBC>   Covariates lflow ;
SUBC>   Means month year;
SUBC>   Fits 'FITS2';
SUBC>   Residuals 'RESI2'.
```

Factor	Levels	Values
month	**8**	3 4 5 6 7 8 9 10
year	**14**	1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991

year		
1978	1.4339	0.08412
1979	1.3467	0.08470
1980	1.6754	0.08378
1981	1.4532	0.08509
1982	1.3426	0.08387
1983	1.1107	0.08378
1984	1.0812	0.08811
1985	1.1054	0.08444
1986	1.2826	0.08398
1987	1.1836	0.08515
1988	1.3039	0.08439
1989	0.9972	0.08458
1990	1.1916	0.08428
1991	1.2352	0.08427

It will be seen that the Mean Square Error increased from .0545 for the second order model to .0561 for the first order so very little is gained by adding the second covariate and in fact its inclusion gives rise to a model which is intuitively unlikely and ugly mathematically so in this case the simpler model is to be preferred.

At this point it is worth examining the residuals for Normality. Experience of the technique has shown that the residuals from the largest and smallest observations are the most likely to show significant departures from normality so those for March and October have been examined with those for August as a further example.

The columns in the worksheet headed Marres etc can be created using Minitab's "Unstack" function but here they were created more simply by using "Copy" and "Paste"

NOTE *** Data window was used to change the worksheet
MTB > %NormPlot 'Marres';
SUBC> Title 'March residuals from first order model'.
Executing from file: C:\MTBWIN\MACROS\NormPlot.MAC
Macro is running ... please wait

Analysis of Variance for lsalmon

Source	DF	Seq SS	Adj SS	Adj MS	F	P
lflow	1	6.2729	1.3843	1.3843	24.66	0.000
month	7	31.9452	32.1071	4.5867	81.70	0.000
year	13	3.2398	3.2398	0.2492	4.44	0.000
Error	90	5.0530	5.0530	0.0561		
Total	111	46.5109				

Term	Coeff	Stdev	t-value	P
Constant	0.6507	0.1262	5.16	0.000
lflow	0.47879	0.09642	4.97	0.000

Unusual Observations for lsalmon

Obs.	lsalmon	Fit	Stdev.Fit	Residual	St.Resid
10	0.00000	0.47639	0.10348	-0.47639	-2.23R
12	0.77815	0.34420	0.10545	0.43395	2.05R
14	0.95424	0.48671	0.10263	0.46753	2.19R
28	0.00000	0.78685	0.10607	-0.78685	-3.71R
39	0.30103	0.88451	0.10333	-0.58348	-2.74R
40	0.00000	0.56090	0.10279	-0.56090	-2.63R
101	2.28330	2.71945	0.10753	-0.43615	-2.07R

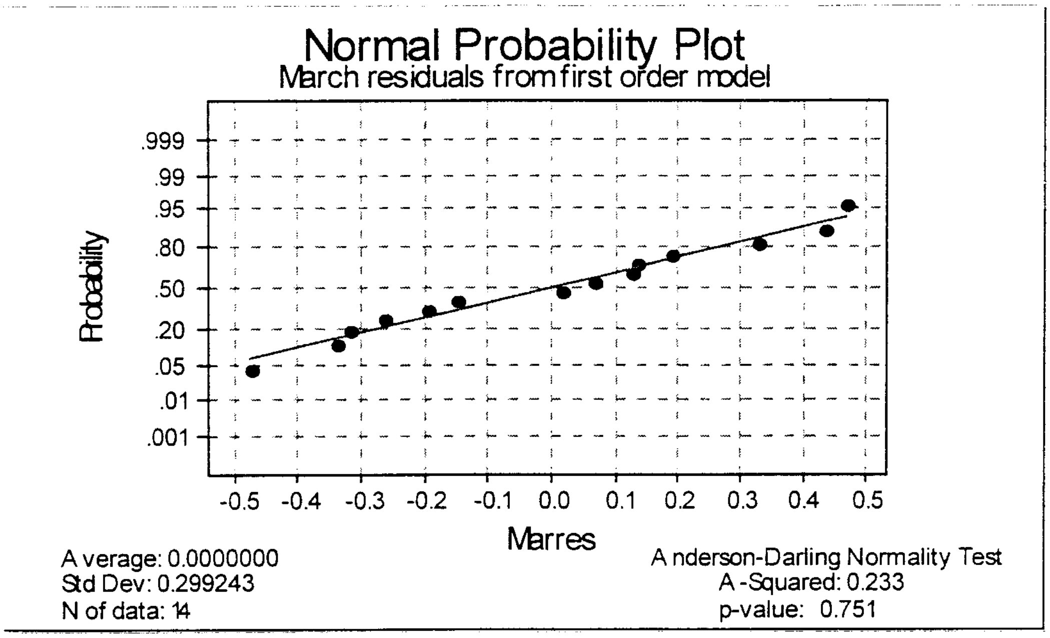
R denotes an obs. with a large st. resid.

Means for Covariates

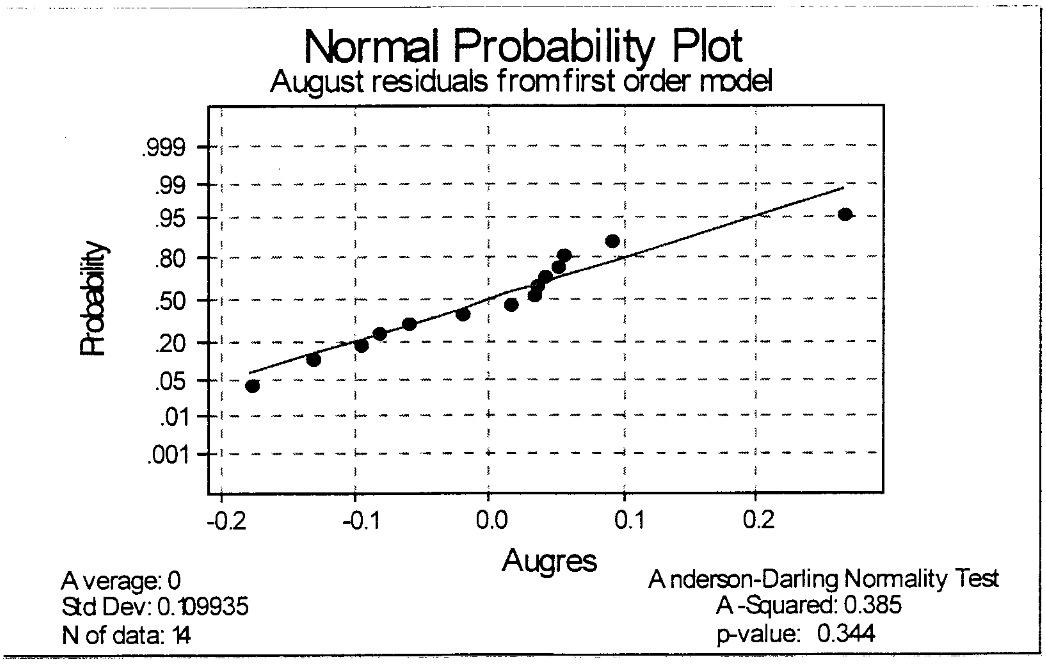
Covariate	Mean	Stdev
lflow	1.288	0.3422

Adjusted Means for lsalmon

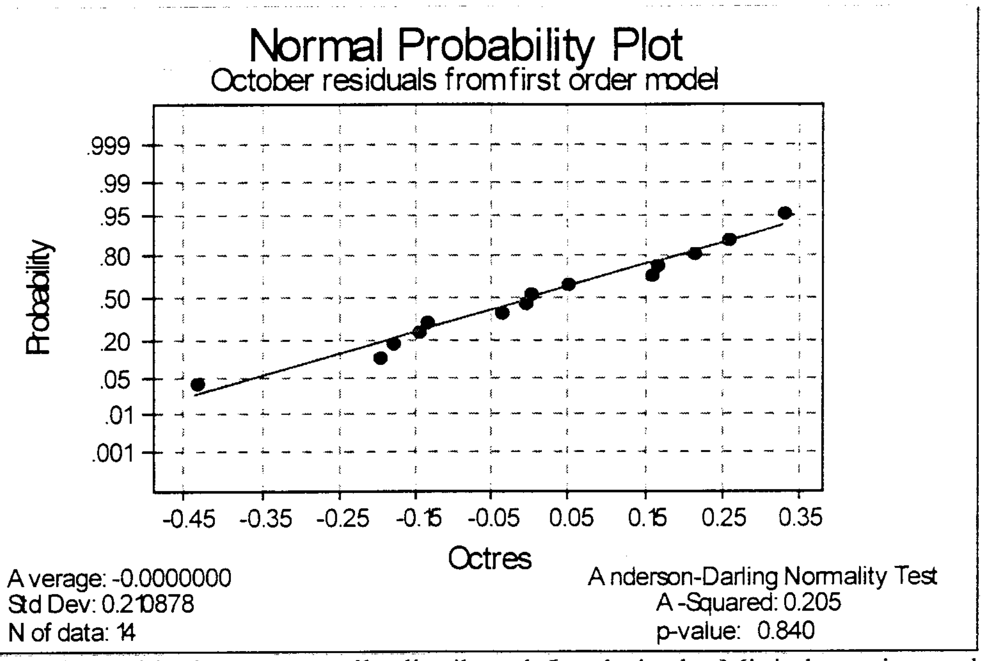
month	Mean	Stdev
3	0.4076	0.06964
4	0.7531	0.06349
5	0.9791	0.06786
6	1.0491	0.06481
7	1.3136	0.06785
8	1.6762	0.06336
9	1.9842	0.06356
10	1.9760	0.07227



MTB > %NormPlot 'Augres';
SUBC> Title 'August residuals from first order model'.
Executing from file: C:\MTBWIN\MACROS\NormPlot.MAC
Macro is running ... please wait

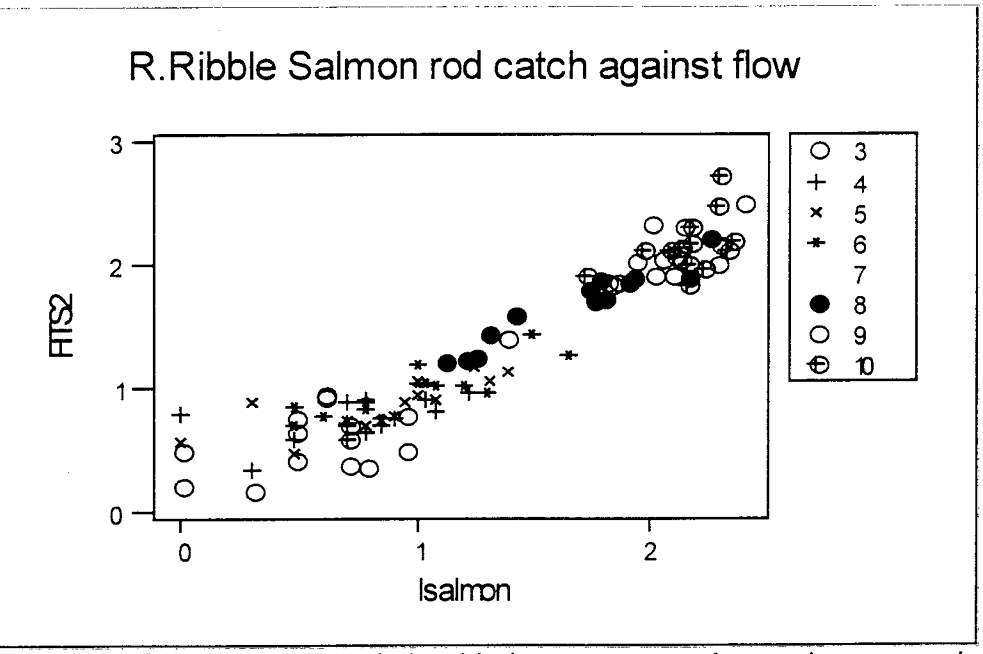


MTB > %NormPlot 'Octres';
SUBC> Title 'October residuals from first order model'.
Executing from file: C:\MTBWIN\MACROS\NormPlot.MAC
Macro is running ... please wait

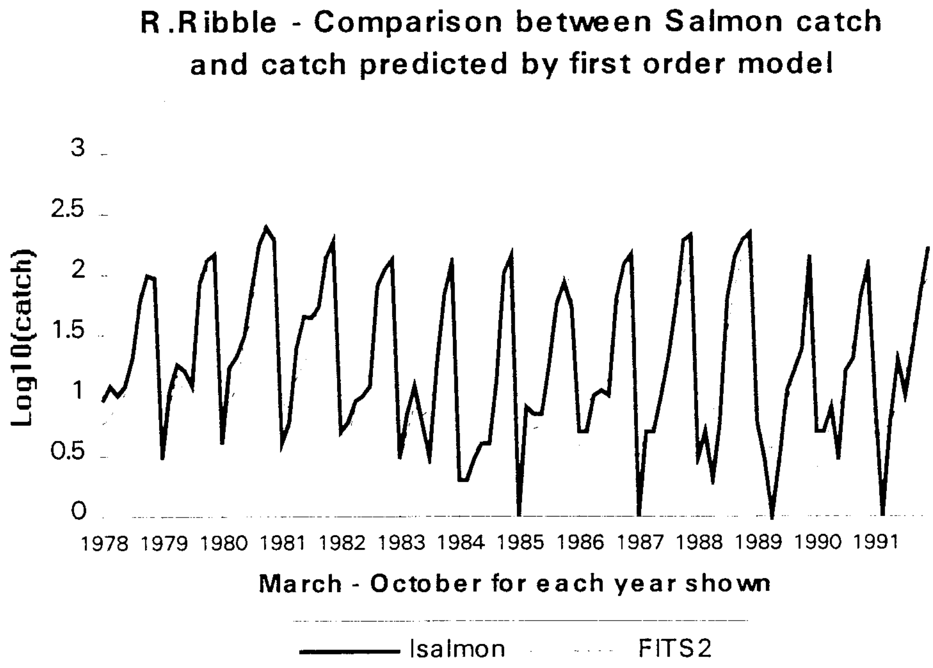


Clearly the residuals are normally distributed. Lastly in the Minitab session a plot of the observed catches was created against those fitted by the model.

MTB > Plot 'FITS2'*'lsalmon';
SUBC> Symbol 'month';
SUBC> Title "R.Ribble Salmon rod catch against flow".

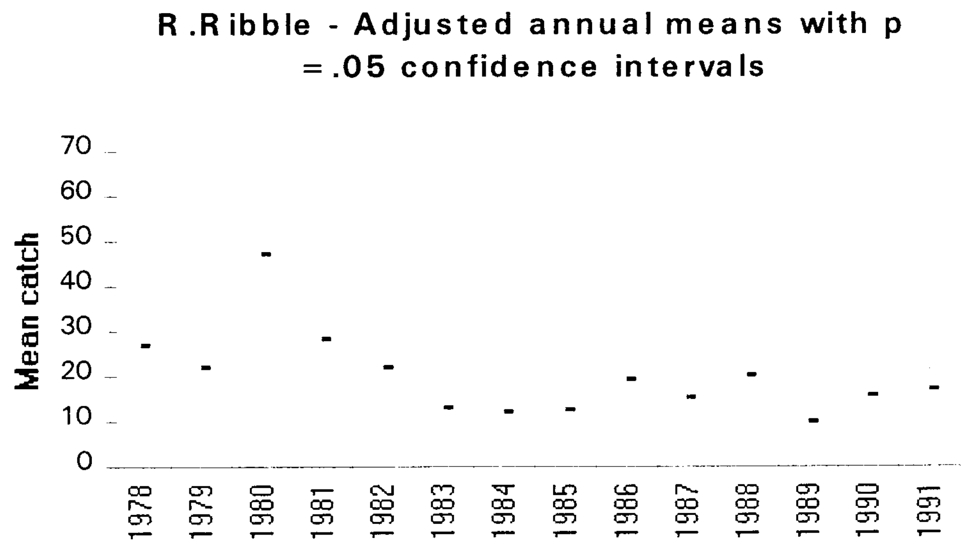


Another way of looking at this relationship is to compare what are in essence time series plots of the actual and fitted catches. This is best achieved under Excel.



It will be seen that the model is a better predictor for moderate catches than for the extremes in the Spring and Autumn.

The annual adjusted means give an estimate of what the mean monthly catch would have been for each year given mean monthly flows equal to the mean over the period considered.



This is a very artificial concept in the context of salmon catches because different sea age classes enter the river at different times and the monthly catch varies widely but none the less it does demonstrate that the observed differences in catch between years is not entirely due to flow and that these differences are not only statistically significant but appreciable.

The analysis can be taken further by assuming three components to the run. In the following case March to May, June to August and September/October. A dummy variable is introduced under the heading "season" and the ANCOVA procedure repeated using the above mentioned months as replicate observations for the three seasons. In this way an interaction term can be introduced into the model and adjusted means calculated for each year and each season and tested for different year strengths between seasons.

```
MTB > GLM 'lsalmon' = season | year;
SUBC>  Covariates lflow ;
SUBC>  Means season | year.
```

Factor	Levels	Values
season	**3**	3 6 9
year	**14**	1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991

Analysis of Variance for lsalmon

Source	DF	Seq SS	Adj SS	Adj MS	F	P
lflow	1	6.2729	0.3663	0.3663	3.15	0.080
season	2	26.8466	27.3017	13.6508	117.33	0.000
year	13	3.5421	3.1152	0.2396	2.06	0.028
season*year	26	1.8212	1.8212	0.0700	0.60	0.925
Error	69	8.0281	8.0281	0.1163		
Total	111	46.5109				

In this instance it is clear that the Mean square error of 0.1163 is greater than either of the previous models and the interaction effect is not significant so we are left with the conclusion that the annual effect is the same or not detectably different for the three seasons.

Note on the design matrix

Under Minitab GLM uses a regression approach to fit the model. This involves the creation of a design matrix the columns of which are the predictors for the regression. In order to illustrate the use of this matrix the first order model has been recalculated and the coefficients of the regression and the design matrix stored as "coef4" and "xmat4" respectively.

MTB > Name c19 = 'COEF4' c20 = 'FITS4' m4 = 'XMAT4'
MTB > GLM 'lsalmon' = season year ;
SUBC> Covariates lflow ;
SUBC> Coefficients 'COEF4';
SUBC> Fits 'FITS4';
SUBC> XMatrix 'XMAT4'.

The fits are stored as "fits4" and can be shown to be calculated from the following matrix manipulations

MTB > Copy 'COEF4' m5. (converts the coef4 column into a vector called **m5**)
MTB > Multiply 'XMAT4' M5 m6. (Stores the result of the matrix multiplication as **m6**)
MTB > Copy M6 c21. (Converts **m6** into column21 on the worksheet where it will seen to be identical to "fits4")

The advantage of this procedure is that any flow can be substituted into the design matrix and the resulting predicted catch calculated for any month or year:-

MTB > Copy 'XMAT4' c30-c51. (Enters the design matrix into the worksheet)
Column of flows (C32) headed "mflow".
MTB > Let 'mflow' = 'lflow'*.95 (Reduces column entries by 5%)
MTB > Copy c30-c51 m7. (Creates a new design matrix with flows reduced by 5%)
MTB > Multiply m7 m5 c52. (Calculates catch estimates from the model with a flow reduction of 5% below the actual)

The standard error (equivalent to stdev term of adjusted mean) of the predictions can be calculated from the equation:-

$$SE = (s^2\mathbf{X_0}'(\mathbf{X'X})^{-1}\mathbf{X_0})^{**}.5$$

where **X** is the design matrix
$\mathbf{X_0}$ is the appropriate row of the design matrix.
s^2 is the Mean square error

It is possible in hindsight to demonstrate what might have happened to the catch had the flows been different and perhaps to predict the effect of a reduction of flow due to a proposed abstraction under the assumption that future annual effects will be similar to those past. However it is suggested that some care is exercised in using the model in this way until it has been tested on a wider selection of rivers and the distribution of fish between the sea and within the river is better understood and included in the model. In particular one problem which might affect the latter calculation is that there may be serial correlation between catches in consecutive months. This could be positive if for instance continually high flows and consequent high catches stimulate prolonged interest from the anglers or negative if for instance one wet month attracts all the available fish into the river and they then become virtually uncatchable due to low flows.

References

There are many text books which give a basic introduction to ANCOVA techniques but the nomenclature used is frequently difficult and whilst the Matrix approach simplifies any exposition on the subject it is not helpful to anyone unfamiliar with matrix algebra.

For a non matrix exposition:- Winer.B.J. (1971). Statistical principles in experimental design. McGraw-Hill. is recommended.

The Minitab reference manual is essential.

For more advanced hypothesis testing with different models:- Bolgiano.N.C. (1993). Interpreting Analysis of Covariance Parameter Estimates using Minitab. Minitab Inc. is available from Clecom on 0121- 471 4199. but this may only be available to registered users.

ACKNOWLEDGEMENTS

The authors would like to express their thanks for the invaluable support, assistance and encouragement provided by the fisheries staff of the EA Regions, MAFF, Dr David Downham and, in particular, Dr Miran Aprahamian of the North West Region. Many thanks are also due to the migratory salmonid anglers and controlling angling bodies of the River Lune for their time and patience.

APPENDIX 3: Worked example of ANCOVA analysis with salmon rod catch data for the River Ribble

An example of the use of the Analysis of Covariance and "Minitab" to demonstrate the effect of flow on Salmon rod catches in the R. Ribble

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0	1	1989	26.566
0	1	1990	81.162
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0	2	1987	31.678
0	2	1988	50.709
0	2	1989	49.709
1	2	1990	71.604
1	2	1991	45.381
8	3	1978	48.93
etc	etc	etc	etc

It was known that in some months the numbers of salmon caught were insignificant and likely to cause more problems by invalidating the normality assumptions than their inclusion was worth so the following basic examination was carried out on the data in order to establish which months to delete:- (In practice this knowledge is likely to be already at hand from the spreadsheet or database file on which it is customarily stored.)

MTB > Describe 'salmon';
SUBC> By 'month'.

	month	N	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN
salmon	1	14	0.00000	0.00000	0.00000	0.00000	0.00000
	2	14	0.571	0.000	0.500	0.756	0.202
	3	14	3.286	3.000	3.167	2.494	0.667
	4	14	5.64	4.50	5.25	4.25	1.14
	5	14	8.79	7.50	8.25	7.14	1.91
	6	14	12.14	9.00	10.33	11.91	3.18
	7	14	21.79	13.00	19.25	21.82	5.83
	8	14	60.6	55.5	55.2	47.6	12.7
	9	14	116.5	105.5	113.7	59.2	15.8
	10	14	147.7	44.0	149.7	45.3	12.1

month		MIN	MAX	Q1	Q3
salmon	1	0.00000	0.00000	0.00000	0.00000
	2	0.000	2.000	0.000	1.000
	3	0.000	8.000	1.750	4.250
	4	0.00	16.00	3.50	7.75
	5	0.00	24.00	3.50	12.50
	6	2.00	44.00	4.50	16.00
	7	2.00	72.00	9.00	25.75
	8	12.0	174.0	18.5	80.0
	9	23.0	244.0	69.3	149.5
	10	52.0	219.0	123.7	188.0

MTB > Describe 'salmon';
SUBC> By 'year'.

salmon

year	N	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN
1978	10	30.8	11.0	26.2	37.6	11.9
1979	10	41.5	13.0	33.6	56.6	17.9
1980	10	75.1	25.0	63.4	92.3	29.2
1981	10	49.5	33.5	38.5	63.4	20.0
1982	10	35.9	8.5	28.4	50.5	16.0
1983	10	23.6	5.5	13.8	41.2	13:0
1984	10	26.6	2.5	15.5	51.3	16.2
1985	10	22.9	6.5	18.0	30.24	9.5
1986	10	36.8	9.0	27.6	54.6	17.3
1987	10	49.2	6.5	35.2	81.3	25.7
1988	10	62.5	4.5	50.8	87.6	27.7
1989	10	19.9	3.5	7.1	43.6	13.8
1990	10	23.3	5.0	14.5	38.0	12.0
1991	10	30.2	8.5	17.1	51.8	16.4

salmon	year	MIN	MAX	Q1	Q3
	1978	0.0	98.0	6.2	66.5
	1979	0.0	146.0	1.5	95.0
	1980	0.0	244.0	2.5	178.3
	1981	0.0	187.0	2.2	73.7
	1982	0.0	132.0	3.5	86.5
	1983	0.0	126.0	1.5	29.5
	1984	0.0	142.0	0.8	34.5
	1985	0.0	85.00	0.00	53.00
	1986	0.0	147.0	3.5	76.7
	1987	0.0	210.0	0.0	88.8
	1988	0.0	219.0	0.8	152.8
	1989	0.0	142.0	0.0	17.0
	1990	0.0	117.0	1.8	30.2
	1991	0.0	165.0	0.8	36.2

```
MTB > Table   'year' 'month';
SUBC>   Frequencies 'salmon';
SUBC>   Counts.
```

ROWS: year   COLUMNS: month

	1	2	3	4	5	6	7	8	9	10	ALL
1978	0	1	8	11	9	11	20	58	96	92	308
1979	0	0	2	10	17	15	11	83	131	146	415
1980	0	1	3	16	20	30	72	174	244	191	751
1981	0	0	3	5	24	44	43	53	136	187	495
1982	0	2	4	5	8	9	11	79	109	132	369
1983	0	0	2	6	11	5	2	17	67	126	236
1984	0	0	1	1	2	3	3	12	102	142	266
1985	0	0	0	7	6	6	17	56	85	52	229
1986	0	2	4	4	9	10	9	62	121	147	368
1987	0	0	0	4	4	9	20	55	190	210	495
1988	0	0	2	4	1	5	63	140	191	219	625
1989	0	0	5	2	0	2	10	15	23	142	199
1990	0	1	4	4	7	2	15	19	64	117	233
1991	0	1	8	0	5	19	9	25	70	165	302
ALL	0	8	46	79	123	170	305	848	1631	2068	5278

CELL CONTENTS -- COUNT

Clearly January and February provided catches of inconsequential size so were deleted from the worksheet and Minitab automatically noted the fact.

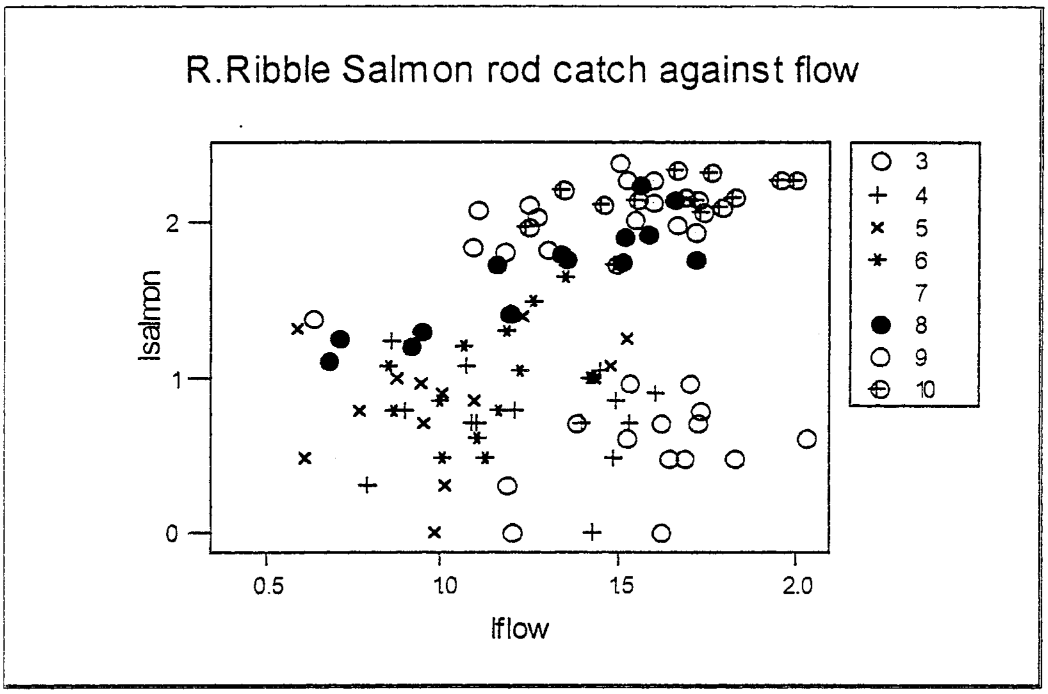
NOTE *** Data window was used to change the worksheet

The variables "salmon" and "flow" were then transformed to stabilise the variance.

MTB > Name c5 = 'lsalmon'
MTB > Let 'lsalmon' = logten(1+ 'salmon')
MTB > Name c6 = 'lflow'
MTB > Let 'lflow' = logten('flow')

Minitab is then used to plot lsalmon against lflow to give some indication of the shape of the relationship.

MTB > Plot 'lsalmon'*'lflow';
SUBC>   Symbol 'month';
SUBC>   Title "R.Ribble Salmon rod catch against flow".



There is clearly a relationship between catch and flow for July, August and September but if the other months were considered on their own such a relationship would be doubtful however, the basic assumption in ANCOVA is that there are a number of parallel regression lines of lsalmon on lflow and that the monthly and annual effects account for the difference in intercept between them so the apparent lack of fit for the other months may be due to the effects of these factors. It also appears that the slope of the line may decrease at high flows so prior to carrying out the ANCOVA procedure a further variable ((Log10 (flow))^2) was added to the list in order to provide a second covariate and thus a second order relationship between logcatch and logflow.

MTB > Name c7 = 'lflowsq'
MTB > Let 'lflowsq' = 'lflow'**2

The ANCOVA procedure and printout follows.

```
MTB > Name c8 = 'FITS1' c9 = 'RESI1'
MTB > GLM 'lsalmon' = month year;
SUBC>   Covariates lflow lflowsq;
SUBC>   Means month year;
SUBC>   Fits 'FITS1';
SUBC>   Residuals 'RESI1'.
```

Factor	Levels	Values
month	**8**	3 4 5 6 7 8 9 10
year	**14**	1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991

Analysis of Variance for lsalmon

Source	DF	Seq SS	Adj SS	Adj MS	F	P
lflow	1	6.2729	0.4531	0.4531	8.32	0.005
lflowsq	1	0.0005	0.2065	0.2065	3.79	0.055
month	7	32.0572	32.3115	4.6159	84.77	0.000
year	13	3.3339	3.3339	0.2565	4.71	0.000
Error	89	4.8465	4.8465	0.0545		
Total	111	46.5109				

Term	Coeff	Stdev	t-value	P
Constant	0.1208	0.2992	0.40	0.687
lflow	1.4179	0.4915	2.88	0.005
lflowsq	-0.3829	0.1966	-1.95	0.055

Unusual Observations for lsalmon

Obs.	lsalmon	Fit	Stdev.	Fit Residual	St.Resid
10	0.00000	0.48029	0.10193	-0.48029	-2.29R
12	0.77815	0.32225	0.10446	0.45590	2.18R
14	0.95424	0.49565	0.10118	0.45859	2.18R
28	0.00000	0.77134	0.10476	-0.77134	-3.70R
39	0.30103	0.91424	0.10290	-0.61321	-2.93R
40	0.00000	0.58409	0.10193	-0.58409	-2.78R

R denotes an obs. with a large st. resid.

Nothing unusual here. With 112 observations a few with large standardised residuals can be expected.

Means for Covariates

Covariate	Mean	Stdev
lflow	1.288	0.3422
lflowsq	1.775	0.8709

Adjusted Means for lsalmon

month	Mean	Stdev
3	0.4305	0.06959
4	0.7337	0.06332
5	0.9774	0.06684
6	1.0173	0.06589
7	1.3166	0.06684
8	1.6733	0.06242
9	1.9745	0.06279
10	2.0155	0.07402
year		
1978	1.4250	0.08297
1979	1.3540	0.08350
1980	1.6959	0.08317
1981	1.4705	0.08427
1982	1.3335	0.08273
1983	1.1201	0.08265
1984	1.1240	0.08951
1985	1.0965	0.08328
1986	1.2658	0.08316
1987	1.1740	0.08400
1988	1.3067	0.08313
1989	0.9997	0.08331
1990	1.1688	0.08382
1991	1.2084	0.08412

In view of the apparently small contribution of the lflowsq covariate to the model the procedure was repeated using only lflow.

```
MTB > Name c10 = 'FITS2' c11 = 'RESI2'
MTB > GLM 'lsalmon' = month year;
SUBC>   Covariates lflow ;
SUBC>   Means month year;
SUBC>   Fits 'FITS2';
SUBC>   Residuals 'RESI2'.
```

Factor	Levels	Values
month	**8**	3 4 5 6 7 8 9 10
year	**14**	1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991

Analysis of Variance for lsalmon

Source	DF	Seq SS	Adj SS	Adj MS	F	P
lflow	1	6.2729	1.3843	1.3843	24.66	0.000
month	7	31.9452	32.1071	4.5867	81.70	0.000
year	13	3.2398	3.2398	0.2492	4.44	0.000
Error	90	5.0530	5.0530	0.0561		
Total	111	46.5109				

Term	Coeff	Stdev	t-value	P
Constant	0.6507	0.1262	5.16	0.000
lflow	0.47879	0.09642	4.97	0.000

Unusual Observations for lsalmon

Obs.	lsalmon	Fit	Stdev.Fit	Residual	St.Resid
10	0.00000	0.47639	0.10348	-0.47639	-2.23R
12	0.77815	0.34420	0.10545	0.43395	2.05R
14	0.95424	0.48671	0.10263	0.46753	2.19R
28	0.00000	0.78685	0.10607	-0.78685	-3.71R
39	0.30103	0.88451	0.10333	-0.58348	-2.74R
40	0.00000	0.56090	0.10279	-0.56090	-2.63R
101	2.28330	2.71945	0.10753	-0.43615	-2.07R

R denotes an obs. with a large st. resid.

Means for Covariates

Covariate	Mean	Stdev
lflow	1.288	0.3422

Adjusted Means for lsalmon

month	Mean	Stdev
3	0.4076	0.06964
4	0.7531	0.06349
5	0.9791	0.06786
6	1.0491	0.06481
7	1.3136	0.06785
8	1.6762	0.06336
9	1.9842	0.06356
10	1.9760	0.07227

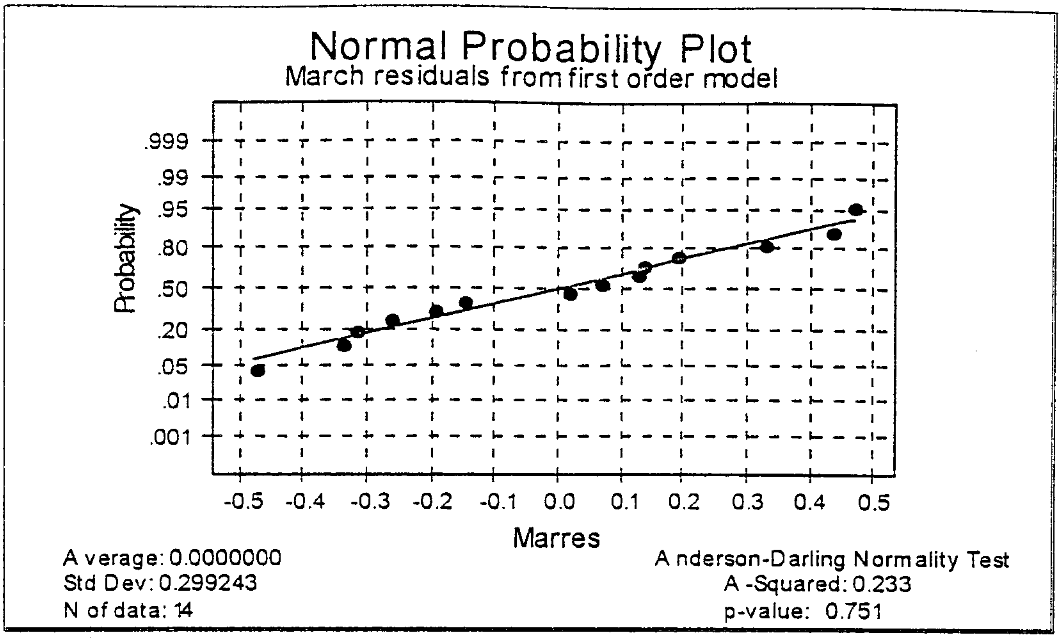
year		
1978	1.4339	0.08412
1979	1.3467	0.08470
1980	1.6754	0.08378
1981	1.4532	0.08509
1982	1.3426	0.08387
1983	1.1107	0.08378
1984	1.0812	0.08811
1985	1.1054	0.08444
1986	1.2826	0.08398
1987	1.1836	0.08515
1988	1.3039	0.08439
1989	0.9972	0.08458
1990	1.1916	0.08428
1991	1.2352	0.08427

It will be seen that the Mean Square Error increased from .0545 for the second order model to .0561 for the first order so very little is gained by adding the second covariate and in fact its inclusion gives rise to a model which is intuitively unlikely and ugly mathematically so in this case the simpler model is to be preferred.

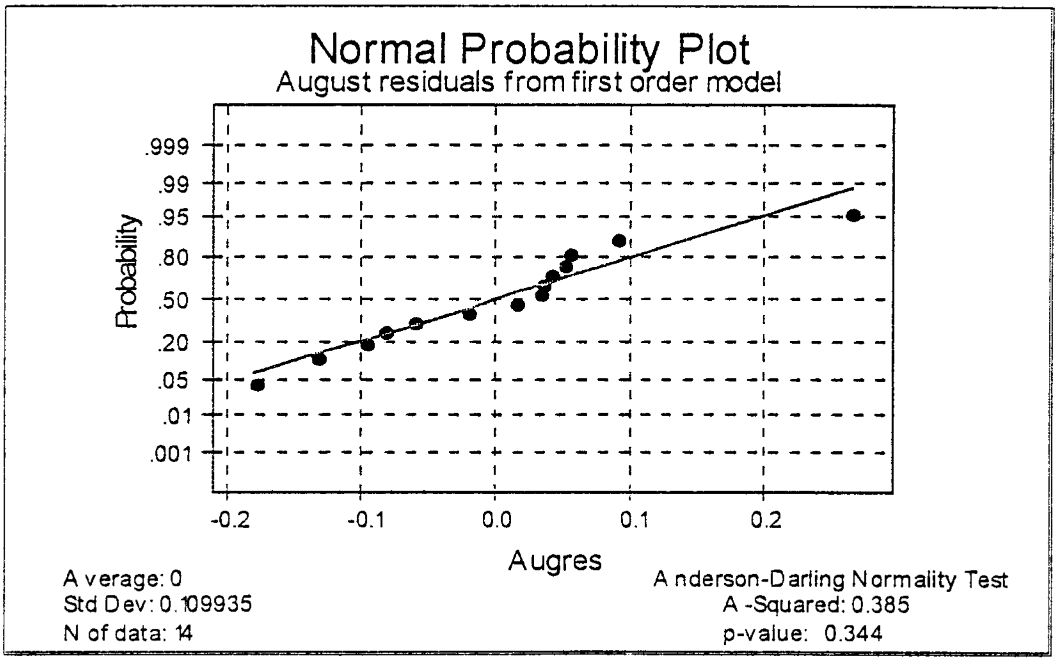
At this point it is worth examining the residuals for Normality. Experience of the technique has shown that the residuals from the largest and smallest observations are the most likely to show significant departures from normality so those for March and October have been examined with those for August as a further example.

The columns in the worksheet headed Marres etc can be created using Minitab's "Unstack" function but here they were created more simply by using "Copy" and "Paste"

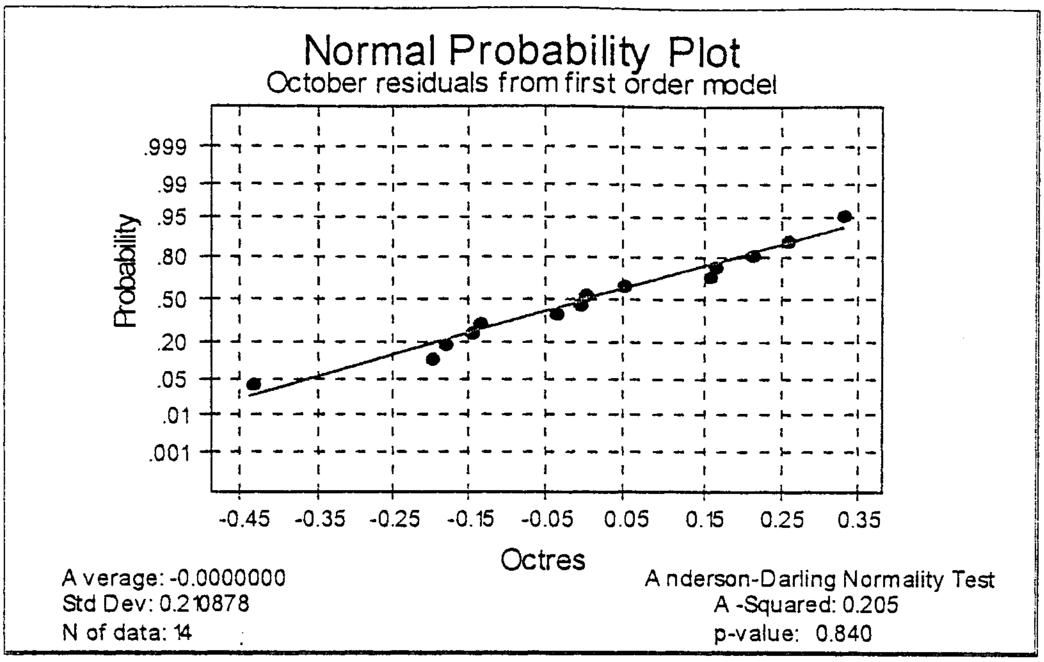
```
NOTE *** Data window was used to change the worksheet
MTB > %NormPlot 'Marres';
SUBC>   Title 'March residuals from first order model'.
Executing from file: C:\MTBWIN\MACROS\NormPlot.MAC
Macro is running ... please wait
```



MTB > %NormPlot 'Augres';
SUBC> Title 'August residuals from first order model'.
Executing from file: C:\MTBWIN\MACROS\NormPlot.MAC
Macro is running ... please wait

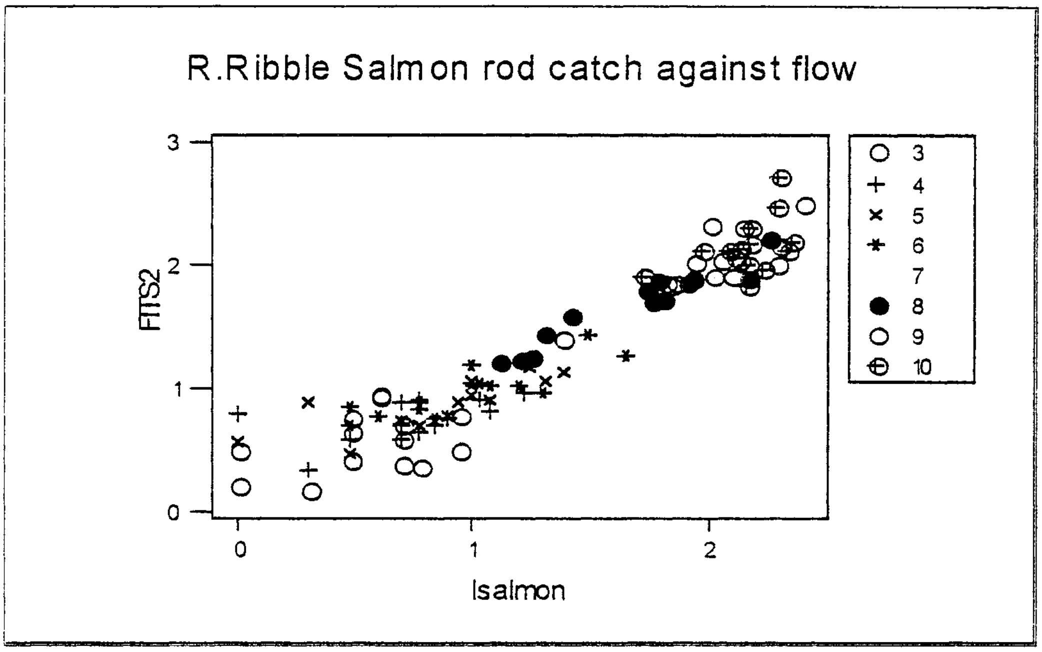


MTB > %NormPlot 'Octres';
SUBC> Title 'October residuals from first order model'.
Executing from file: C:\MTBWIN\MACROS\NormPlot.MAC
Macro is running ... please wait

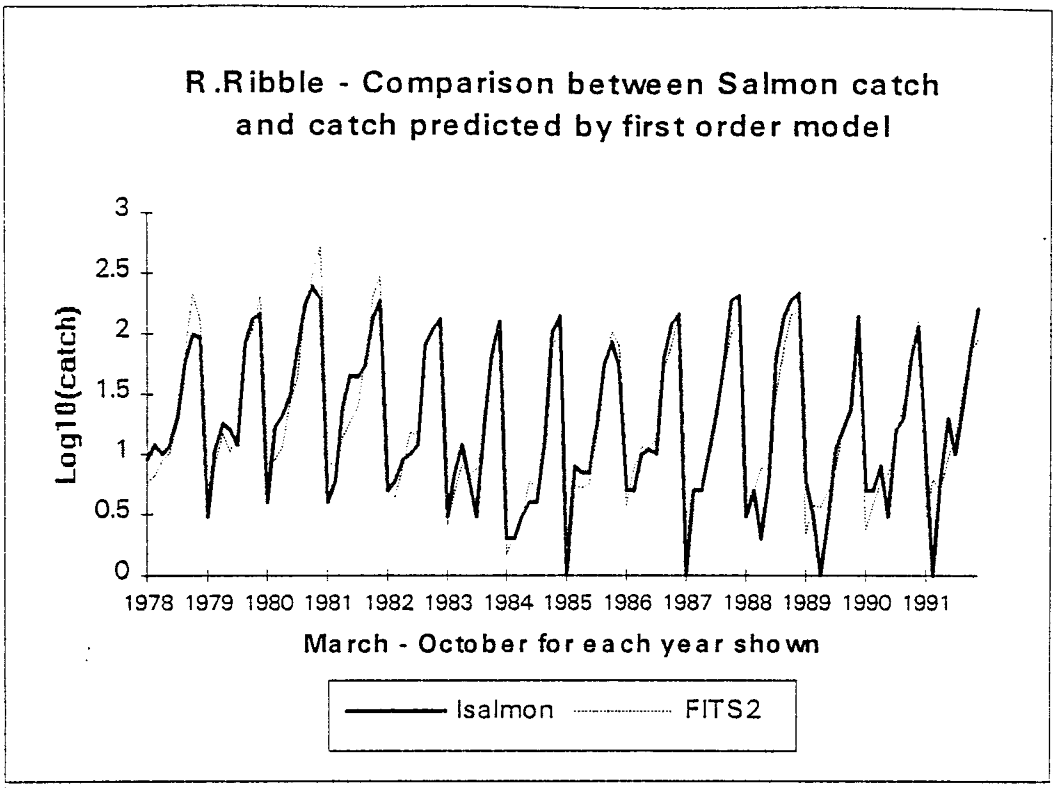


Clearly the residuals are normally distributed. Lastly in the Minitab session a plot of the observed catches was created against those fitted by the model.

```
MTB > Plot 'FITS2'*'lsalmon';
SUBC>   Symbol 'month';
SUBC>   Title "R.Ribble Salmon rod catch against flow".
```

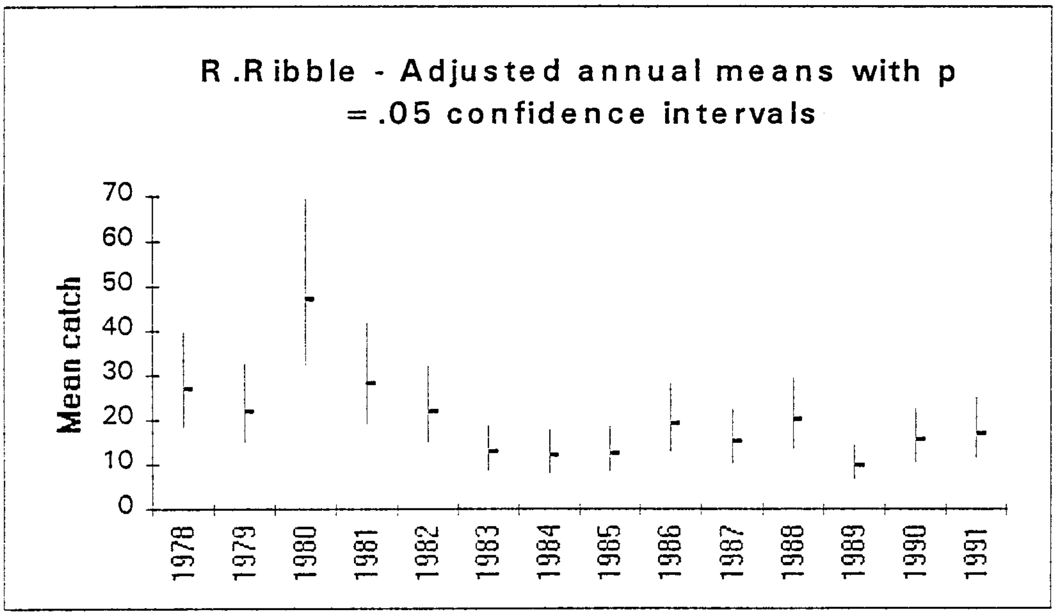


Another way of looking at this relationship is to compare what are in essence time series plots of the actual and fitted catches. This is best achieved under Excel.



It will be seen that the model is a better predictor for moderate catches than for the extremes in the Spring and Autumn.

The annual adjusted means give an estimate of what the mean monthly catch would have been for each year given mean monthly flows equal to the mean over the period considered.



This is a very artificial concept in the context of salmon catches because different sea age classes enter the river at different times and the monthly catch varies widely but none the less it does demonstrate that the observed differences in catch between years is not entirely due to flow and that these differences are not only statistically significant but appreciable.

The analysis can be taken further by assuming three components to the run. In the following case March to May, June to August and September/October. A dummy variable is introduced under the heading "season" and the ANCOVA procedure repeated using the above mentioned months as replicate observations for the three seasons. In this way an interaction term can be introduced into the model and adjusted means calculated for each year and each season and tested for different year strengths between seasons.

```
MTB > GLM 'lsalmon' = season | year;
SUBC>   Covariates lflow ;
SUBC>   Means season | year.
```

Factor	Levels	Values
season	**3**	3 6 9
year	**14**	1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991

Analysis of Variance for lsalmon

Source	DF	Seq SS	Adj SS	Adj MS	F	P
lflow	1	6.2729	0.3663	0.3663	3.15	0.080
season	2	26.8466	27.3017	13.6508	117.33	0.000
year	13	3.5421	3.1152	0.2396	2.06	0.028
season*year	26	1.8212	1.8212	0.0700	0.60	0.925
Error	69	8.0281	8.0281	0.1163		
Total	111	46.5109				

In this instance it is clear that the Mean square error of 0.1163 is greater than either of the previous models and the interaction effect is not significant so we are left with the conclusion that the annual effect is the same or not detectably different for the three seasons.

<u>Note on the design matrix</u>

Under Minitab GLM uses a regression approach to fit the model. This involves the creation of a design matrix the columns of which are the predictors for the regression. In order to illustrate the use of this matrix the first order model has been recalculated and the coefficients of the regression and the design matrix stored as "coef4" and "xmat4" respectively.

```
MTB > Name c19 = 'COEF4' c20 = 'FITS4' m4 = 'XMAT4'
MTB > GLM 'lsalmon' = season  year ;
SUBC>   Covariates lflow ;
SUBC>   Coefficients 'COEF4';
SUBC>   Fits 'FITS4';
SUBC>   XMatrix 'XMAT4'.
```

The fits are stored as "fits4" and can be shown to be calculated from the following matrix manipulations

MTB > Copy 'COEF4' m5. (converts the coef4 column into a vector called **m5**)
MTB > Multiply 'XMAT4' M5 m6. (Stores the result of the matrix multiplication as **m6**)
MTB > Copy M6 c21. (Converts **m6** into column21 on the worksheet where it will seen to be identical to "fits4")

The advantage of this procedure is that any flow can be substituted into the design matrix and the resulting predicted catch calculated for any month or year:-

MTB > Copy 'XMAT4' c30-c51. (Enters the design matrix into the worksheet)
Column of flows (C32) headed "mflow".
MTB > Let 'mflow' = 'lflow'*.95 (Reduces column entries by 5%)
MTB > Copy c30-c51 m7. (Creates a new design matrix with flows reduced by 5%)
MTB > Multiply m7 m5 c52. (Calculates catch estimates from the model with a flow reduction of 5% below the actual)

The standard error (equivalent to stdev term of adjusted mean) of the predictions can be calculated from the equation:-

$$SE = (s^2\mathbf{X_0}'(\mathbf{X}'\mathbf{X})^{-1}\mathbf{X_0})^{**}.5$$

where **X** is the design matrix
$\mathbf{X_0}$ is the appropriate row of the design matrix.
s^2 is the Mean square error

It is possible in hindsight to demonstrate what might have happened to the catch had the flows been different and perhaps to predict the effect of a reduction of flow due to a proposed abstraction under the assumption that future annual effects will be similar to those past. However it is suggested that some care is exercised in using the model in this way until it has been tested on a wider selection of rivers and the distribution of fish between the sea and within the river is better understood and included in the model. In particular one problem which might affect the latter calculation is that there may be serial correlation between catches in consecutive months. This could be positive if for instance continually high flows and consequent high catches stimulate prolonged interest from the anglers or negative if for instance one wet month attracts all the available fish into the river and they then become virtually uncatchable due to low flows.

References

There are many text books which give a basic introduction to ANCOVA techniques but the nomenclature used is frequently difficult and whilst the Matrix approach simplifies any exposition on the subject it is not helpful to anyone unfamiliar with matrix algebra.

For a non matrix exposition:- Winer.B.J. (1971). Statistical principles in experimental design. McGraw-Hill. is recommended.

The Minitab reference manual is essential.

For more advanced hypothesis testing with different models:- Bolgiano.N.C. (1993). Interpreting Analysis of Covariance Parameter Estimates using Minitab. Minitab Inc. is available from Clecom on 0121- 471 4199. but this may only be available to registered users.

ACKNOWLEDGEMENTS

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The use of catch statistics to estimate stock size

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The use of catch statistics to estimate stock size:

R&D Technical Reports W27, W139, W140, W141

Implementation Plan:

The main findings outlined below for migratory salmonids and coarse fish should be implemented through their respective Centres, once approved and supported by the Function.

1. The standard forms for the recording of net caught salmon and sea trout, from both small and large fisheries, should be adopted.

2. The distribution of log books to migratory salmonid anglers needs to be examined as the present system may lead to biases when using catch per unit effort as an index of abundance.

3. The study outlined an approach for adjusting catch for variation in effort and flow enabling an estimate of the true stock status to be determined. The method may have implications with regard to the setting and evaluation of spawning targets and for assessing the affects of abstraction and regulation schemes and needs to be further evaluated.

4. The method used to classify rivers needs to be further developed, in particular links with other catchment and habitat variables, as a classification system may help with the setting and evaluation of spawning targets.

5. Similar to the situation for migratory salmonids it is suggested that greater emphasis be placed on obtaining catch data from coarse fisheries. It is suggested that this be carried out on a National scale and some of the approaches and recommendations made in the report be adopted. In the long term the collection of catch data will provide a better understanding of coarse fishery dynamics, will assist with responding to angler enquires and evaluation of impacts on a fishery. Ultimately there is a need that such catch data be included in the Fisheries Classification Scheme.

6. When the study began, in 1992, there was comparatively little data allowing comparison of stock with catch. Since then more comprehensive salmonid data have become available from traps and validated fish counters. It is suggested that further analysis of these data sets be carried out using some of the methods outlined in this project together with others as appropriate. However with regard to coarse fish little additional data relating catch to stock has been obtained and there is still a need for studies to be set up which can address this particular issue.

The Use of Catch Statistics to Monitor Fishery Change

Migratory Salmonid Study

Technical Report
W27

The Use of Catch Statistics to Monitor Fishery Change

Migratory Salmonid Study

Technical Report W27

T Champion, I Small, K O'Hara and R Steel

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This report is aimed at fisheries scientists who need to collate and analyse migratory salmonid catch data.

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Amendments
Any corrections or proposed amendments to this manual should be made through the regional Agency representative on the Water Resources National Abstraction Licensing Group.

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EXECUTIVE SUMMARY

The overall objective of the R&D contract was to develop methods for estimating the stock size of migratory salmonids from catch statistics data and to examine new techniques for the collection of this data. However, due to the large degree of varaition in the datasets for a range of underlying reasons, it became obvious that to achieve estimates of stock size would be a difficult goal to achieve. Therefore the project focused towards examining methods for accounting for the variability in the data sets and for estimating trends of runs of fish into rivers. This work was coulped with an examination of the temperoral and spatial variability with and between river systems and the development of alternative data collection methods. As a result of the not being able to derive formulae to estimate of absolute stock size, it was agreed that the title of the project be changed. Outputs for the project are presented for migratory salmonids in R&D Technical Reports W27 and W139 and for coarse fish in R&D Technical Reports W140 and W141.

Compilation and examination of data sets for migratory salmonids were conducted between 1992-94. The historical annual catch records collected by the Water Authorities and National Rivers Authority (NRA) were obtained from the Ministry of Agriculture, Fisheries and Food (MAFF) and further detailed sets were obtained for some individual fisheries and rivers.

Methods were studied for the collection of data from migratory salmonid anglers using techniques analogous to the creel census surveys widely undertaken in the Untied States. A preliminary survey indicated that the encounter rate with anglers who had caught fish was low and therefore a single river was chosen with known popular fisheries for intensive study. The encounter rate of anglers catching fish was approximately 10% and this method would appear to have little value for the Agency as a survey method other than as an aid to the study of specific fisheries. It was concluded that the present method of catch returns for salmon and sea trout offers the most effective and realistic method of collecting data on a national basis. The use of logbooks may be used as a supplement to provide detailed data for specific rivers but should only be used on a regional basis. However, the current distribution systems for the issuing of logbooks needs to be formalised.

The Agency, formerly NRA, inherited a wide range of collection methods of data from net catches of migratory salmonids. This diversity reflected the range of capture methods that have evolved. A standardised data collection method was developed such that a National database could potentially be created. Based on the information currently collected two new catch return forms were produced which were designed for small and large catch net fisheries. It is considered that the new forms when coupled with a scale sampling programme would provide a more useful data set which would allow comparisons to be made on a countrywide basis.

Three approaches to the study of catch and stock size were developed for migratory salmonids:

- An ANCOVA method which allows catches to be assessed and compared with expected values. Of particular interest was an analysis of the effects of flow on angler behaviour and catches. The adjustment of the actual catch size arising from removal of variation arising from effort and flow would allow the true stock availability to be established. This method would have particular potential for the Agency in setting and evaluating spawning / catch targets for individual rivers by the comparison of expected catch, determined by flow, with actual catch. The method once established could potentially provide an assessment technique for the likely affects of flow abstraction and regulation schemes.

- An iterative technique which allows the trends of stock size to be established on rivers where no counting system is available. This provides a simple model estimation method which could be refined further by collection of detailed data to provide benchmark values for a range of input parameters for the model.

- The development of a classification system based on ANOVA techniques. Previous techniques were shown to be unsuitable when different time scales of data were utilised. The method developed showed groupings of sets of rivers based on catch. These rivers were usually geographically close and the similarity of the flow regimes appears to be an overriding factor affecting catch size. Recommendations were provided for further areas of study in the development of classification systems.

All the analytical techniques examined were developed from existing available data sets. Whilst it may be preferable to obtain more detailed data sets this is unlikely to be practicable on a national basis. Specific studies should be undertaken to address specific fishery or river based problems and to provide supplementary information to that presently collected. An important aspect to allow further development of models and techniques for studying migratory salmonid populations is the development of a national database which is accessible to fisheries staff of all regions.

KEY WORDS: Migratory salmonids, Catch Statistics, Population Size, Creel Census, Angling, Flow, Effort

1.0 CREEL CENSUS OF MIGRATORY SALMONID ANGLERS IN ENGLAND AND WALES

1.1 INTRODUCTION

The collection of catch statistics for individual migratory salmonid rod fisheries has relied on the submission of catch returns from anglers and fishery owners (e.g. Wye Owner Annual Reports). These data have formed the basis of the historical catch record. However, there have been inherent problems with this method of data collection resulting from:

- Poor response to requests for catch returns (even following reminders)
- Changes in collection procedures
- Under and over reporting of catches
- Limitations on the level of data that can be collected

The current catch return system will provide sufficient information for assisting in estimation of trends of runs of fish (Small 1994) but does not provide the data that may be required for more detailed analyses. For example, the determination of the relationships between daily flow, angling effort and catch. Previously, finer level data have been recorded on individual fishery owners records or bailiff records such as collected on the Welsh Dee (e.g. Dee and Clwyd River Authority Annual Reports). However, the collection of this information is not statutory and is no longer collected for the Welsh Dee. In addition, access to this data for analysis is often difficult.

As a response to obtaining this finer level of information on specific fisheries or river systems, the North West and Welsh Regions of the Agency have recently initiated logbook schemes to collate data. Logbooks are currently issued to anglers on a voluntary basis. The data collated by this method have proved useful in developing the relationships between angler behaviour, flow and catch at a fine level (Aprahamian 1993).

Creel surveys of migratory salmonid anglers have received little attention in the UK. Even within the United States and Canada, where anglers surveys are routinely practised there appears to be few examples of creel surveys for migratory fish to examine the stock. (e.g. Claytor and O'Neil 1991). Most of the surveys are directed to the collection of information on angling economics, sociology and angler satisfaction. These types of information may be of considerable value to the Agency for providing a broader view of migratory salmonid fisheries and angling behaviour.

It was agreed within the present contract that some work would be undertaken to determine the applicability of an American style roving creel census technique for collecting data from migratory salmonid anglers in England and Wales.

1.2 PILOT STUDY

1.2.1 Methodology

A pilot study was undertaken in 1992 to initially test the applicability of the technique using a survey form (see Appendix 1). This preliminary survey was conducted in April and May 1992 at fisheries on the River Tyne, Dee and Wye. However, the anglers who can be present at the start of the season were missed due to the starting date of the contract and very few anglers were encountered. In addition, the low encounter rate during this spring period may be a reflection of the reduced abundance of spring fish with a corresponding reduction in angling effort, particularly on the River Wye and Welsh Dee. This made surveying unviable for cost-benefit purposes and the census of migratory salmonid anglers was deferred until the autumn run of fish. A further survey was then undertaken in the Autumn of 1992 at fisheries on the Lune, Derwent and Kent. Two surveyors were assigned to selected fisheries on these rivers and interviewed anglers as they were encountered.

1.2.2 Results

A total of 21 survey days (42 man days of surveying) were undertaken during which 121 migratory salmonid anglers were encountered. The mean number of interviews conducted per surveying day was 3. A total of 8 fish captured were encountered during the surveying. The common practice of migratory salmonid anglers wading whilst fishing created difficulties for interviewing some of the anglers.

Migratory salmonid anglers did not demonstrate the contagious distribution around access points that was found from coarse anglers (see R&D Report 404 Coarse Fish Study, Section 4.5.2) with 90% of salmonid anglers dispersed over a distance of 1200 metres from an access point (see Figure 1).

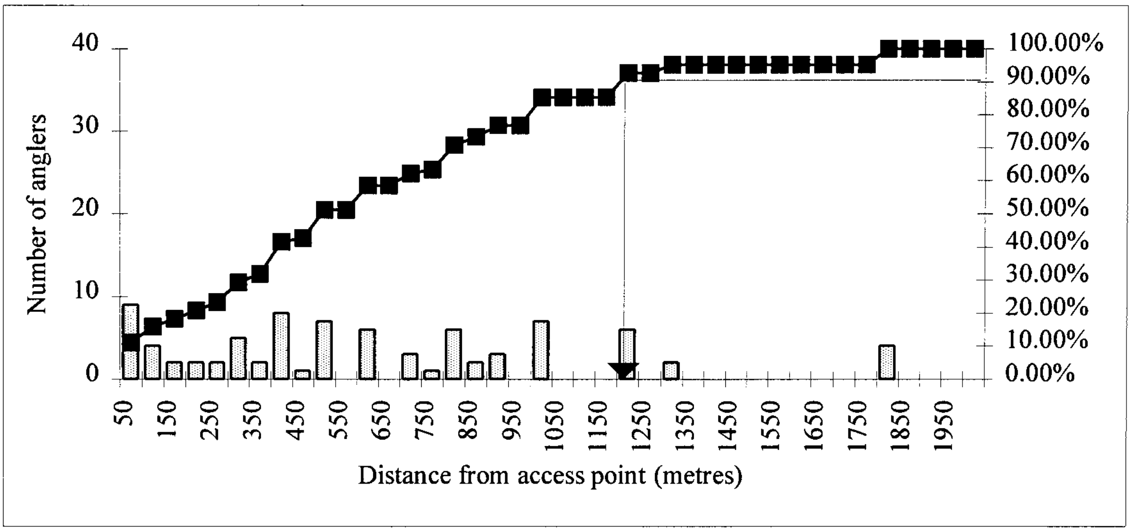


Figure 1: Distance of migratory salmonid anglers from the access point to the fishery.

1.2.3 Discussion

The conclusions from the pilot study are:

- The encounter rate with salmon anglers was low. This is considered to result from the relatively low density of anglers on the fisheries.

- Anglers demonstrated a very low catch rate. From interviews it appears that the majority of migratory salmonids are caught by few anglers. (see Section 1.3.4).

- Migratory salmonid anglers were well distributed from access points throughout the length of the fishing beat.

- The common practice of wading in the river during angling for migratory salmonids can present interview difficulties

1.3 INTENSIVE CREEL SURVEY OF THE RIVER LUNE

1.3.1 Introduction

Following the 1992 survey, it was agreed with the Agency that a full intensive survey of a selected river would be undertaken during 1993 to test the robustness and applicability of creel census techniques.

1.3.2 Selection of survey sites

The River Lune in the North West Region was selected for intensive surveying for the following reasons:

- The River Lune has a good historical catch data record.

- A validated fish counter is present on the river at Forge Weir.

- A logbook scheme is operated on the river by North West Region of the Agency and data collected for 1992 and 1993 seasons were available for comparison with the creel census

The names and addresses of all the fishery owners on the River Lune were supplied to SGS Environment by the Agency. Fifteen owners/angling clubs were contacted for permission to use their fisheries for surveying purposes. This provided fisheries for surveying throughout the River Lune system with a total of 17 beats being made available for surveying out of a possible 59.

1.3.3 Methodology

A revised creel census form was produced based on the experience gained in the pilot study. The main difference between the survey forms was a reduction in the number of questions to reduce the interview time. A copy of this form is presented in Appendix 1. Surveying was carried out by two people between the 18/7/93 and 31/10/93 (the end of the migratory salmonid angling season on the River Lune) between 5am and 7pm. Fisheries were initially selected at random for surveying, however it soon became apparent that the fisheries on the upper reaches of the river had such a low density of anglers, particularly during the summer, that surveying was not cost effective. Of the 17 fisheries available 12 fisheries were surveyed in July. Thereafter the survey was mainly conducted on two fisheries (fisheries 53 and 58) where a satisfactory encounter rate with anglers was achieved. These fisheries can be contrasted since fishery 58 is tidal in nature and fishery 53 is non-tidal. Each fishery was surveyed throughout it length on each interview occasion.

The location of the surveyed fisheries is presented in Map 1.

1.3.4 Results

Basic survey statistics

A total of 1337 angler interviews were conducted during the survey period by two interviewers. The survey comprised of 75 surveying (150 man days) days during which 176 survey occasions were undertaken, since it was possible to survey more than 1 fishery in a single survey day. A mean number of 9 anglers were interviewed per man day. The survey recorded a catch of 146 salmon and 16 sea trout. This represents 10.2% for salmon and 1.1% for sea trout of the total declared rod catch for 1993. The number of days of surveying effort expended on fisheries 53 and 58 is presented in Table 1 Additional surveying was undertaken on two upper beats, fisheries 11 and 26 as the season progressed and the numbers of anglers increased. However, the number of anglers encountered was still low. Therefore the analysis of data has concentrated on information collected from fisheries 53 and 58.

Fishery Number	Month				
	July	August	September	October	Total
58	8	21	20	21	69
53	6	17	13	16	52
26	3	1	6	14	24
11	3	2	5	9	19

Table 1: Number of days of surveying effort undertaken on fisheries 11, 26, 53 and 58 on the River Lune.

The mean numbers of anglers encountered per survey day on fisheries 53 and 58 are presented in Figure 2(a) and for fisheries 11 and 26 in Figure 2(b).

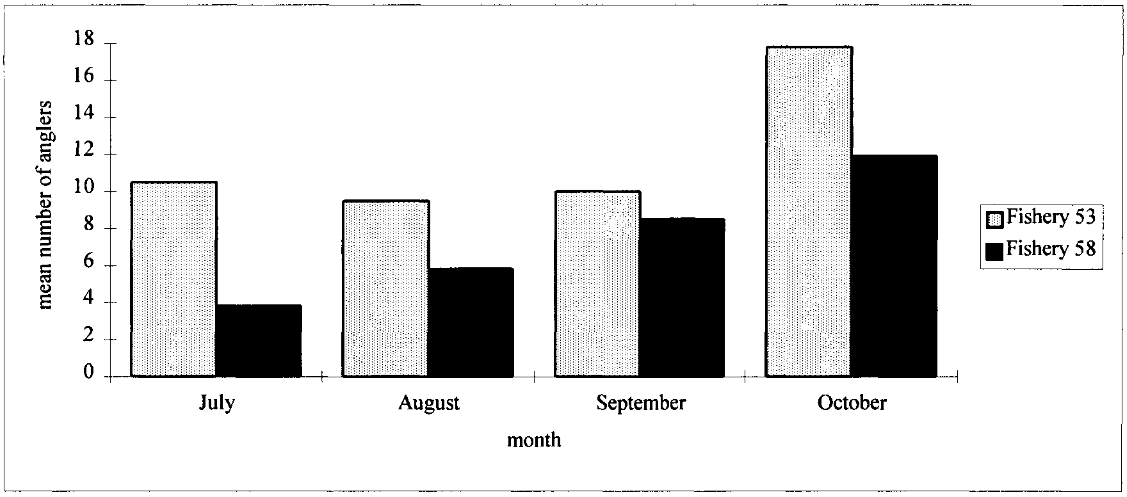


Figure 2(a): Mean numbers of anglers encountered per day on fisheries 53 and 58.

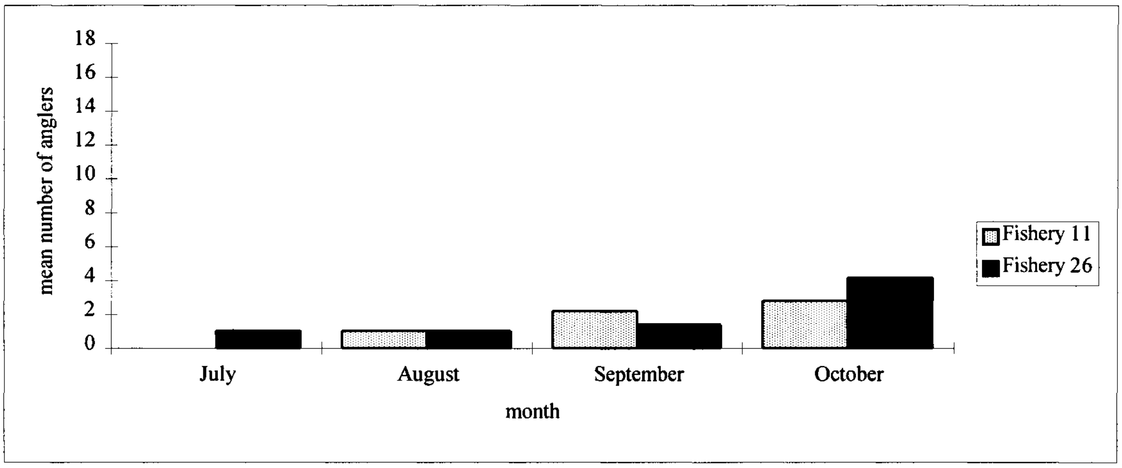


Figure 2(b): Mean numbers of anglers encountered per day on fisheries 11 and 26

Angler behaviour

Data from this study tended to confirm that migratory salmonid anglers show less contagion in their distribution on the fishery than coarse anglers on a channelised river (see Figure 3). Contagion was observed around popular pools on certain beats, but such pools were not necessarily near to the access point to the fishery, and in this respect salmonid anglers and coarse anglers on habitat diverse fisheries tend to show similarities in behaviour.

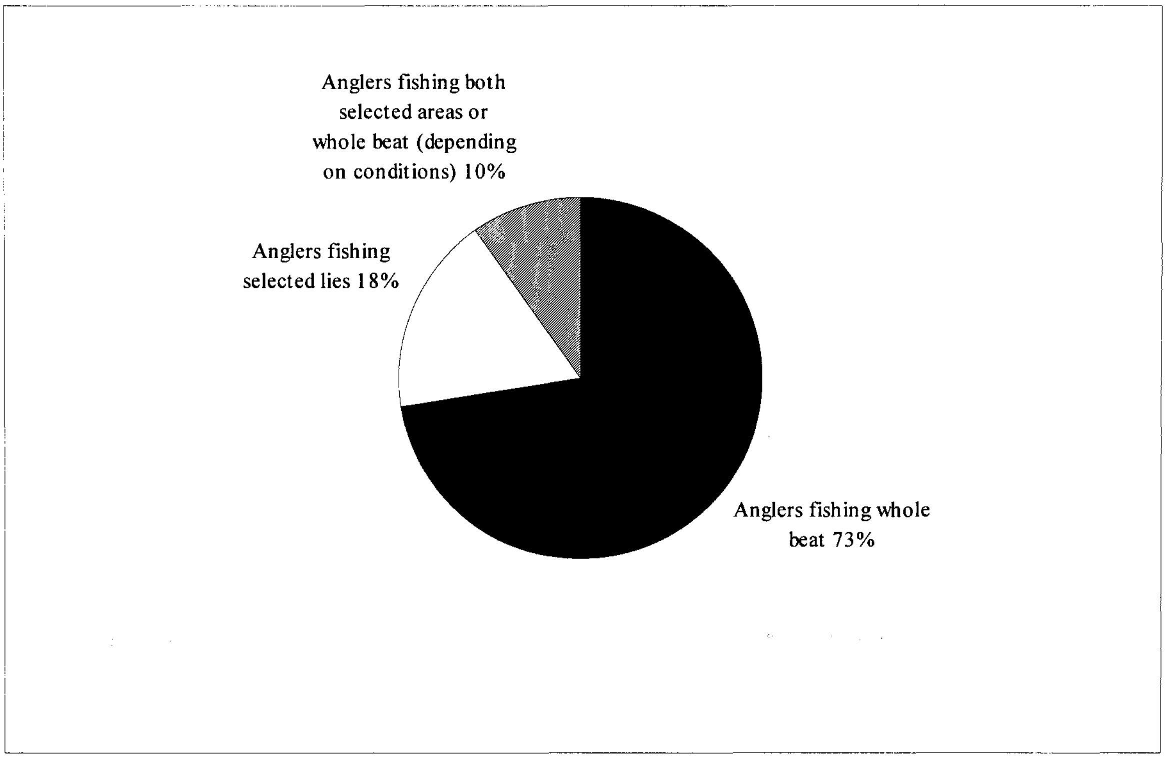


Figure 3: Migratory salmonid angler behaviour on fishing beats.

The majority of migratory salmonid anglers started fishing between 9 and 11am (see Figure 4) with 90% having commenced angling by 1pm. The majority of sea trout angling is undertaken at night. No night surveys were undertaken for safety reasons and so the specific starting times for sea trout anglers was not determined.

From the 1337 interviews a total of 4059 hours of angler effort were encountered, providing a mean fishing time per angler interviewed of 3 hours (range 5 minutes -10 hours)

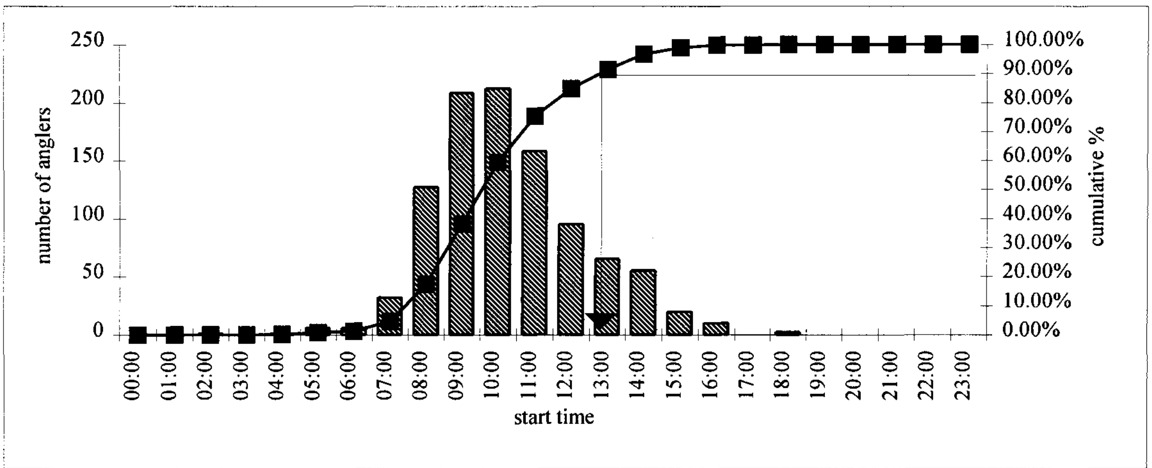


Figure 4: Recorded start times of migratory salmonid anglers on the River Lune

For fishery numbers 53 and 58 further analysis was undertaken to determine if there was a relationship between angling effort and flow. The number of anglers present on the beats was plotted against mean daily flow at Caton. (see Figure 5(a) and 5(b)).

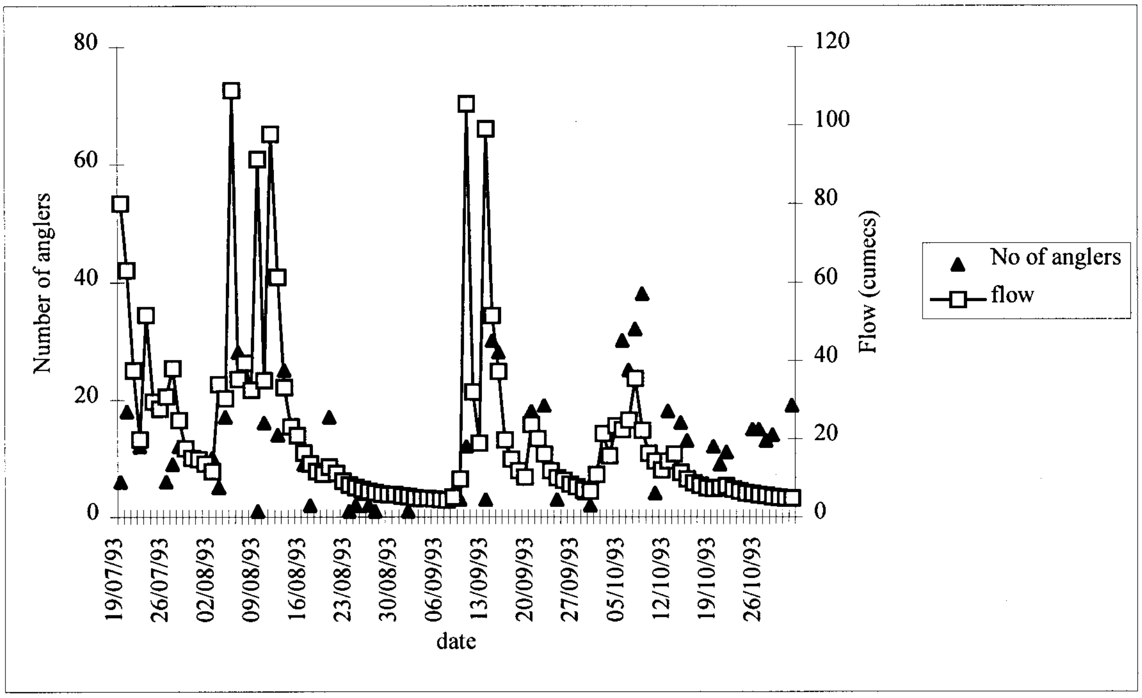


Figure 5(a): Number of anglers present on fishery 53 with flow

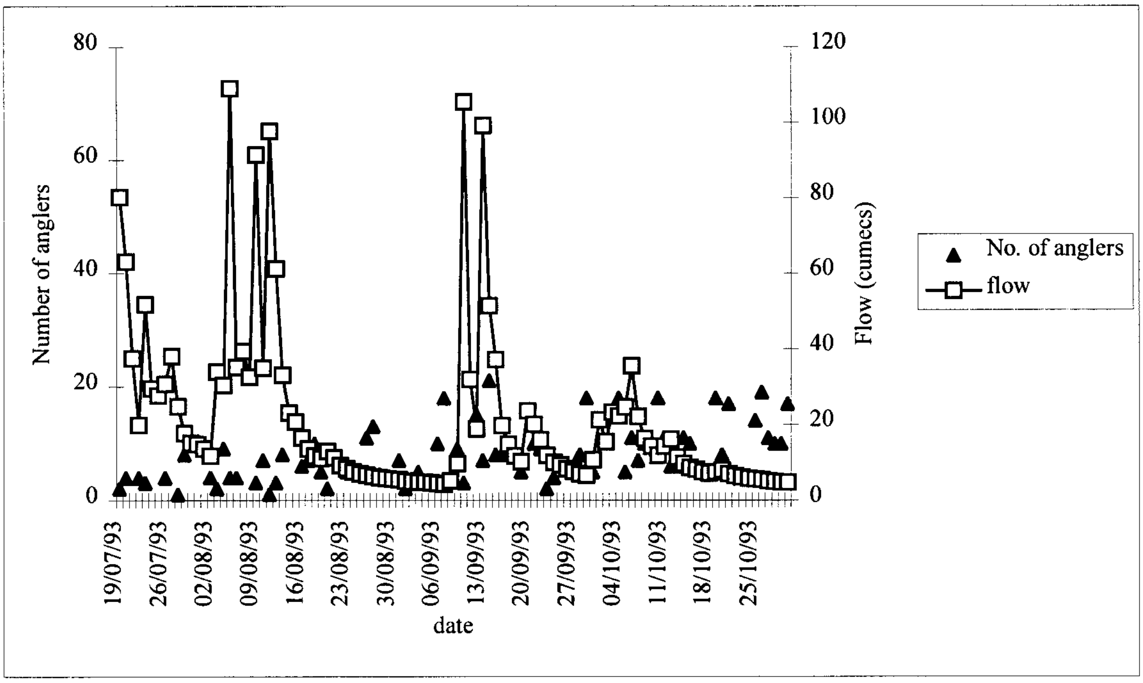


Figure 5(b): Number of anglers present on fishery 58 with flow

Regression analysis of numbers of anglers against flow indicated outliers to be present for flows above 55 cumecs. This is thought to result from anglers not fishing under flood conditions.

Therefore for the regression analysis all data for flows above 55 cumecs were omitted. Scattergrams for the data are present in Figures 6(a) and 6(b) and analysis of variance for the regressions presented in Tables 2(a) and 2(b).

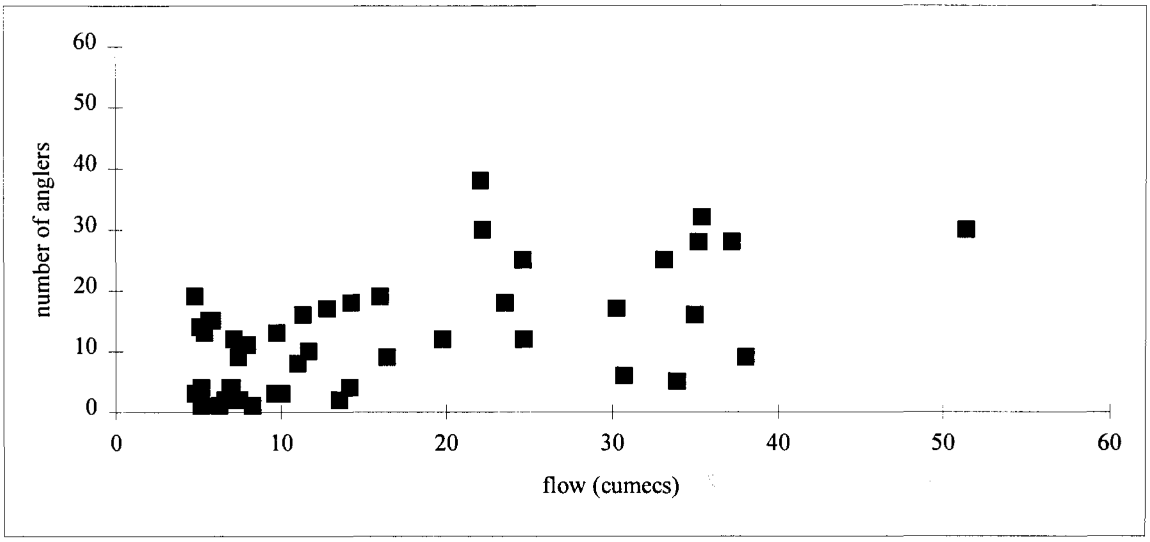


Figure 6(a): Scattergram of number of anglers on fishery 53 against mean daily flow at Caton (flows >55 cumecs not included) (Multiple R = 0.59, **R^2** = 0.34)

Analysis of variance for fishery 53

	df	SS	Mean Sq	F	P
Regression	1	1448.3	1444.3	22.98	<0.001
Residual	44	2773.0	63.0		
Total	45	4221.3			

Table 2(a): Regression analysis for number of anglers and flow for fishery 53

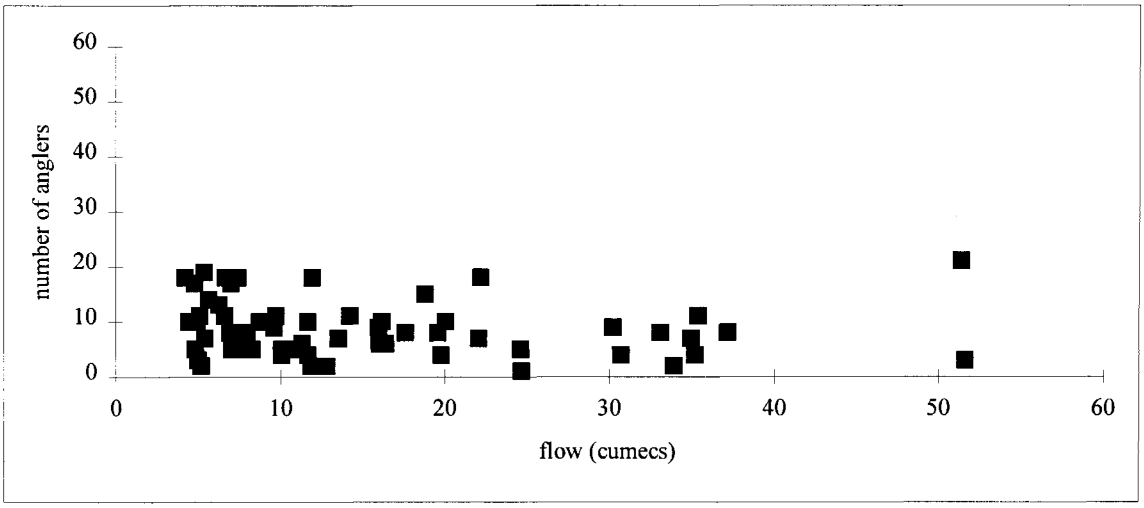


Figure 6(b): Scattergram of number of anglers on fishery 58 against mean daily flow at Caton (flows >55 cumecs not included) (Multiple R = 0.13, **R^2** = 0.017)

Analysis of variance

	df	SS	Mean Sq	F	P
Regression	1	24.98	24.98	0.974	0.32
Residual	58	1487.2	25.64		
Total	59	1512.18			

Table 2(b): Regression analysis for number of anglers and flow for fishery 58

Anglers' catch

The angling success of migratory salmonid anglers for both salmon and sea trout was compared to data collected by the NRA logbook scheme on the River Lune (Figures 7(a) and 7(b)). The catch of 146 salmon encounter during interviews were caught by 119 anglers or 9% of the total number interviewed.

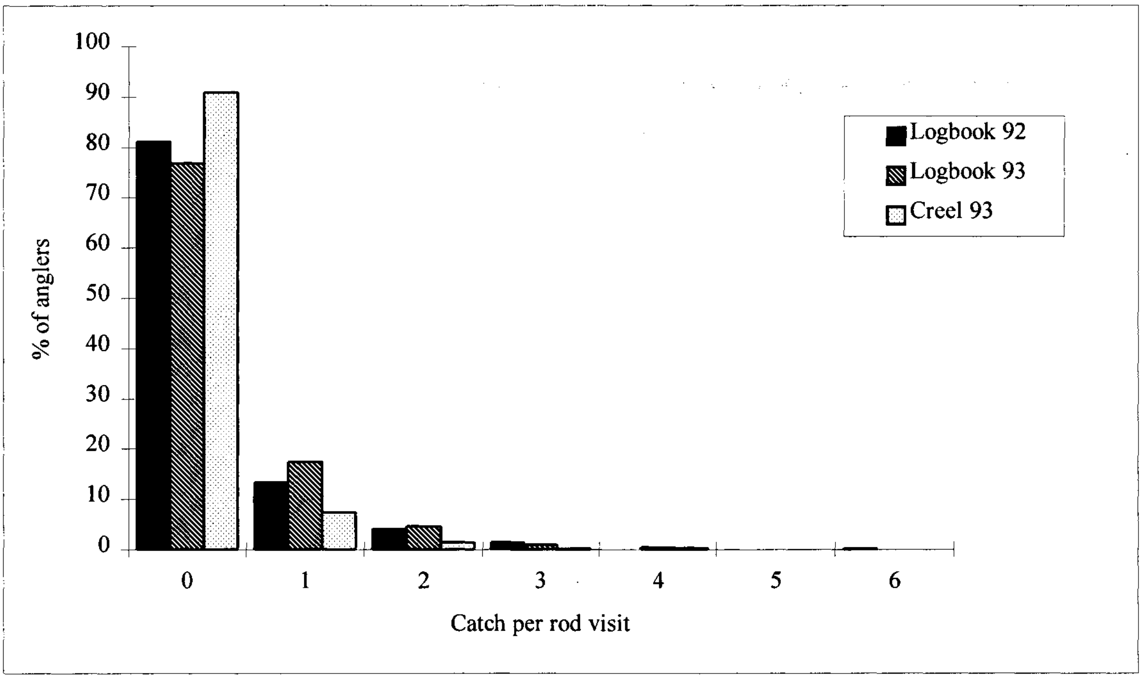


Figure 7(a): Catch per rod visit for salmon anglers for the 1992 and 1993 logbook schemes and creel census survey of 1993.

The mean catch per unit effort (CPUE) was calculated for the creel survey in 1993 and comparison is made with logbook surveys for the years 1991-1994 on the River Lune (Table 3).

	NRA (North-West) Logbooks					Creel Census
Year	1991	1992	1993	1994		1993
CPUE (fish per hour)	0.061	0.031	0.061	0.058		0.036
Hours to catch 1 salmon	16.4	32.3	16.4	17.2		27.8

Table 3: Comparison of CPUE values and hours to catch 1 salmon from NRA logbooks and creel survey of salmon anglers on the River Lune

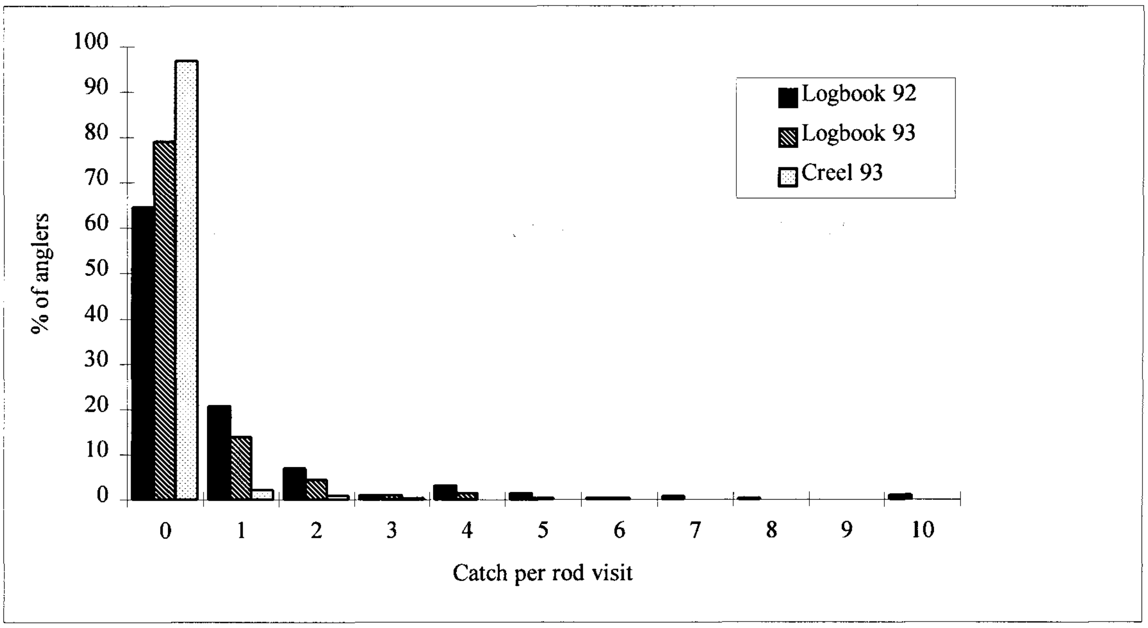


Figure 7(b): Catch per rod visit for sea trout anglers for the 1992 and 1993 logbook schemes and creel census survey of 1993.

1.3.5 Discussion

Surveying

A low mean encounter rate between anglers and surveyors was found during the intensive creel survey of the River Lune in 1993. From this the following points should be noted:

1) The encounter rate with salmonid anglers is relatively low, even on popular beats, when compared to coarse anglers. This is not unexpected since there are considerably fewer migratory salmonid anglers in England and Wales than coarse anglers (NOP 1994). Peak numbers of anglers were encountered on the banks during flow events in the autumn. This period could be targeted for surveying to provide a 'snapshot' of catches and angling patterns on the fishery or to maximise the encounter rate with anglers for determining other types of information.

2) Encounter rates with anglers on the upper reaches of the River Lune were particularly low especially during the summer period. This may have resulted partially from certain beats limiting the number of rods that can fish per day. However, the low fishing effort is more likely to be a response to the anglers perception of the abundance of fish in the upper reaches at this time. It was noted from the census that there was an increase in effort in these upper reaches towards the end of the season (September and October).

3) A benefit of the creel census technique is the contact it provides between anglers and the Agency, therefore assisting in maintaining and improving public relations.

Angler behaviour

The creel census data showed that the majority of anglers fish the whole beat during an angling session (see Figure 3). This results in a low encounter rate with anglers when combined with the short duration of angling sessions and the low number of anglers. This limits the quantity of data that may be collected for considerable surveying effort. The locations of anglers on the fishery when combined with their catch data may be useful for adult habitat studies, particularly if combined with enquiries on where the anglers usually fish. From this the selection of river habitat features used for angling by migratory salmonid anglers under different flow conditions may be established.

A relationship between number of anglers and flow was demonstrated for fishery number 53 but was not present for fishery 58. These analyses indicate that anglers on fishery 53 use flow as a guide to potential fishing success. No such relationship was found on fishery 58 which is probably a result of the tidal nature of this beat. Outlier values, where low numbers of anglers were encountered under high flows, were found for mean daily flow values of above 55 cumecs at the Caton gauging station.

Anglers' Catch

The number of anglers encountered with captured fish was also low with only 120 anglers (9%) having caught salmon (146 fish) and 11 anglers (0.8%) having caught sea trout (16 fish). Therefore an inherent problem with the survey technique in that the probability of encountering anglers who have caught fish is relatively low which limits the amount of catch data that may be collected. These values can be compared to the declared catches for the River Lune in 1993 of 1434 salmon and 1474 sea trout. The low numbers of sea trout encountered results from the timing of the surveys with the majority of this type of angling being pursued at night. The anglers encountered therefore accounted for 10.2 % of the declared catch for salmon which is relatively low considering the number of man days of surveying effort expended. The creel census technique is successful as a general method for collecting information on catch and angler behaviour, particularly if concentrated on a specific fishery, but is relatively costly when compared to other techniques of data collection such as voluntary logbook schemes. The value of the technique may be enhanced if combined, for example, with mark-recapture experiments (e.g. Claytor and O'Neil 1991)

Logbook anglers were more successful than those encountered during the creel survey (see Figures 7(a) and 7(b) and Table 3). This may result from the method of logbook distribution. At present there is no method for ensuring that the anglers completing Agency logbooks comprise a random sample of anglers. Logbooks are distributed to anglers who wish to participate in the scheme and who are therefore possibly keener and potentially more successful are being selected. Additionally, logbook schemes may have targeted more productive fisheries which provide large catches than those surveyed in the creel census. However, if only catch is being examined it may be preferable to have a biased sample from experienced anglers since more data is provided. The establishment of a migratory salmonid angler database, possibly through licence sales may assist in the distribution and targeting of logbooks. Anglers participating in logbook scheme could be rewarded by a discount voucher for the purchase of a rod licence in the following year.

The creel census method will collect data from anglers of all abilities and it is suggested that this is why the recorded catch rate is lower. This is likely to create some bias in the resulting datasets as a random sample of anglers of differing experience and ability have not been selected. It is probable that the anglers likely to participate in such a scheme are experienced and regular fishermen.

Cost / Benefit of Creel Census compared to Logbook Schemes

It is difficult to directly compare the costs of operating a logbook scheme and a creel census. Therefore the analysis of cost / benefit can only at best be an approximation. The example provided is based on collection of information from 1000 anglers (this assumes that the creel census does not interview the same person twice) and has not considered data entry.

For creel census:

If it is assumed that the average encounter rate is 9 anglers per interviewer a day, then a total of 111 man days of surveying would be required. If a cost of £100 / day to cover wages, accommodation and expenses is allocated then the total cost would be in the region of £12000.

For logbooks:

The production of logbooks (50 pence per logbook), administration (assume database exists, staff at £100 / day) and postage (assume three postings i.e. sending out , reminder, collecting) would cost approximately £4000.

The estimates indicate that logbook system is considerably cheaper to operate than a creel census and is likely to provide a greater quantity of data. However, this data will not be as fishery specific as the creel census technique. A combination of creel census and logbooks may be a beneficial approach, particularly if a specific fishery was being examined.

The presence of surveyors on the bank would be useful for maintaining a contact between the Agency and anglers and could assist in maintaining the enthusiasm for the logbook schemes, particularly if coupled with a presentation to the anglers at the end of the fishing season.

1.4 SUMMARY

Creel census method may be used to provide similar types of information but appear costly in terms of personnel time requirements. Even when fisheries were surveyed on a daily basis only limited amounts of information on catch were obtained. The main problem encountered with the technique was the relatively low encounter rates with anglers and captured fish. The Agency logbook schemes for migratory salmonid anglers have been shown to provide useful fine detailed information on angling effort and catch that can not be collected by the statutory catch return system (Aprahamian 1993). The present study has highlighted potential problems with the current distribution of angling logbooks which may introduce bias to the results.

1.5 RECOMMENDATIONS

1) Creel census should only be used for studies on angling behaviour and used in intensive studies of specific fisheries.

2) Creel census techniques are not suitable for use on a National level and should only be used in specific regional studies.

3) It is recommended that logbook schemes are implemented on a wider scale through England and Wales, particularly on rivers with counting devices. These schemes could be combined with a targeted creel census when peak numbers of anglers will be encountered.

4) It is recommended that consideration should be given to the distribution of Agency logbooks such that a random sample of anglers is employed if this is considered appropriate.

2.0 NATIONAL NET CATCH RETURN FORM

2.1 INTRODUCTION

At the present there is no standardised method for the collection of catch statistics for migratory salmonids from net catches in England and Wales. This is because the catch return forms vary on a regional basis.

The methods employed for the net exploitation of salmon traditionally vary with region. The catch return systems originally developed by the Water Authorities was designed to reflect the fishing methods employed in that area. The National Rivers Authority (NRA), and subsequently the Environment Agency (Agency), therefore inherited a collection of regional specific methods of data collection for migratory salmonids.

An objective of the R&D contract was to develop a net catch return form that could be implemented on a national basis.

2.2 ASSESSMENT OF EXISTING CATCH RETURN SYSTEMS

To develop the new catch return form the existing systems were collated and analysed. The information collected from these forms is summarised in Table 4.

Region	Effort Information	Catch Data	
		Weight Categories	Grisle / salmon
North West	Tides, hours	Yes	No
Welsh	Tides	Yes	No
Northumbrian / Yorkshire	Tides*	No	Yes
South West	Tides*	Yes (I)	No
Severn Trent	None	Yes(I)	No
Wessex (1)	Tides	Yes (I)	No
Wessex (2)	Net draws	No	Yes

Table 4: Summary of information collected by current net catch return forms
Notes for Table 1:
Tides* = No effort required by form but requires catch per day to be indicated.
Yes(I) = Form requires individual weights of fish to be provided.

2.3 THE NATIONAL CATCH RETURN FORM

Based on the assessment of the existing Agency regional catch returns the following criteria were set for the design of the new form.:

- The form should be easily understood by net fishermen.
- The form should be easily completed and not require much more additional information than that already provided.
- The form should provide biologically meaningful information.
- The form should be easily completed by fisheries which produce both large and small catches of fish.
- The form should cover all types of instrument currently employed in England and Wales.

2.3.1 Effort information

There are three types of effort information that would need to be collected on a National catch return form to cover all types of fishing method. These are:

1. Number of hours fished
2. Number of tides fished
3. Number of draws of net

2.3.2 Catch data

Five of the Agency regions currently collect weight information of fish either as the number caught in each weight category or individual weights of fish. In two of the regions, Northumbrian / Yorkshire and South Western seine net fisheries (Dorset and Avon Region), the catch data is recorded as the number of salmon and grilse caught.

It was agreed with the Agency that the new form would include the collection of catch data on a weight category basis. This would allow, particularly if combined with a scale sampling programme, a more accurate assessment of the population structure of net catches and allow changes in the stock composition to be identified. This change in recording method would only affect a few fishermen in the South Western Region. The change would present more of an inconvenience on the Northumbrian drift net fishery where large catches are made.

The recording of catches by weight categories on fisheries where large catches are made e.g. Northumbrian drift nets and the River Severn, may present some inconvenience to the fishermen. This problem was addressed in the design of the new form by production of a separate form with a reduced number of weight categories.

Based on these criteria two new net catch return forms for migratory salmonids were produced to record returns on fisheries with both large and small catches. Two draft forms were produced and circulated to the Agency regions for comment (see Appendix 2). The following recommended catch return forms presented are the result of incorporation of all these comments into the original form.

It is recommended that the catch returns are produced in the form of a bound A3 ledger with ink-pressure duplicate pages. This will allow a copy to be sent to the Agency and a copy to be retained by the fishermen for their records. The A3 format was selected to facilitate ease of completion.

On the back of the proposed Catch Return form information is provided for the fishermen on the type of effort information they should collect depending on their method of fishing. This information could be printed on the inside cover of the ledger.

2.4 SCALE SAMPLING PROGRAMME

To improve the interpretation of the data collected by catch returns it would be preferable if a scale sampling programme of the catches is undertaken. Scale samples would allow the age structure of catches to be determined, the changes in the population structure of the stocks to be examined and the selectivity of different gear types.

Scale sampling has been undertaken previously on a voluntary basis in the South West Region where fishermen were rewarded for the provision of scale samples. However, such a scheme can generate problems with multiple scale samples submitted from a single fish. Scale samples provided by fishermen have also been collected from the Welsh Dee net fishery. However, the response to this scheme has been relatively poor. For any scheme to be successful, scale sample collection should be undertaken by Agency staff. The practicality of the sampling programme would need to be assessed at a local level.

The scale sampling programme should be both robust and designed for long-term objectives to provide continuity to the data. In practice it will be difficult to establish a national programme due to regional differences in fishing techniques. Therefore scale collection should be undertaken on a regional basis to reflect the fishing methods employed. However, the resulting data should be pooled into a database which is accessible at a national level.

Where sites and methods permit it the Agency should aim to collect as many scale samples as is practical from the landing sites of fish, for example, on a weekly basis.

2.5 RECOMMENDATIONS

1) The Agency should implement a National Catch Return form for migratory

salmonid anglers.

2) The catch return form should be based on the type presented and provided to the fishermen as a bound A3 size ledger with removal copy pages for submission to the Agency.

3) A scale sampling programme should be implemented with the National return and undertaken by Agency staff with aim of obtaining as many scale samples as is practical. This is likely to involve the collection of scales from all fish at the landing site on at least a once weekly basis.

4) The collected data should be entered onto a database by trained data entry clerks for accuracy and cost effectiveness. This database should be accessible by all Agency regions fishery staff and MAFF personnel.

3.0 ANALYSIS OF MIGRATORY SALMONID CATCH STATISTICS

3.1 INTRODUCTION

For many years anglers and netsmen have been required by law to send to the relevant Authority a return of all salmon and sea trout that they have caught during a particular year. This has resulted in a considerable data set of historical catch statistics being accumulated by the Environment Agency (formerly the National Rivers Authority). These data have recently been documented by MAFF (1995). The true worth of this catch data as an indicator of stock or even total catch is unknown, because the relationship between angler catches and stock has never been properly investigated (Small 1991). Additionally the quality of these data is doubtful (Aprahamian 1993).

A generally low proportion of anglers send in their returns without reminders, although this does vary by region. There is also a persistent belief (held particularly by anglers) that netsmen routinely falsify their returns to hide a high level of exploitation and to disguise their true income from the Inland Revenue. The latter aspect of the historical data set has not been investigated nor has the equally reasonable supposition that anglers deliberately minimise their returns to hold down their rents.

More recently efforts have been made to include a measure of effort in the returns in the belief that catch per unit effort (CPUE) will be a better measure of abundance than catch alone. This initiative has not been in operation long enough to be examined critically but numerous authorities have collected data on catch and effort from anglers on a small scale (Aprahamian 1993)

The primary objectives of this section are to establish which factors affect the number of salmon and sea trout caught by anglers and netsmen in a river system, and to examine methods of correcting the data set in order to derive indices of abundance of stock. For the purpose of this contract stock abundance is defined as the number of salmon or sea trout available to a river system at a point before first legal cropping.

3.2 CATCH PER UNIT EFFORT

Catch per unit effort has been used for many years as a measure of fish stock density particularly in commercial marine fisheries (Pitcher and Hart 1982). In these fisheries measures of effort such as catch per number of hooks, per length of drift net or per timed run of trawl seem to possess obvious advantages with few potential sources of error.

The use of such a simple measure derived from anglers returns of salmon caught is likely to be less satisfactory for the following reasons:-

1) The dispersion of migratory salmonids through a river system is unlikely to remain constant and is most unlikely to be random.

2) The different age classes of salmon and sea trout which contribute to any particular stock tend to enter river systems at different but overlapping times.

3) Although it has been shown that flows (Aprahamian and Ball 1995) above the average favour high catches, the reason for this is not understood.

4) The efficiency of a unit of angling effort probably varies greatly between individual anglers and probably with such environmental factors as temperature, flow and sediment load.

It therefore seems unlikely that a simple figure such as annual catch per day fished for an entire river system is likely to be a useful parameter unless a greater understanding of the sources of error involved can be obtained.

3.3 DATA SETS

A search of archived data sets for England and Wales was undertaken with the objective of finding data which would allow an examination of the variation in catch which could be attributed to river flow, fishing effort, temporal variation and position within a river system.

A number of potential data sets were found which may have provided this information but the River Wye was selected for detailed analyses. These data were chosen because of the length of the catch archive, its breakdown into separate areas of the river, the large number of fish involved and the existence of a five year study of catch and effort initiated and partially analysed by Gee and others (e.g. Gee 1980)

The work described involves an exploration of the nature of the relationship between effort and flow, catch and effort and catch and flow. The latter is considered to be of interest because of the possibility that much of the variability of catch can be accounted for by variation in flow (Aprahamian and Ball 1995). If this hypothesis is correct, then the historical data sets of catch from many rivers may be examined and possibly standardised by removing the effect of flow. This can not be achieved by correcting for effort because the effort data are not available for many river systems.

4.0 THE RIVER WYE ANALYSIS

4.1 THE WYE FISHERY OWNERS DATA

For the years 1976 to 1980 voluntary returns from River Wye fisheries owners were collated.

The information recorded consisted of data on hours fished and salmon caught on beats throughout the mainstem of the River Wye from January through to December. In order to consolidate the information and to allow an approximate differentiation between that period when the grilse component was absent from the run and that period when it was present the data was pooled into:-

"Spring" = February 1 - May 31
"Summer" = June 1 - September 30.

and the beats into:-

"Lower" = Below Monmouth
"Middle" = Between Ross on Wye and Hereford
"Upper" = Above Hereford

The flow information was taken from the gauges at Redwood, Belmont and Erwood. The location of the beats and flow gauging stations are presented in Map 2.

4.2 ANALYSIS OF EFFORT DATA WITH FLOW

To allow direct comparison between these sites the flows were expressed in terms of standard deviations from the mean. Expected values of catch and effort were calculated with the following formulae for each flow Q class:

Expected Effort = (Total Effort hours/ Total Flow days) X (No.of days in each flow class)

Expected Catch = (Total Catch / Total hours of effort) X (No. of hours of effort in each flow class)

The graphs presented in Figures 8(a) - 8(f) display the differences between between observed and expected effort under the null hypothesis that effort remains constant regardless of flow. For the graphs of observed catch and expected catch (Figures 9(a) - 9(f), the null hypothesis assumes the catch to effort ratio remains constant regardless of flow.

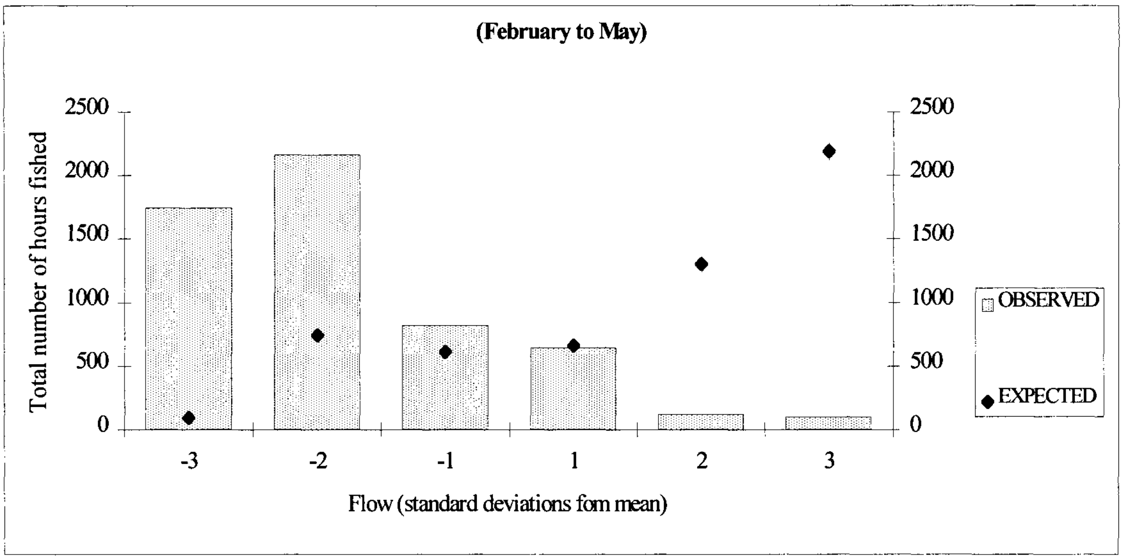


Figure 8(a): Comparison of observed effort and expected effort with standardised flow for the River Wye (Lower Section)

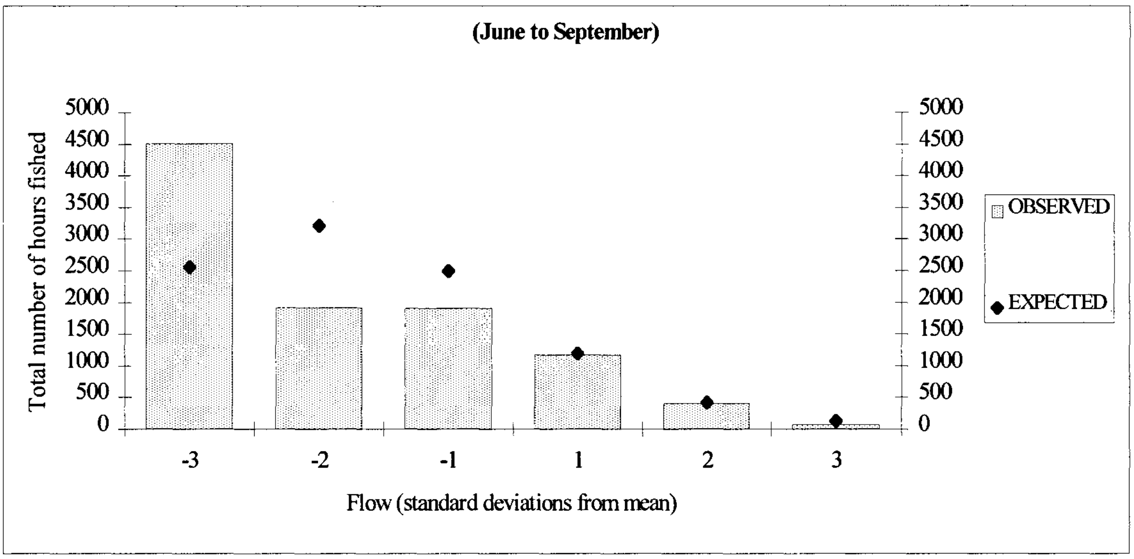


Figure 8(b): Comparison of observed effort and expected effort with standardised flow for the River Wye (Lower Section)

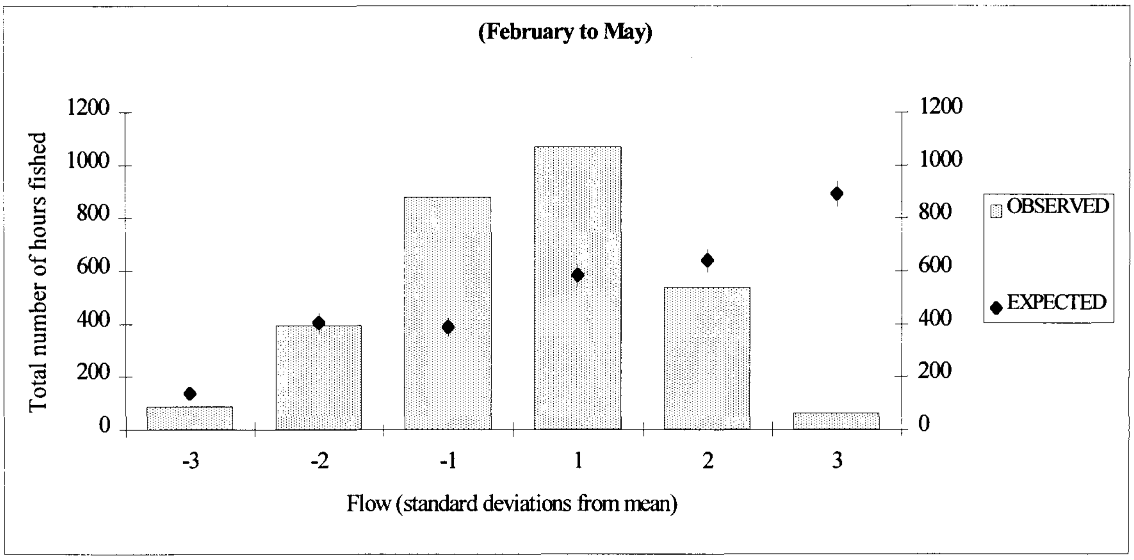


Figure 8(c): Comparison of observed effort and expected effort with standardised flow for the River Wye (Mid Section)

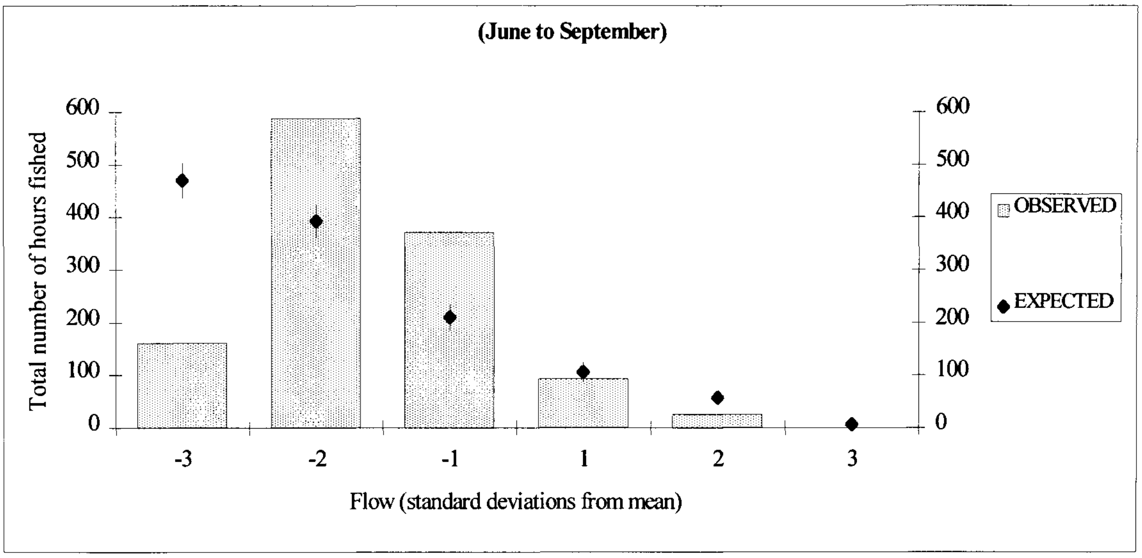


Figure 8(d): Comparison of observed effort and expected effort with standardised flow for the River Wye (Mid Section)

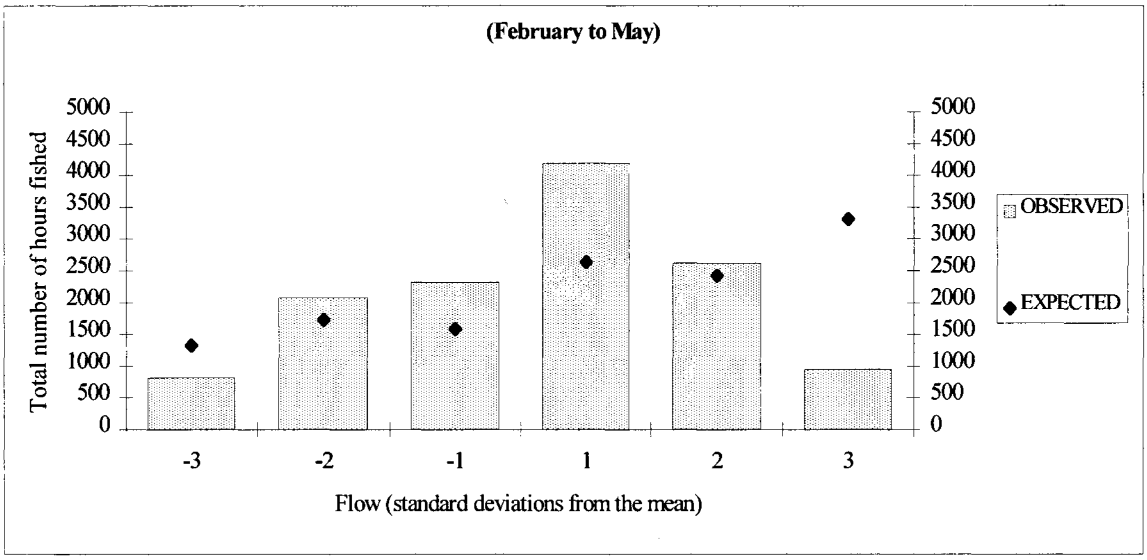


Figure 8(e): Comparison of observed effort and expected effort with standardised flow for the River Wye (Upper Section)

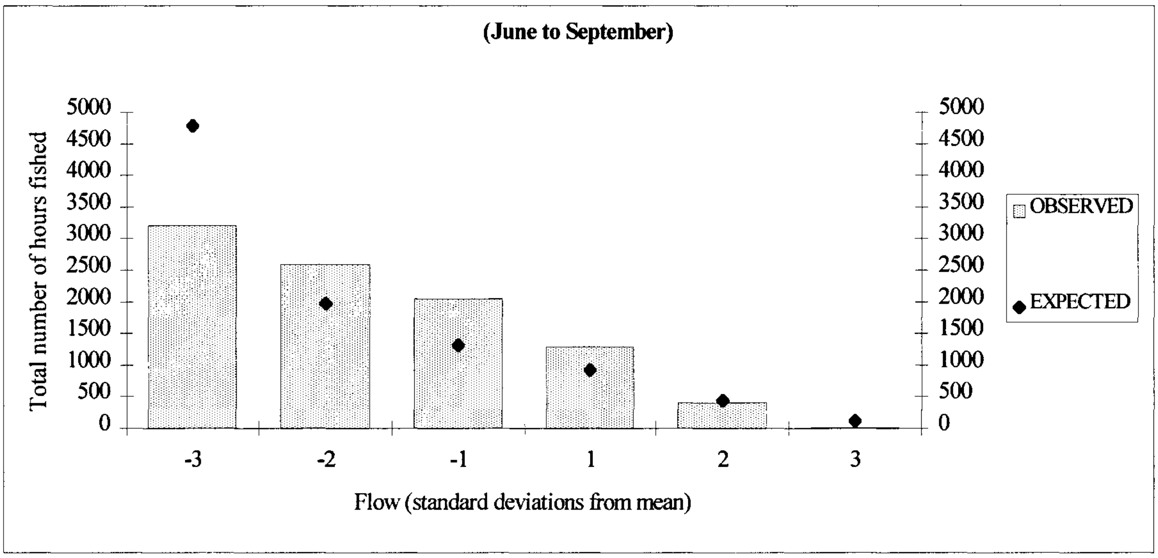


Figure 8(f): Comparison of observed effort and expected effort with standardised flow for the River Wye (Upper Section)

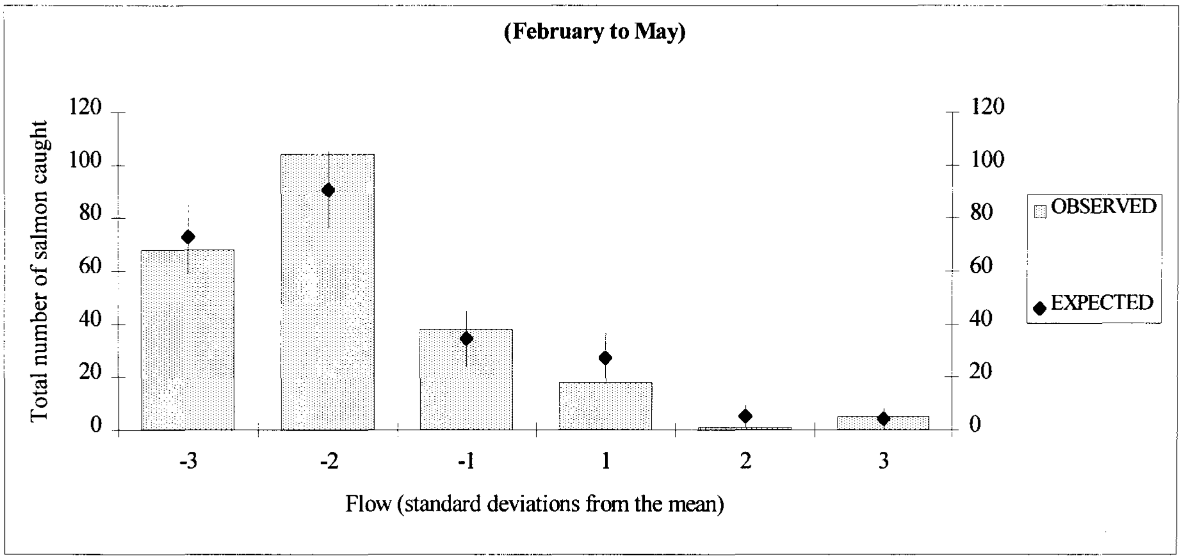


Figure 9(a): Comparison of observed catch and expected catch with standardised flow for the River Wye (Lower Section)

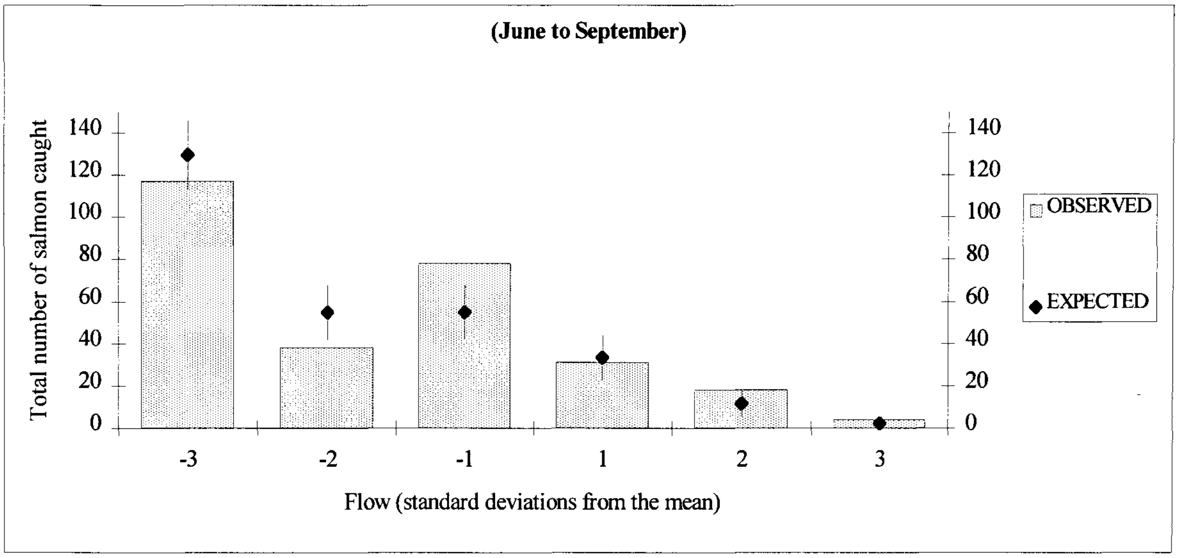


Figure 9(b): Comparison of observed catch and expected catch with standardised flow for the River Wye (Lower Section)

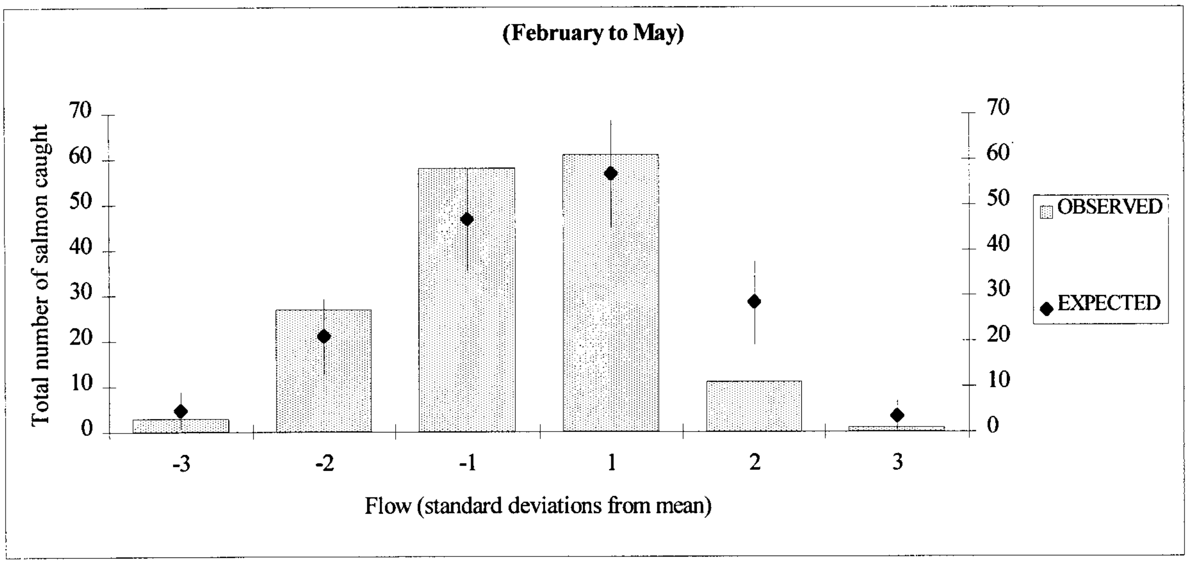


Figure 9(c): Comparison of observed catch and expected catch with standardised flow for the River Wye (Mid Section)

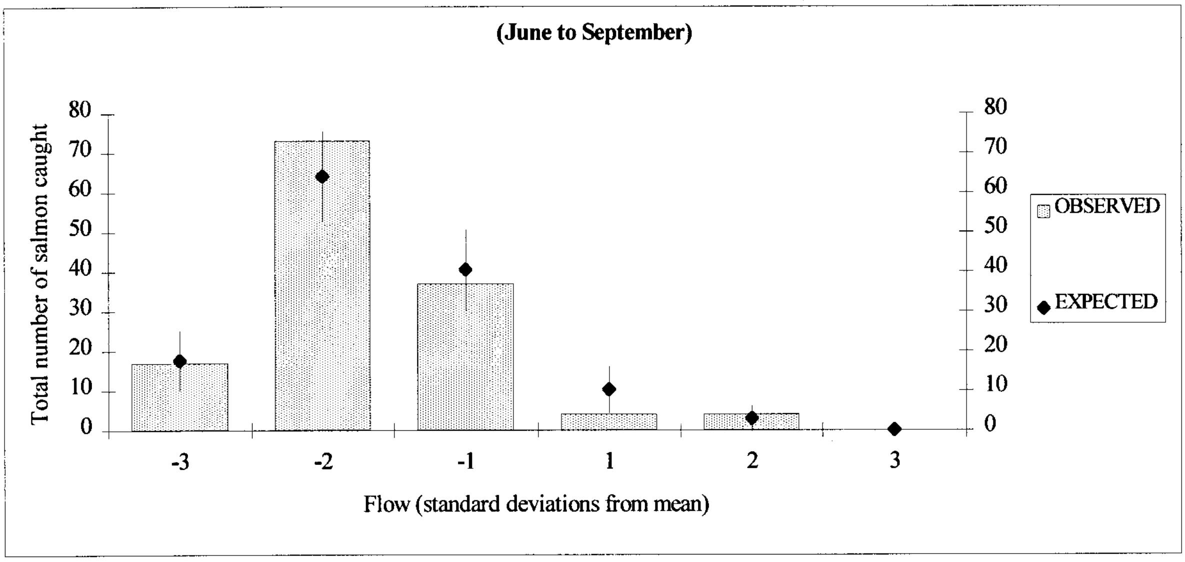


Figure 9(d): Comparison of observed catch and expected catch with standardised flow for the River Wye (Mid Section)

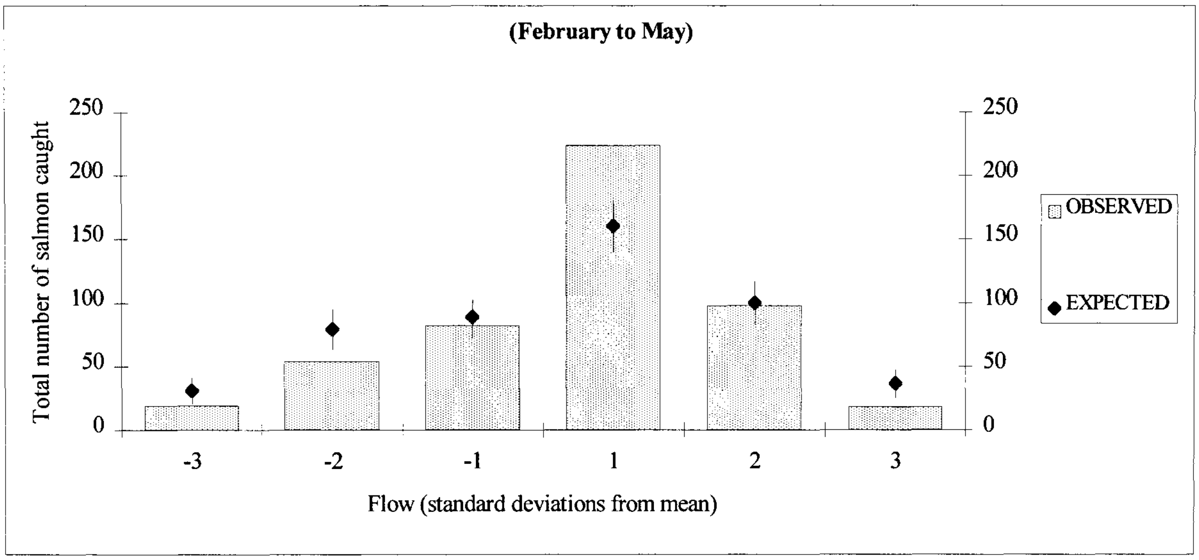


Figure 9(e): Comparison of observed catch and expected catch with standardised flow for the River Wye (Upper Section)

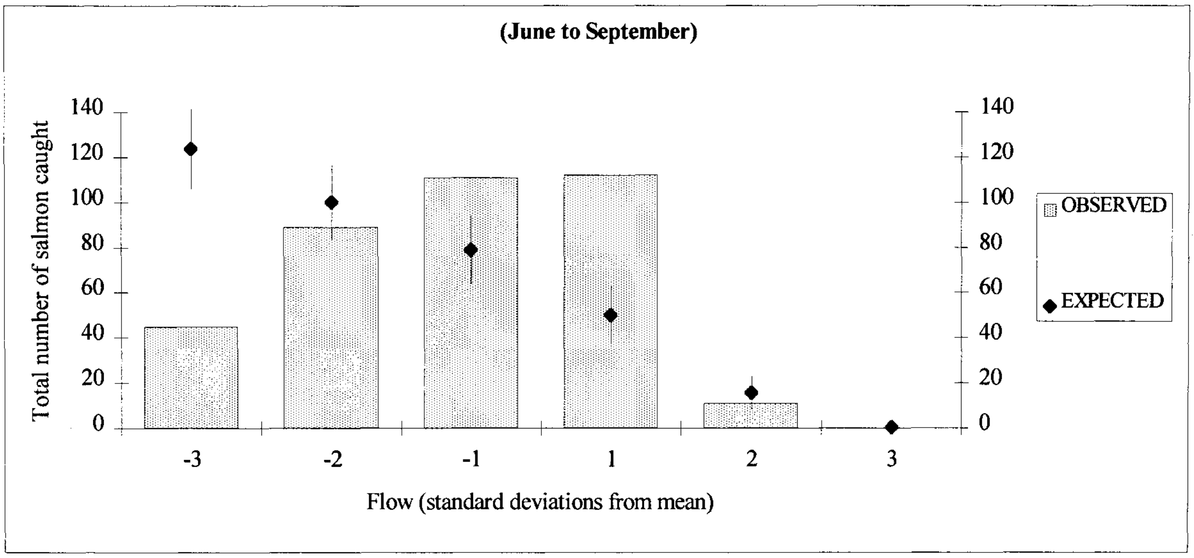


Figure 9(f): Comparison of observed catch and expected catch with standardised flow for the River Wye (Upper Section)

From these results it is clear that in the River Wye fishing effort, catch and catch per unit effort are not independent of the flow. Therefore flow is likely to affect not only the temporal and spatial variation of catch but also the total annual catch in the river system.

If the figures presented in Figures 8(a) - 9(f) are to be used as an indicator of stock a mathematical model needs to be formulated which will allow standardisation of the catch in terms of particular levels of flow or effort.

4.3 ANCOVA ANALYSIS OF EFFORT DATA

Analysis of covariance (ANCOVA) techniques were used for exploring relationships in the data set and the models based on daily and weekly data. These models are described and discussed below for the following basic relationships:-

1) Effort varying with flow.
2) Catch varying with effort.
3) Catch varying with flow.

There are differences between the levels of reported effort between beats and between years. Differences between beats are to be expected as a result of the differences in size. Table 5 demonstrates the variation in reporting from the various beats in the data set. From Table 5, which shows the total effort reported for each beat on an annual basis, large apparently random variation takes place within certain beats and in some cases no effort has been reported. The form of these data suggest voluntary returns were submitted by a few anglers whose enthusiasm was not maintained for the full five year period and for this reason the data must be carefully analysed and interpreted.

	Hours fished				
Beat No	**1976**	**1977**	**1978**	**1979**	**1980**
1	5043	682	609	5961	7010
2	-	208	-	-	-
3	-	667	679	409	492
4	452	-	-	-	-
5	219	578	341	328	289
7	-	513	125	233	87
8	46	-	83	52	149
9	57	536	-	-	-
10	110	-	-	-	-
11	370	-	-	-	-
12	769	-	2264	1804	695
13	176	-	765	307	650
14	-	1410	1655	1282	526
15	1066	1406	1152	533	752
16	533	-	-	-	-

Table 5: Recorded angling effort (hours fished) reported for selected beats on the River Wye

The majority of the data were collected on 8 beats and generally the level of reporting does not provide sufficient data for an analysis by beat; therefore the decision was taken to "bulk up" the data by combining certain beats. This required care and an element of subjective judgement to minimise any bias caused by combining results in an unbalanced manner.

Although on Beat 1 the returns for 1977 and 1978 were much lower than the other years, they were only likely to be a source of bias if the anglers providing returns for those years behaved very differently to the generality of anglers in the other years. Therefore it was felt that there were sufficient data on Beat 1 for it to stand alone as Reach 1.

Reach 2 was made up by combining the data from Beats 3, 5 and 7 for the years 1977 - 1980 only.

Reach 3 seemed to pose a choice between Beats 14 and 15 for the same four years or Beats 12, 13, 14 and 15 for 1978 - 1980. In the event the latter was chosen somewhat arbitrarily but there still appears to be a diminution of returns from beats with time.

Daily mean flow measurements for the three reaches respectively were taken from the gauging stations at Redbrook, Belmont and Erwood.

4.4 THE EFFORT / FLOW MODEL

From inspection of Figures 8(a) and 8(b), it is apparent that a second order equation may provide the best fit for the relationship between Effort and Flow. However, an inspection of Table 5 reveals variation in the data that have all the hallmarks of variability in reporting. For this reason a model is required that removes these sources of variation and highlights any relationship of effort with flow. Such a model is shown below. It is multiplicative and the "Annual" and "Monthly" effects include variation due to systematic variation in recording as well as true variation due to population differences.

Such considerations suggest the following model:-

$$\mathbf{E = MY(a+b_1F+b_2F^2)Er}$$

where:-	**E**	=	Effort
	Y	=	Annual effect
	M	=	Monthly effect
	F	=	Mean daily flow
	Er	=	Error
and	**a, b_1, b_2**	=	Constants

This model requires the assumption that the level of effort varies between years but there is also a constant monthly pattern of effort. Additionally, it specifies that the daily effort applied is a proportion of the product of the monthly and annual effects which depend on a function of the mean daily flow.

Initial examination of the data demonstrated significant departures from normality and increasing variance with size of observation and so the following transformations were applied:-

Flow -------> Ln(Flow)
Effort -------> Ln(1+ Effort)
Catch -------> Ln(1 + Catch)

This transformation results in a non-linear model which presents analysis problems.

Therefore to avoid this difficulty the basic model was reformulated as :-

$$\mathbf{LnE = \mu + LnW + LnY + LnM + LnMLnY + b_1 LnF + b_2(LnF)^2 + b_3LnP + Er}$$

where:

μ is the overall mean effect

LnMLnY is the interaction term between monthly and annual effects and provides a test of the hypothesis that the pattern of monthly effort does not remain constant between years.

'P' represents a further covariate (the logarithm of the average flow in the previous week) which was also included in the model to account for possible variation in effort due to the anglers perception of the effect of previous flows.

An additional main effect (**LnW**) was introduced to test for differences in effort between days of the week, since it was considered likely that the pattern of angling effort might reflect the general pattern of leisure time,

This model, whilst being less satisfactory from a purely mathematical point of view, allows stabilisation of the variance, expresses flow, which usually approaches a lognormal distribution, as an approximately Normal distribution and provides an additive model of a form suitable for ANCOVA techniques.

4.4.1 Results

Analysis of variance results for effort with flow for Reach 1-3 are presented in Table 6(a)-(c).

Source	DF	SeqSS	AdjSS	AdjMS	P
lnflow	1	40.6	54.8	54.8	<0.005
lnflowsq	1	264.4	112.9	12.9	<0.005
preflow	1	58.2	12.0	12.0	<0.005
month	6	142.1	84.2	14.0	<0.005
year	4	977.8	916.1	229.0	<0.005
month*year	24	352.5	352.5	14.7	<0.005
Error	997	613.7	613.7	0.6	
Total	1034	2449.2			

Term	Coeff	Stdev	t-value	P
Constant	-3.67	0.61	-6.06	<0.005
lnflow	3.27	0.35	9.44	<0.005
lnflowsq	-0.60	0.04	-13.54	<0.005
preflow	0.56	0.13	4.41	<0.005

Table 6(a): Analysis of Variance for Effort for Reach 1

Source	DF	SeqSS	AdjSS	AdjMS	P
lnflow	1	0.8	27.8	27.8	<0.005
lnflowsq	1	187.7	55.1	55.1	<0.005
preflow	1	49.5	5.7	5.7	<0.005
month	6	164.3	154.5	25.8	<0.005
year	3	29.8	31.2	10.4	<0.005
month*year	18	26.5	26.5	1.5	<0.005
Error	797	515.1	515.1	0.6	
Total	827	973.6			

Term	Coeff	Stdev	t-value	P
Constant	-1.42	0.42	-3.40	<0.005
lnflow	1.83	0.28	6.56	<0.005
lnflowsq	-0.37	0.04	-9.24	<0.005
preflow	0.25	0.09	2.97	<0.005

Table 6(b): Analysis of Variance for Effort for Reach 2

Source	DF	SeqSS	AdjSS	AdjMS	P
lnflow	1	7.6	49.5	49.5	<0.005
lnflowsq	1	219.0	91.4	91.4	<0.005
preflow	1	42.6	17.7	17.7	<0.005
month	6	10.2	11.1	1.8	<0.005
year	2	149.4	140.0	70.0	<0.005
month*year	12	26.4	26.4	2.2	<0.005
Error	597	267.3	267.3	0.4	
Total	620	722.4			

Term	Coeff	Stdev	t-value	P
Constant	-1.50	0.33	-4.56	<0.005
lnflow	2.63	0.25	10.51	<0.005
lnflowsq	-0.54	0.04	-14.29	<0.005
preflow	0.48	0.08	6.28	<0.005

Table 6(c): Analysis of Variance for Effort for Reach 3

4.4.2 Discussion

Clearly although the significance levels of the various factors and covariates are generally high, the total fit of the model on the three reaches is not good due to the fact that the level of detail was too fine.

There are also problems with the basic assumptions of the analysis of covariance model and there is strong serial correlation and a lack of normality in the residuals. For this reason the results must be viewed with some caution particularly with regard to tests of differences between factor levels and therefore further comment is restricted to the importance of the variables in the model and its general suitability.

Reach 1

All effects were significant and better than the 0.001 probability level and the model accounted for 75% of the total sum of squares. However, as would be expected from the obvious differences in effort between the years the annual effect accounted for a very high proportion of the sum of squares. This makes it more difficult to interpret the contribution of the other effects and covariates in the model. The interaction effect between months and years was also large but this also may be symptomatic of the lack of consistency in data collection.

The effect of flow was substantial but the daily flow had a greater effect than the average flow for the week before the observation. Clearly the practical significance would be increased if the main annual effect was reduced by better experimental design.

The relationship between effort and the previous average flow was positive and between effort and daily flow positive up to a maximum at a logflow figure of approximately 2.7 units and thereafter negative.

Reach 2

The model only accounted for 47% of the total sums of squares and as on Reach 1 the annual and interaction effects were the greatest but the shape of the relationship of effort and flow was similar with a maximum at about 2.5 units of logflow.

Reach 3

The model accounted for 63% of the total sum of squares. The effect of flow was second only to the annual effect and showed a similar pattern to the other reaches with a maximum at a logflow of 2.4 units.

4.4.3 Variation due to days of the week

Over the entire season the model did not demonstrate any significant effects due to effort varying with the day of the week but it was considered likely that such an effect could be seasonal. Therefore the data set was split at the end of May and two models fitted to the time period March to May and to June to September.

No significant differences between effort on different days of the week were found for Reach 1 but on Reach 2 significant effects were found in both the Spring and the Summer months. On Reach 3 only the Summer months showed a significant effect.

The ANCOVA tables for those models showing significant effects are shown in Tables 7(a)-7(c) with the means for effort on each day adjusted according to the mean level of effort.

Source	DF	SeqSS	AdjSS	AdjMS	F	P
lnflow	1	104.8	0.9	0.9	1.3	0.26
lnflowsq	1	84.8	5.3	5.3	7.3	0.01
preflow	1	0.1	0.2	0.2	0.3	0.58
year	3	17.6	23.2	7.7	10.6	<0.005
month	2	17.1	17.5	8.8	12.0	<0.005
wkday	6	14.6	14.1	2.4	3.2	0.01
year*month	6	11.9	11.1	1.9	2.5	0.02
year*wkday	18	14.5	12.9	0.7	1.0	0.48
month*wkday	12	8.5	8.9	0.7	1.0	0.44
year*month*wkday	36	16.7	16.7	0.5	0.6	0.95
Error	339	475.6				

Adjusted mean effort for weekdays

wkday	Mean Effort	Stdev
Sun	1.86	0.13
Mon	2.05	0.13
Tue	1.79	0.13
Wed	1.42	0.12
Thu	1.45	0.12
Fri	1.74	0.13
Sat	1.80	0.12

Table 7(a): Analysis of Variance for lneffort for Reach 2 March to May

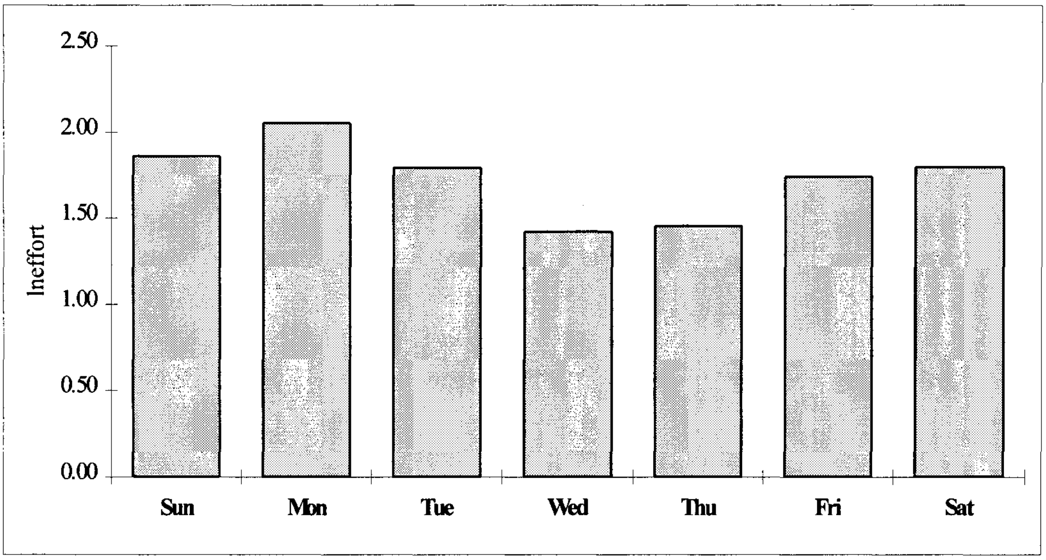


Figure 10(a): Reach 2 (March - May) adjusted mean lneffort for weekdays

Source	DF	SeqSS	AdjSS	AdjMS	F	P
lnflow	1	5.2	8.2	8.2	18.9	<0.005
lnflowsq	1	43.6	10.7	10.7	24.7	<0.005
preflow	1	14.7	11.6	11.6	26.8	<0.005
year	3	15.4	15.9	5.3	12.2	<0.005
month	3	28.1	27.0	9.0	20.7	<0.005
wkday	6	50.9	51.4	8.6	19.7	<0.005
year*month	9	15.9	15.6	1.7	4.0	<0.005
year*wkday	18	8.3	7.9	0.4	1.0	0.44
month*wkday	18	10.0	10.0	0.6	1.3	0.20
year*month*wkday	54	27.6	27.6	0.5	1.2	0.19
Error	373	161.9	161.9	0.4		
Total	487	381.6				

Adjusted mean effort for weekdays

wkday	Mean Effort	Stdev
Sun	1.15	0.08
Mon	1.44	0.08
Tue	0.80	0.08
Wed	0.65	0.08
Thu	0.62	0.08
Fri	0.71	0.08
Sat	1.38	0.08

Table 7(b): Analysis of Variance for lneffort for Reach 2 June to September

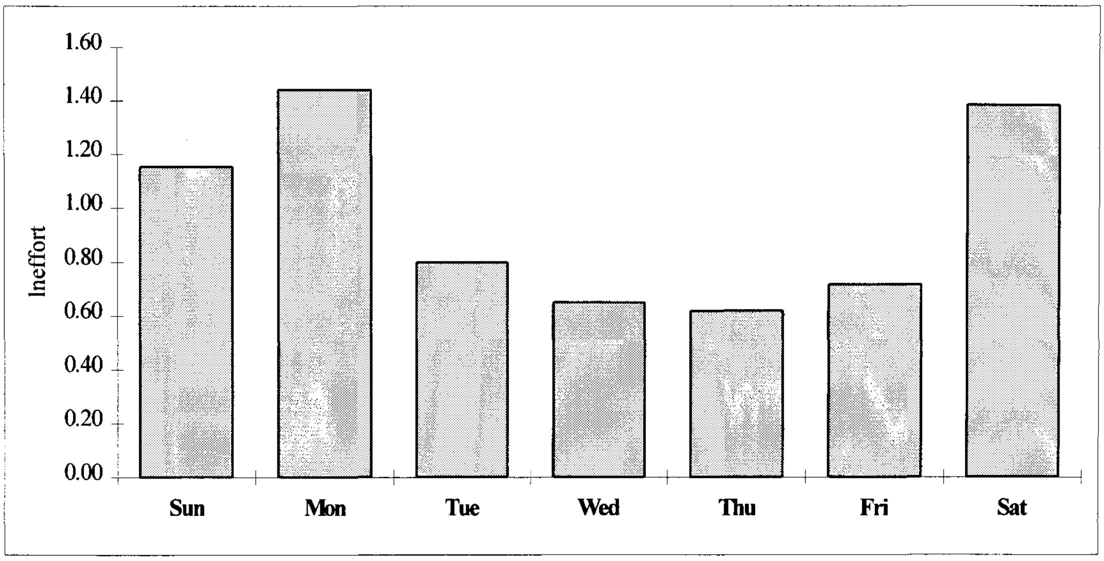


Figure 10(b): Reach 2 (June - Sept) adjusted means for lneffort for weekdays

Source	DF	SeqSS	AdjSS	AdjMS	F	P
lnflow	1	2.4	13.1	13.1	35.8	<0.005
lnflowsq	1	69.3	19.6	19.6	53.6	<0.005
preflow	1	12.4	21.8	21.8	59.7	<0.005
year	2	75.0	63.9	32.0	87.5	<0.005
month	3	5.9	4.6	1.5	4.2	0.01
wkday	6	8.7	8.4	1.4	3.8	<0.005
year*month	6	14.3	14.4	2.4	6.6	<0.005
year*wkday	12	7.7	7.4	0.6	1.7	0.07
month*wkday	18	6.4	6.5	0.4	1.0	0.47
year*month*wkday	36	11.5	11.5	0.3	0.9	0.68
Error	279	102.0	102.0	0.4		
Total	365	315.5				

Adjusted mean effort for weekdays

wkday	Mean effort	Stdev
Sun	2.44	0.08
Mon	2.64	0.08
Tue	2.69	0.08
Wed	2.48	0.08
Thu	2.70	0.08
Fri	2.28	0.08
Sat	2.39	0.08

Table 7(c): Analysis of Variance for lneffort for Reach 3 June to September

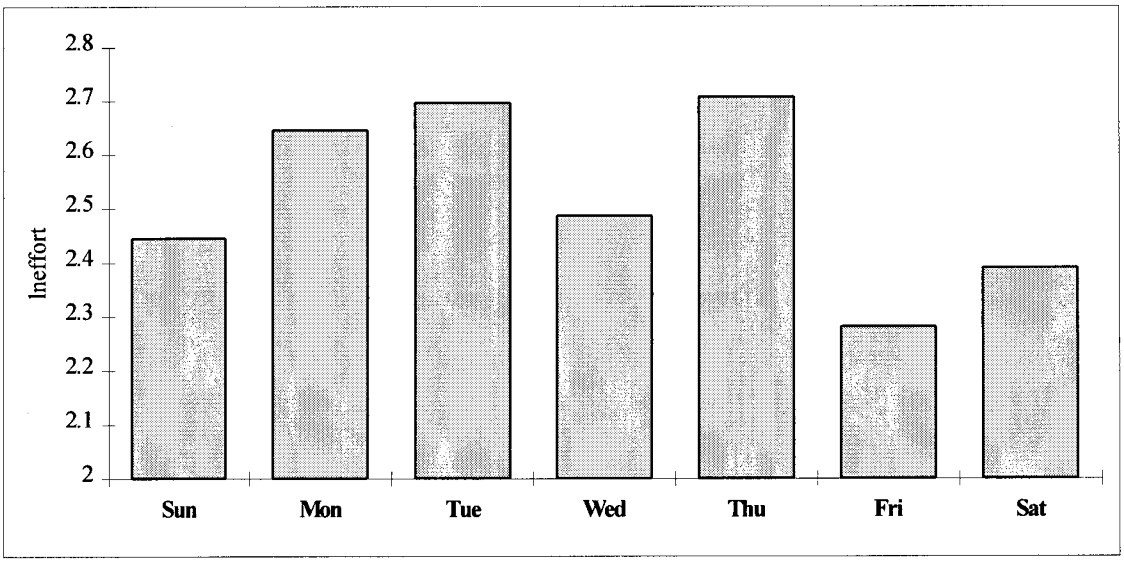


Figure 10(c): Reach 3 (June - Sept) adjusted means for lneffort for weekdays

For reach 2 and 3 the effects attributable to different weekdays were not the same and were only substantial during the summer months on reach 2 where there was a tendency for greater fishing effort to occur on Saturdays, Sundays and Mondays. The pattern was similar on reach 2 during the Spring but not so pronounced.

On reach 3 there appears to have been greater fishing effort during the week rather than at weekends.

Some of the ANOVA tables (Tables 7(a)-(c)) include non-significant effects indicating that these elements do not contribute to the fit of the model and could be omitted from analysis.

4.5 THE CATCH / EFFORT MODEL

Identical arguments to those used for the Effort/flow model have been used to formulate the Catch/effort model as follows:-

$$\mathbf{LnC = \mu + LnW + LnY + LnM + LnMLnY + b_1\,LnE + b_2(LnE)^2 + b3LnP + Er}$$

This model examines the variation of catch (**C**) between and within months and years using effort (**E**) as a covariate. It also tests whether or not the relationship between catch and effort is defined by a straight line. This model was chosen in preference to one using catch per unit effort (CPUE) for the dependent variable because days on which there was no effort recorded are otherwise excluded from the model. This can cause computational problems due to loss of rank in the variance/ covariance matrix. It should be noted that the inclusion of these points cause bias of the regression line to the origin, a desirable result since clearly if there is no effort there can be no catch.

The main monthly and annual effects can be considered to represent an index of the available population of salmon on which the daily effort operates. It is reasonable to expect that this model will not be affected by the gross differences in the level of reporting. However, this may remain a possibility if the efficiency of the effort applied varies widely. At some times only keen and possibly therefore more successful anglers will have reported and on other occasions, perhaps after the submission of reminders, the less successful majority.

4.5.1 Results

The results of analysis of variance of catch and effort are presented in Tables 8(a)-(c)

Source	DF	SeqSS	AdjSS	AdjMS	P
lneff	1	90.6	0.8	0.8	0.03
lneffsq	1	8.3	11.6	11.6	<0.005
preflow	1	3.5	3.4	3.4	<0.005
month	6	9.1	5.8	1.0	<0.005
year	4	15.4	9.9	2.5	<0.005
month*year	24	9.3	9.3	0.4	<0.005
Error	997	160.4	160.4	0.2	
Total	1034	296.7			

Term	Coeff	Stdev	t-value	P
Constant	-0.62	0.14	-4.38	<0.005
lneff	-0.07	0.03	-2.24	0.03
lneffsq	0.08	0.01	8.50	<0.005
preflow	0.18	0.04	4.57	<0.005

Table 8(a): Analysis of Variance for Catch for Reach 1

Source	DF	SeqSS	AdjSS	AdjMS	P
lneffort	1	24.7	0.00	0.00	0.87
lneffsq	1	0.7	2.18	2.18	<0.005
preflow	1	1.0	0.04	0.04	0.56
month	6	2.3	2.04	0.34	<0.005
year	3	5.6	4.68	1.56	<0.005
month*year	18	9.6	9.63	0.54	<0.005
Error	797	85.4	85.37	0.11	
Total	827	1	29.4		

Term	Coeff	Stdev	t-value	P
Constant	0.07	0.09	0.79	0.43
lneffort	-0.01	0.04	-0.16	0.87
lneffsq	0.06	0.01	4.51	<0.005
preflow	-0.02	0.03	-0.59	0.56

Table 8(b): Analysis of Variance for Catch for Reach 2

Source	DF	SeqSS	AdjSS	AdjMS	P
lneffort	1	39.8	1.0	1.0	0.01
lneffsq	1	19.2	6.7	6.7	<0.005
preflow	1	0.9	3.6	3.6	<0.005
month	6	9.1	6.3	1.0	<0.005
year	2	9.6	9.2	4.6	<0.005
month*year	12	8.3	8.3	0.7	<0.005
Error	597	97.6	97.6	0.2	
Total	620	184.5			

Term	Coeff	Stdev	t-value	P
Constant	-0.52	0.12	-4.42	<0.005
lneffort	-0.14	0.06	-2.46	0.01
lneffsq	0.10	0.02	6.38	<0.005
preflow	0.17	0.04	4.69	<0.005

Table 8(c): Analysis of Variance for Catch for Reach 3

4.5.2 Discussion

Reach 1

The model accounted for 46% of the total sum of squares with exception for the weekday effect. For this reason the weekday effect has been omitted from the results for all reaches. All other factors and covariates demonstrated a very high degree of significance. Of particular note is the fact that daily flow appears to be the most important factor followed by the main effects stemming from the different years, months and the interaction between the two.

Reach 2

The model only accounted for 34% of the total sum of squares with the annual and interaction effects of greater importance than effort. However, the shape of the relationship between catch and effort is the same as for Reach 1 with catch increasing with effort and increasing more at high levels of effort than low levels. Catch increased with the mean flow prior to the day of observation.

Reach 3

The model accounted for 47% of the total sum of squares and effort accounted for the biggest proportion with the main and interaction effects following. The effect of effort and weekly flow prior to the observation was substantially the same as for Reaches 1 and 2.

On all three reaches an increase in the average flow for the week prior to the daily observation results in an increase in the catch. The relationship between catch and daily effort is not described by a straight line. Catch per unit effort was shown to increase with effort but to a greater degree at higher levels of effort.

The general shape of the relationship is presented in Figure 11 where the variables have been transformed back to their original form. Therefore the relation between catch and effort can be considered as a straight line for practical purposes. As before no attempt has been made to test for significant differences between reaches.

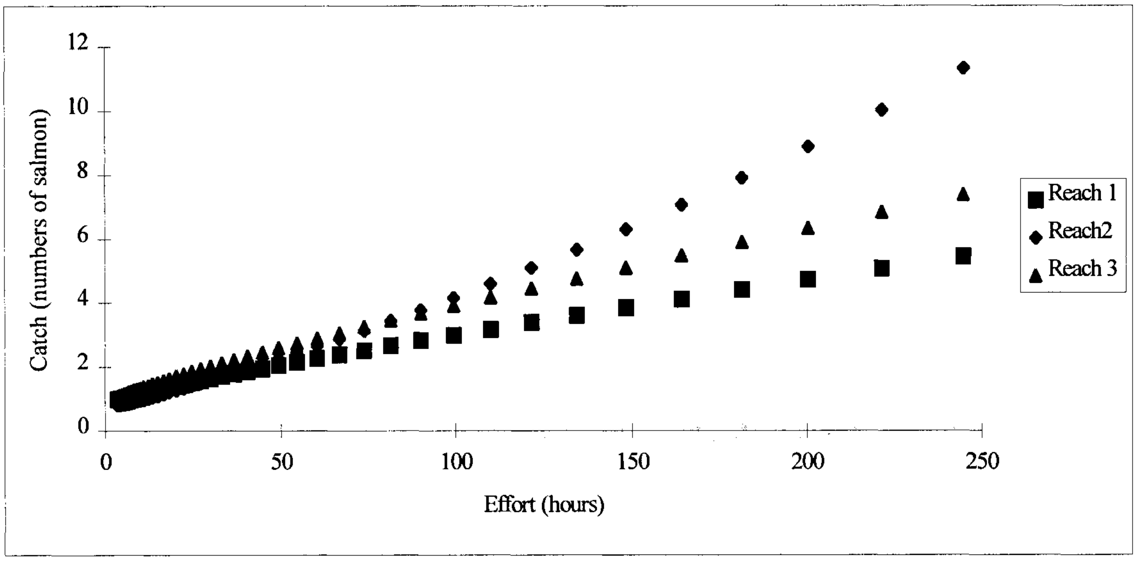


Figure 11: Estimated weekly relationships between Catch and Effort for each reach

4.5.3 Variation due to days of the week

As for the Effort/flow model the weekday effect was re-examined after splitting the data into two seasons. The results of the analysis of variance are presented in Table 9. The effect was only detectable in the summer on reach 2. It is noticeable that the lowest catches were taken on Sundays and Mondays in contrast to the earlier observation that the heavy effort on this reach occurred on those two days.

Source	DF	SeqSS	AdjSS	AdjMS	F	P
lneffort	1	12.0	0.0	0.0	0.4	0.52
lneffsq	1	0.5	1.5	1.5	16.0	<0.005
preflow	1	0.0	0.1	0.1	0.6	0.45
year	3	1.6	1.3	0.4	4.5	<0.005
month	3	0.5	0.5	0.2	1.7	0.17
wkday	6	1.7	1.8	0.3	3.0	0.01
year*month	9	4.5	4.6	0.5	5.4	<0.005
year*wkday	18	1.8	1.8	0.1	1.1	0.39
month*wkday	18	2.6	2.5	0.1	1.5	0.10
year*month*wkday	54	5.2	5.2	0.1	1.0	0.49
Error	373	35.8	35.8	0.1		
Total	487	66.1				

Adjusted mean catch for weekdays

wkday	Mean Catch	Stdev
Sun	0.06	0.04
Mon	0.05	0.04
Tue	0.21	0.04
Wed	0.17	0.04
Thu	0.20	0.04
Fri	0.22	0.04
Sat	0.16	0.04

Table 9: Analysis of Variance for lncatch

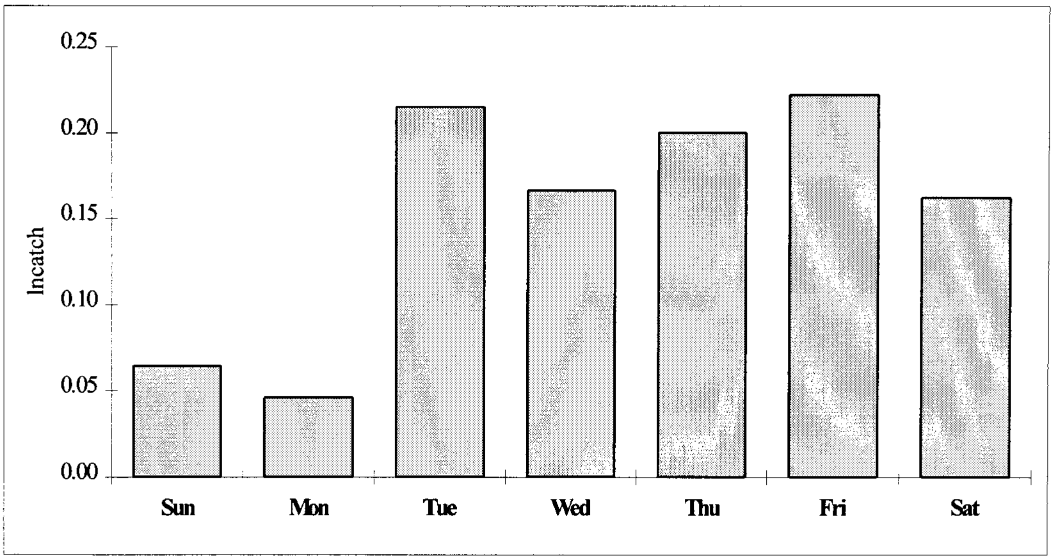


Figure 12: Reach 2 Jun-Sept adjusted means for weekdays

4.6 THE CATCH / FLOW MODEL

Identical arguments to those used for the Catch/effort model have been used to formulate the Catch/flow model as follows:-

$$LnC = \mu + LnY + LnM + LnMLnY + b_1 LnF + b_2(LnF)^2 + b_3 LnP + Er$$

4.6.1 Results

Results of the analysis of variance of catch and flow are presented in Table 10(a)-(c).

Source	DF	SeqSS	AdjSS	AdjMS	P
lnflow	1	0.0	2.0	2.0	<0.005
lnflowsq	1	17.6	4.0	4.0	<0.005
preflow	1	3.4	2.1	2.1	<0.005
month	6	22.7	15.9	2.7	<0.005
year	4	29.4	23.5	5.9	<0.005
month*year	24	32.1	32.1	1.3	<0.005
Error	997	191.4	191.4	0.2	
Total	1034	296.7			

Term	Coeff	Stdev	t-value	P
Constant	-1.20	0.34	-3.56	<0.005
lnflow	0.62	0.19	3.21	<0.005
lnflowsq	-0.11	0.02	-4.59	<0.005
preflow	0.24	0.07	3.34	<0.005

Table 10(a): Analysis of Variance for lncatch for Reach 1

Source	DF	SeqSS	AdjSS	AdjMS	P
lnflow	1	0.3	0.6	0.6	0.03
lnflowsq	1	6.9	1.2	1.2	<0.005
preflow	1	0.4	0.0	0.0	0.58
month	6	4.5	4.8	0.8	<0.005
year	3	7.7	6.9	2.3	<0.005
month*year	18	9.4	9.4	0.5	<0.005
Error	797	100.1	100.1	0.1	
Total	827	129.4			

Term	Coeff	Stdev	t-value	P
Constant	-0.15	0.18	-0.83	0.41
lnflow	0.26	0.12	2.14	0.03
lnflowsq	-0.05	0.02	-3.05	<0.005
preflow	0.02	0.04	0.56	0.58

Table 10(b): Analysis of Variance for lncatch for Reach 2

Source	DF	SeqSS	AdjSS	AdjMS	P
lnflow	1	1.2	1.2	1.2	0.01
lnflowsq	1	25.0	2.7	2.7	<0.005
preflow	1	6.7	9.8	9.8	<0.005
month	6	12.3	11.8	2.0	<0.005
year	2	12.2	11.2	5.6	<0.005
month*year	12	11.4	11.4	0.9	<0.005
Error	597	115.8	115.8	0.2	
Total	620	184.5			

Term	Coeff	Stdev	t-value	P
Constant	-1.01	0.22	-4.64	<0.005
lnflow	0.41	0.16	2.51	0.01
lnflowsq	-0.09	0.03	-3.76	<0.005
preflow	0.36	0.05	7.10	<0.005

Table 10(c): Analysis of Variance for lncatch for Reach 3

4.6.2 Discussion

These models generally accounted for a smaller proportion of the total sum of squares than the effort models (36%, 22%, and 37% respectively for reaches 1, 2 & 3 as opposed to 46%, 35% and 47% for the effort models) however they do demonstrate that although catch is dependent on effort, both catch and effort are ultimately dependent on flow.

The shape of the catch/flow relationship is shown in Figure 13 along with the mean daily flows for each reach over the five year period. The maximum catch for reach 1 and 2 occurs below the mean daily flow. Reach 3 appears to be different to the middle and upper reaches with the maximum catch taking place around the mean daily flow value. Tests of significance have not been carried out on these relationships because of doubts regarding the data set.

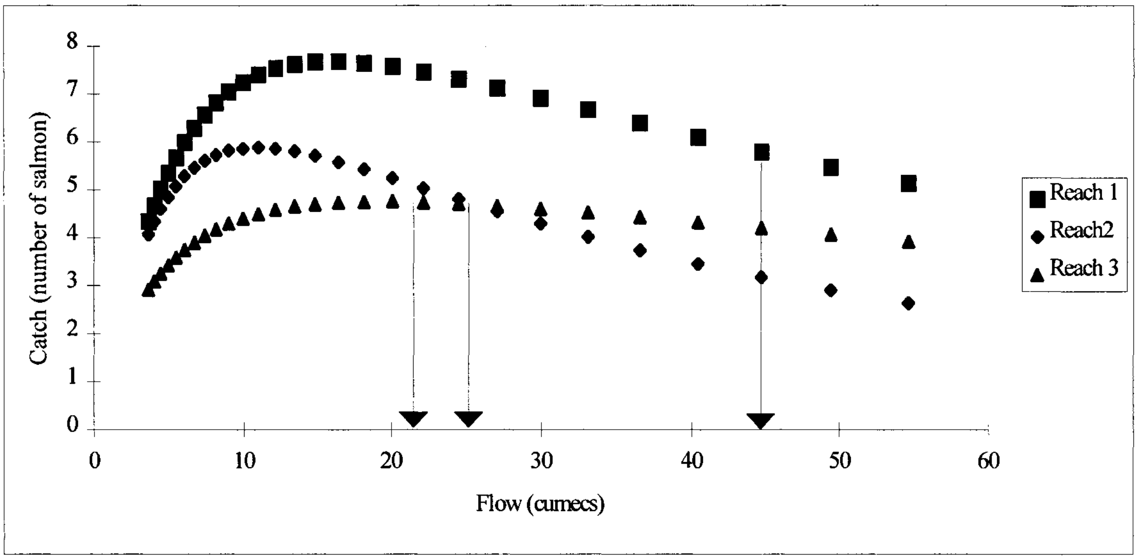


Figure 13: Comparison of catch/weekly flow relationships for Reaches 1-3 showing average daily flow for period for each reach

4.7 OVERALL DISCUSSION OF THE RESULTS FROM UTILISING DAILY DATA

The Effort/Flow model appeared to meet the assumptions required for the ANCOVA technique but the Catch/Effort and Catch/Flow models showed significant departures from Normality and were therefore less suitable despite the robustness of the technique. However, because of the very high levels of statistical significance involved there can be little doubt that the relationships described are real and of great practical significance.

The critical observations that can be made from the results are:

1) Angling effort increases with flow to a maximum at a moderately low level and thereafter decreases with further increases of flow.

2) The relationship between catch and flow follows a very similar pattern to 1.

3) The relationship between catch and effort demonstrates an increase in catch with effort and an increase in CPUE with increasing effort, however, this is small and probably of little practical significance.

The folklore of angling dictates that the best time to catch salmon is on or just after moderately high flows. The above models are entirely consistent with this view and in fact suggest that the anglers who submitted their returns largely selected the days on which they fished according to their perception of possible success and moreover, because catch/unit effort increased with effort, it would appear that they were correct in their assessment of their chances.

The reason for this successful behaviour characteristic is not difficult to establish. Many workers have endeavoured to model the movement of salmon into a river system and although none have succeeded because it has been impossible to define or estimate the availability of salmon which will respond to a given flow stimulus all agree that flow is a prime deciding factor in the movement of salmon into river systems (Cragg-Hine 1984). Furthermore Solomon and Potter (1992) have demonstrated that the catchability of at least some of those salmon already within a river system is increased by raised flow levels. Clearly anglers are responding to the accumulated expert knowledge of the sport that raised flows imply increased numbers of salmon or high catchability.

The models identified there to be monthly patterns of effort and catch and that there was variation between years. This was to be expected as far as the monthly main catch effects were concerned because it is well known that different age classes enter the river at different times and for the Wye is demonstrated by Figure 17(a) and 17(b) (contour plots showing the distribution of weights of rod caught salmon with time). A monthly pattern of effort was not to be expected but if anglers are responding to their perception of the stock of salmon in the river then it is not surprising. Holiday seasons and the increase in daylight hours in the summer would be expected to provide greater opportunities for anglers to fish.

This point is supported by the observation that on Reach 2 at least there was an increase in effort on Saturdays, Sundays and Mondays, the latter presumably being due to increased effort on Bank holidays although this was not tested. However it contrasts with the overriding behaviour pattern of the selection of days when success is more likely.

It is therefore possible to hypothesise two differing behaviour patterns for anglers:

1) Those whose leisure time allows, tend to fish on the best possible days.

2) Those whose leisure time is circumscribed and are prepared to fish at other times even if the chance of success is diminished. However even members of this group do not normally fish on very high or very low flows.

It is interesting to note that apparently on Reach 3 anglers have been avoiding the weekend period. This can be dismissed as an anomalous result but judgement should be reserved until data has been specifically collected to investigate this area which while it may seem unimportant and of little practical significance at this stage may well be important in the design of a logbook type survey of anglers catches on other rivers. This results from the distribution of angling effort being biased with respect to weekends. As such some allowance would be required to avoid an inaccurate estimate of the effects of flow on catch and effort.

Annual effects for effort are almost certainly due to variation in reporting and in fact can be seen from a cursory examination of Table 6(a) but there may be other reasons that cannot be identified.

Annual effects for catch are harder to explain because theoretically the numerical strength of the different age classes entering the river in the same year should be independently distributed and an overall annual effect should only be apparent if the abundance of one age class swamps the others. There is also the possibility that normally the mortality rates of salmon in and around the estuary are high and suitable flow conditions in the river provided by a wet year allow a greater number of salmon to escape into the river.

From the above discussion the interaction effects, interpreted as variation between years of the monthly pattern of catch, are a likely consequence of variation in the effort of anglers as fresh runs of salmon enter the river and their subsequent catchability varies. However, the inclusion in the model of the various forms of flow as variables should account for this. The remaining interaction effect can then be interpreted as resulting from changes in the monthly availability from one year to the next caused by differences in the ratio of the abundance of salmon of different age classes, since it is known for instance that grisle have a different temporal run pattern than multi-seawinter fish.

5.0 USING WEEKLY CATCH DATA

5.1 INTRODUCTION

Discrete models based on the Poisson distribution can be formulated to minimise the difficulty posed by small daily catches. An alternative approach would be to combine daily information into weekly data to allow the formulation of a further series of models which are more suitable for the classical ANCOVA technique. Such models would reduce bias arising due to different fishing patterns at weekends by taking the week's activity as a whole. In fact by pairing successive weeks pseudo replicates would be produced allowing the calculation of interaction effects defined as relative differences between the weekly effects in different years. This requires the assumption that the weekly effect is constant between the two replicates in each pair and then the weekly main effect stems from the mean of two successive weeks and may be referred to as a fortnightly effect.

This approach has been followed in the next model in which logarithmic transformations were effected for the total weekly effort and catch and the mean weekly flow and in order to investigate the effect of previous flows the logarithm of the mean weekly flow for the previous week was included in all models.

5.2 THE EFFORT / FLOW MODEL

The model was defined as follows:-

$$\mathbf{LnE = \mu + LnY + LnW + LnYLnW + b_1LnF + b_2(LnF)^2 + b_3LnP + Er}$$

where E = Weekly effort
Y = Annual main effect
W = Weekly main effect (referred to as "fort")
F = Mean weekly flow
P = Mean weekly flow for the previous week
Er = Error

5.2.1 Results

Results of the analysis of variance for lneffort on lnflow are presented in Table 11(a)-(c).

Source	DF	SeqSS	AdjSS	AdjMs	P
lnflow	1	0.3	1.5	1.5	0.02
lnflowsq	1	11.9	12.8	2.8	<0.005
preflow	1	7.6	2.5	2.5	<0.005
Fort	13	42.6	17.7	1.4	<0.005
year	4	273.3	247.4	61.9	<0.005
Fort*year	52	95.0	95.0	1.8	<0.005
Error	67	17.9	17.9	0.3	
Total	139	448.7			

Term	Coeff	Stdev	t-value	P
Constant	-1.69	2.03	-0.83	0.41
lnflow	2.54	1.07	2.38	0.02
lnflowsq	-0.47	0.14	-3.25	<0.005
preflow	0.78	0.26	3.04	<0.005

Table 11(a): Analysis of variance for effort for Reach 1

Source	DF	SeqSS	AdjSS	AdjMs	P
lnflow	1	2.4	2.8	2.8	0.01
lnflowsq	1	47.0	4.2	4.2	<0.005
preflow	1	20.4	0.2	0.2	0.44
Fort	13	34.8	31.5	2.4	<0.005
year	3	10.5	11.2	3.7	<0.005
Fort*year	39	21.1	21.1	0.5	0.07
Error	53	18.3	18.3	0.3	
Total	111	154.4			

Term	Coeff	Stdev	t-value	P
Constant	-0.90	1.62	-0.55	0.58
lnflow	2.93	1.04	2.82	0.01
lnflowsq	-0.56	0.16	-3.49	<0.005
preflow	0.19	0.24	0.79	0.44

Table 11(b): Analysis of variance for effort for Reach 2

Source	DF	SeqSS	AdjSS	AdjMs	P
lnflow	1	0.9	0.6	0.6	0.19
lnflowsq	1	11.1	0.8	0.8	0.12
preflow	1	10.4	3.5	3.5	<0.005
Fort	13	3.4	3.4	0.3	0.62
year	2	22.9	22.0	11.0	<0.005
Fort*year	26	9.0	9.0	0.3	0.37
Error	39	12.1	12.1	0.3	
Total	83	69.8			

Term	Coeff	Stdev	t-value	P
Constant	0.80	1.53	0.52	0.61
lnflow	1.50	1.12	1.35	0.19
lnflowsq	-0.29	0.19	-1.58	0.12
preflow	0.76	0.22	3.39	<0.005

Table 11(c): Analysis of variance for effort for Reach 3

5.2.2 Discussion

The three models improved dramatically on those utilising daily data accounting for 94%, 88% and 83% respectively of the total sum of squares in the three reaches. The pattern of importance of main effects interactions and covariates remained the same. It will be noted that in these and some subsequent models the various flow variables do not invariably show up as significant; this problem is considered in the discussion section later.

5.3 THE CATCH / EFFORT MODEL

The model was defined as follows:-

$$\mathbf{LnC = \mu + LnY + LnW + LnYLnW + b_1LnE + b_2(LnE)^2 + b_3LnP + Er}$$

where C = Weekly catch
E = Weekly effort
Y = Annual main effect
W = Weekly main effect (referred to as "fort")
P = Mean weekly flow for the previous week
Er = Error

5.3.1 Results

Results for the analysis of variance of lncatch on lneffort are presented in Tables 12(a)-(c).

Source	DF	SeqSS	AdjSS	AdjMs	P
lneff	1	85.9	0.1	0.1	0.59
lneffsq	1	8.7	1.3	1.3	0.02
preflow	1	9.6	0.1	0.1	0.61
Fort	13	12.6	8.2	0.6	<0.005
year	4	8.9	2.9	0.7	0.01
Fort*year	52	19.9	19.9	0.4	0.02
Error	67	14.6	14.6	0.2	
Total	139	160.2			

Term	Coeff	Stdev	t-value	P
Constant	-0.16	0.82	-0.19	0.85
lneff	-0.12	0.23	-0.54	0.59
lneffsq	0.08	0.03	2.44	0.02
preflow	0.12	0.24	0.52	0.61

Table 12(a): Analysis of variance for lncatch on lneffort for Reach 1

Source	DF	SeqSS	AdjSS	AdjMs	P
lneffort	1	24.4	0.6	0.6	0.13
lneffsq	1	2.4	2.7	2.7	0.00
preflow	1	2.4	0.5	0.5	0.15
fort	13	7.3	5.4	0.4	0.09
year	3	7.5	5.5	1.8	<0.005
fort*year	39	12.9	12.9	0.2	
Total	111	76.8			

Term	Coeff	Stdev	t-value	P
Constant	1.24	0.69	1.79	0.08
lneffort	-0.36	0.24	-1.54	0.13
lneffsq	0.15	0.04	3.33	<0.005
preflow	-0.30	0.20	1.48	0.15

Table 12(b): Analysis of variance for lncatch on lneffort for Reach 2

Source	DF	SeqSS	AdjSS	AdjMs	P
lneffort	1	29.8	0.0	0.0	0.92
lneffsq	1	9.4	0.2	0.2	0.40
preflow	1	1.6	1.2	1.2	0.04
Fort	13	14.3	7.0	0.5	0.04
year	2	10.9	9.7	4.9	<0.005
Fort*year	26	8.4	8.4	0.3	0.25
Error	39	10.0	10.0	0.3	
Total	83	84.4			

Term	Coeff	Stdev	t-value	P
Constant	-1.54	0.84	-1.84	0.07
lneffort	-0.05	0.49	-0.10	0.92
lneffsq	0.08	0.09	0.85	0.40
preflow	0.54	0.25	2.14	0.04

Table 12(c): Analysis of variance for lncatch on lneffort for Reach 3

5.3.2 Discussion

As for the models of weekly effort on flow a considerable improvement has been achieved with the models for catch on effort now accounting for 91%, 83% and 88% of the total sum of squares for the three reaches respectively.

5.4 THE CATCH / FLOW MODEL

The model was defined as follows:-

$$\mathbf{LnC = \mu + LnY + LnW + LnYLnW + b_1LnF + b_2(LnF)2 + b_3LnP + Er}$$

where C = Weekly catch

Y = Annual main effect

W = Weekly main effect (referred to as "fort")

F = Mean weekly flow

P = Mean weekly flow for the previous week

Er = Error

5.4.1 Results

Results of the analysis of variance of lncatch on lnflow are presented in Tables 13(a)-(c).

Source	DF	SeqSS	AdjSS	AdjMs	P
lnflow	1	3.2	0.5	0.5	0.17
lnflowsq	1	19.0	0.9	0.9	0.07
preflow	1	5.4	0.8	0.8	0.09
Fort	13	28.4	16.1	1.2	<0.005
year	4	41.1	34.3	8.6	<0.005
Fort*year	52	45.7	45.7	0.9	<0.005
Error	67	17.5	17.5	0.3	
Total	139	160.2			

Term	Coeff	Stdev	t-value	P
Constant	-2.02	2.00	-1.01	0.32
lnflow	1.47	1.05	1.40	0.17
lnflowsq	-0.27	0.14	-1.86	0.07
preflow	0.44	0.25	.71	0.09

Table 13(a): Analysis of variance for lncatch on lnflow for Reach 1

Source	DF	SeqSS	AdjSS	AdjMs	P
lnflow	1	0.0	0.7	0.7	0.13
lnflowsq	1	16.2	1.3	1.3	0.04
preflow	1	1.6	0.1	0.1	0.61
fort	13	9.9	10.7	0.8	<0.005
year	3	10.9	8.6	2.9	<0.005
fort*year	39	22.5	22.5	0.6	0.01
Error	53	15.7	15.7	0.3	
Total	111	76.8			

Term	Coeff	Stdev	t-value	P
Constant	-0.32	1.50	-0.21	0.83
lnflow	1.48	0.96	1.54	0.13
lnflowsq	-0.31	0.15	-2.09	0.04
preflow	-0.11	0.22	-0.51	0.61

Table 13(b): Analysis of variance for lncatch on lnflow for Reach 2

Source	DF	SeqSS	AdjSS	AdjMs	P
lnflow	1	3.1	0.3	0.3	0.34
lnflowsq	1	28.8	0.3	0.3	0.34
preflow	1	8.6	4.6	4.6	<0.005
Fort	13	10.5	10.6	0.8	0.01
year	2	10.9	10.3	5.2	<0.005
Fort*year	26	10.9	10.9	0.4	0.16
Error	39	11.5	11.5	0.3	
Total	83	84.4			

Term	Coeff	Stdev	t-value	P
Constant	-2.45	1.50	-1.64	0.11
lnflow	1.05	1.09	0.96	0.34
lnflowsq	-0.18	0.18	-0.98	0.34
preflow	0.87	0.22	3.96	<0.005

Table 13(c): Analysis of variance for lncatch on lnflow for Reach 3

5.4.2 Discussion

As in the other fortnightly models, fits have been improved by bulking the data without changing their overall characteristics and the sums of squares accounted for on the three reaches are 94%, 80% and 86%.

5.5 OVERALL DISCUSSION OF THE RESULTS FROM MODELS UTILISING WEEKLY DATA

All the models examined required careful interpretation of the results. The adjusted sum of squares, on which the significance tests are conducted, are calculated as the increase in the error term resulting from the omission of that particular effect or covariant from the model. The sequential sum of squares result demonstrates the reduction of the error term by including each effect or covariant in the model in the order shown. If two effects or covariates are strongly correlated the omission of either will make little difference to the fit of the model and show a low significance level. Thus taking as an example the catch/effort model for Reach 1 (see Table 12(a)) the linear component of weekly effort is not significant (p=0.59) but as the first variable introduced to the model it accounted for the largest proportion of the total sum of squares; thus either lneffort or lneffortsq satisfactorily describes the contribution of flow to the model.

It is not obvious from the above ANCOVA tables but correlation also exists between the flow covariates and the interaction effect. This is demonstrated by the following analyses for Reach 1 (Tables 14(a)-14(c)):-

Source	DF	SeqSS	AdjSS	AdjMS	F	P
lneff	1	85.9	0.1	0.1	0.3	0.59
lneffsq	1	8.7	1.3	1.3	6.0	0.02
preflow	1	9.6	0.1	0.1	0.3	0.61
Fort	13	12.6	8.2	0.6	2.9	<0.005
year	4	8.9	2.9	0.7	3.4	0.01
Fort*year	52	19.9	19.9	0.4	1.8	0.02
Error	67	14.6	14.6	0.2		
Total	139	160.2				

Table 14(a): Analysis of variance of catch /effort for Reach 1 using full model

Source	DF	SeqSS	AdjSS	AdjMS	F	P
Fort	13	46.9	46.9	3.6	12.4	<0.005
year	4	32.7	32.7	8.2	28.0	<0.005
Fort*year	52	60.3	60.3	1.2	4.0	<0.005
Error	70	20.4	20.4	0.3		
Total	139	160.2				

Table 14(b): Analysis of variance of catch / effort for Reach 1 with omission of flow variables

Source	DF	SeqSS	AdjSS	AdjMS	F	P
lneff	1	85.9	0.9	0.9	3.3	0.07
lneffsq	1	8.7	12.3	12.3	42.4	<0.005
preflow	1	9.6	4.9	4.9	17.1	<0.005
Fort	13	12.6	7.5	0.6	2.0	0.03
year	4	8.9	8.9	2.2	7.7	<0.005
Error	119	34.5	34.5	0.3		
Total	139	160.2				

Table 14(c): Analysis of variance of catch/effort for Reach 1 with omission of interaction term

The full model (Table 14(a)) accounts for 91% of the total sum of squares of which 12% are accounted for by the interaction term and 65% by the flow covariates. If however the latter are omitted, the model still accounts for 87% and the interaction term for 38% so the model is still a good fit but the effect of the covariates has been absorbed into the interaction term and the fortnightly and annual mean effects. The fortnightly and annual main effects also account for substantially greater proportions of the sums of squares than in the full model. The flow covariates account for a proportion of the variance of the main effects as well as the interaction effect.

Similar conclusions can be drawn from these weekly models as for those using daily data namely that flow both instantaneous and historical has a significant effect on both angling effort and success. The most likely explanation for this observation is that flow has a major if not overriding influence on the entry of salmon to the river, their subsequent distribution and catchability. Moreover it appears that since angling effort is also related to flow, anglers respond to their perception of the availability of catchable salmon in the river by increasing their effort. However, very high flows are known not to be conducive to angling success and in consequence angling effort decreases with increasing flow above a certain level (Aprahamian and Ball 1995).

These observations amount to a hypothesis which must be tested on better data from a river equipped with a trap or counter so that the calculated main and interaction effects can be compared with the known abundance of salmon in the river and allowances made for varying catchability; but so far in this investigation it appears that models of this type may be used for establishing the role of flow in the total catch. It seems unlikely that the interaction effects reflect the abundance of salmon before entry to the river except in years with consistently high flows.

If flow in its various forms is omitted from the model it seems likely that the interaction effect reflects the variation about the monthly mean of the catch of salmon in the river brought about by variation in catchability and angling effort. If the full model is applied it seems possible that the interaction effect reflects the general availability of salmon at that time and this may well be an indication of stock availability in the river system.

5.6 A COMPARISON BETWEEN INTERACTION EFFECTS FROM THE CATCH/EFFORT AND THE CATCH/FLOW MODELS

Adjusted means were calculated for the interaction effects; these are the expected catch using the full model but using the overall mean for each covariate instead of the observed value. In other words the adjusted means are the estimated means corrected to a standard flow level.

The correlation coefficients of the adjusted means for the interaction effects from the catch/flow and catch/effort models were found to be only 0.69, 0.72 and 0.82 respectively for the three reaches. This is despite the fact that a comparison between the estimated catches and the actual catches from the two models yielded correlation coefficients of a very high order indeed. It will be seen from the analysis of covariance using the adjusted means from the flow model as the dependent variable that a large proportion of the variance can be attributed to the difference between years (see Tables 15(a)-(c). This is also well demonstrated by the graph presented in Figure 14(a) on which the adjusted means from the two models are plotted as scatter diagrams for each reach.

It should be noted that on reaches 1 & 3 there are significant differences in the constant terms of the equation between years and on Reach 2 between more particularly between fortnightly effects.
This is demonstrated in the second graph for Reach 2 (Figure 14(c)) which has identical points to the first but they are highlighted according to whether they represent the first 5 fortnights of the year or later.

Source	DF	SeqSS	AdjSS	AdjMS	F	P
effort	1	27.99	21.31	21.31	316.20	<0.005
fort	13	1.45	0.65	0.05	0.74	0.71
year	4	26.30	26.30	6.57	97.57	<0.005
Error	51	3.44	3.44	0.07		
Total	69	59.18				

Table 15(a): Analysis of variance for Reach 1

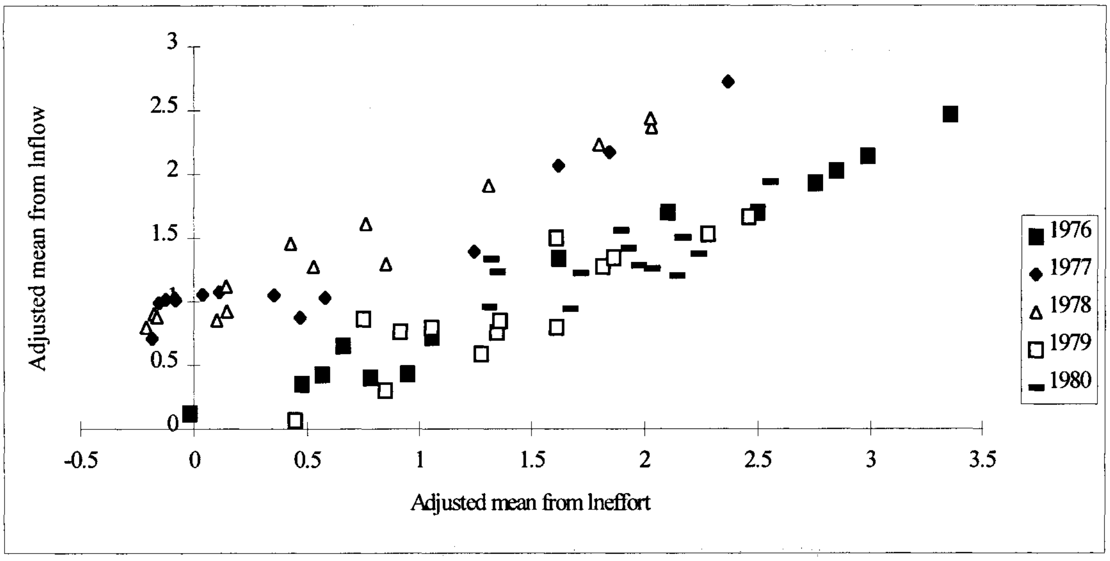


Figure 14(a): Reach 1 comparison of adjusted mean catch from lncatch on lneffort and lncatch on flow

Source	DF	SeqSS	AdjSS	AdjMS	F	P
effort	1	18.88	14.50	14.50	279.40	<0.005
fort	13	14.39	14.39	1.11	21.33	<0.005
year	3	1.11	1.11	0.37	7.13	<0.005
Error	38	1.97	1.97	0.05		
Total	55	36.35				

Table 15(b): Analysis of variance for Reach 2

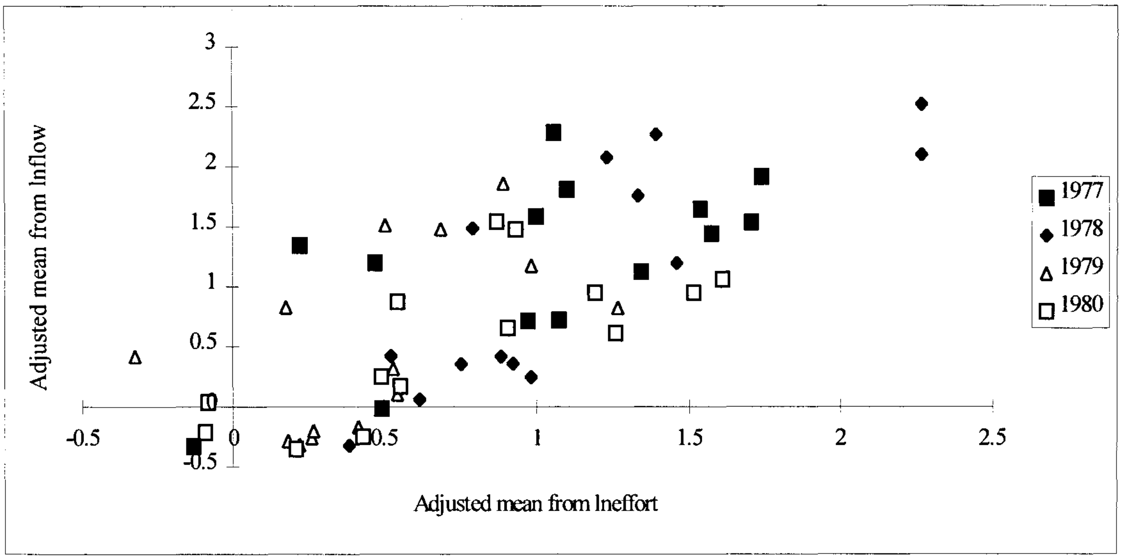


Figure 14(b): Reach 2 comparison of adjusted mean catch from lncatch on lneffort and lncatch on lnflow

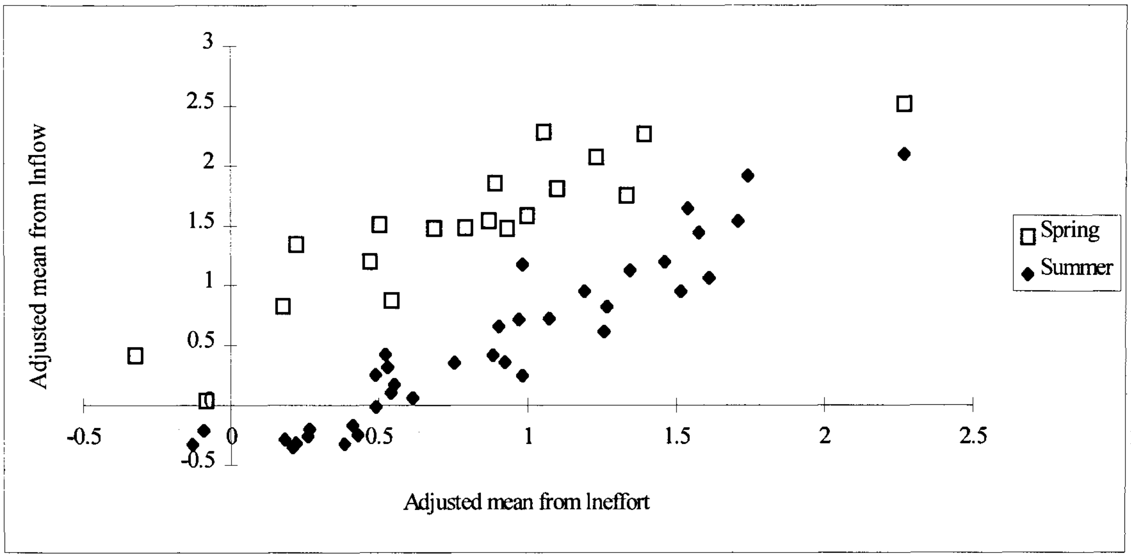


Figure 14(c): Reach 2 comparison of adjusted mean catch from lncatch on lneffort and lncatch on lnflow models

Source	DF	SeqSS	AdjSS	AdjMS	F	P
effort	1	23.69	4.67	4.67	108.86	<0.005
fort	13	1.49	0.81	0.06	1.45	0.21
year	2	3.45	3.45	1.72	40.21	<0.005
Error	25	1.07	1.07	0.04		
Total	41	29.71				

Table 15(c): Analysis of variance for Reach 2

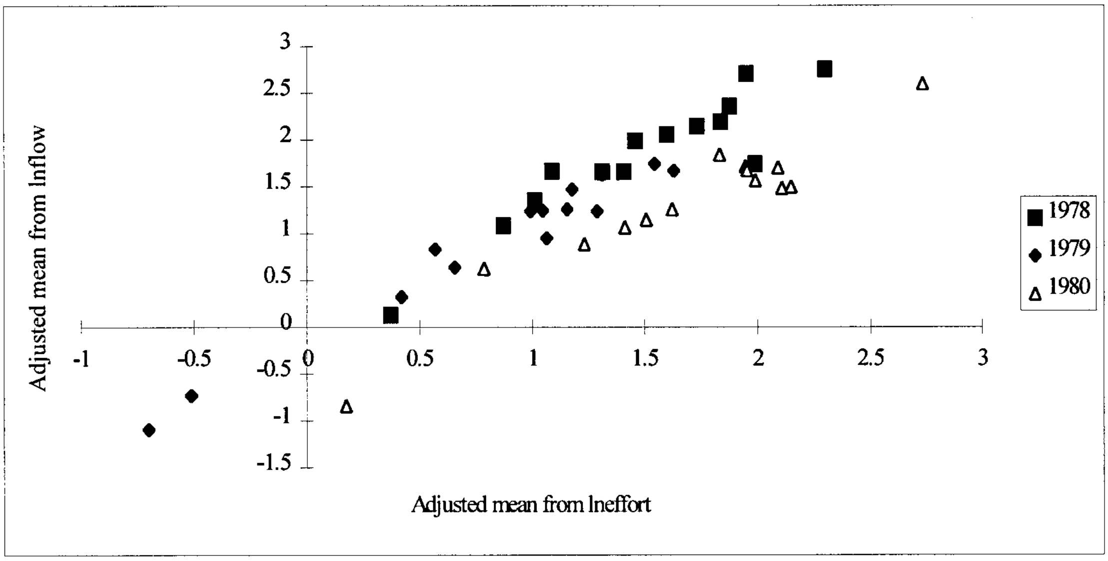


Figure 14(d): Reach 3 comparison of adjusted mean catch from lncatch on lneffort and lncatch on lnflow models

5.6.1 Discussion of the comparison of catch/effort and catch/flow models

The catch/flow model gives rise to adjusted mean catch estimates which are closely correlated with those from the catch/effort model for both Reaches 1 and 3 but there are systematic differences. These are probably due to the fact that the mean level of effort as reported was not applied at the same level of flow in each year or each month and since the graphs are second order in the covariates the adjusted means are not strictly comparable. This is an area which requires further investigation on better data. Therefore as a long term index of availability the adjusted means of one or possibly both models are inadequate.However it is noticeable that for Reach 1 the years 1977 and 1978 are clearly different from the other three years and it may be more than coincidental that these are the two years in which the level of recorded effort was low and possibly the quality of the data is dubious. Moreover for Reach 3 1980 appears to give a substantially different result to the other two years; again it is that year which appears to have a lower level of reporting. Reach 2 is different because there are clear differences on both an annual and fortnightly basis. However when the first five fortnights are plotted using different symbols to those later in the year it is clear that the differences are due to discrepancies in the behaviour of the models between the spring and summer months and it again seems likely that the data may be at fault in that no account has been taken in its collection of potential temporal variation in the quality of effort for local reasons.

Much of this discussion is of necessity speculative but is justified on the grounds that no better data has been available. The object of this exercise is to identify and demonstrate sources of variance so that in the future better data sets may be obtained on which the hypotheses developed here can be tested.

These hypotheses include:

1) Salmon (and probably sea trout) arrive off a river mouth with a reasonably consistent temporal pattern.
2) The subsequent distribution of salmon (and probably sea trout) throughout a river system depends mainly on flow.
3) Most anglers respond to flow because they believe that relatively high flows enhance their chances of success but in the short term (a few days) they may also respond to the success of others and their perception of the presence of catchable fish in the river. Thus effort may be related to recent catch and folklore concerning flow as well as catch to effort.
4) Holiday and weekend anglers have less option to respond in this way and therefore the efficiency of their effort is low compared with local anglers with continuous access to the water.

From these hypotheses it follows that catch is a function of the abundance of salmon in the river at low to moderate flows and may be a function of total abundance at high flows when possibly all available salmon enter the river.

The adjusted mean catches as calculated from the models using this data set do not give rise to comparable indices, but in view of the above comments and the considerable advantages to fishery management, if catch could be corrected for flow to give indices of abundance, it was considered worthwhile to explore the relationship between catch and flow on two data sets from the archive of salmon catch returns. It should be noted at this point that although returns from anglers are required by law the historical data set is essentially voluntary and statistically uncontrolled in its nature.

6.0 THE R.WYE HISTORICAL DATA SET OF SALMON CATCH RETURNS

6.1 INTRODUCTION

Reports of salmon caught on the River Wye differ from other rivers in England and Wales in that the riparian owners rather than individual anglers send in the returns from their particular beats. Since most of the river is run as a number of commercially based recreational fisheries whose rental and capital value depends on the number of fish caught it is generally accepted that these records are more complete and more accurate than the general run of catch returns on other rivers.

Monthly records of catches are available from before 1920 to 1991 and are reported in the River Wye annual reports by month and weight according to five different areas of the river as follows:-

1) Below Ross on Wye
2) Hereford to Ross
3) Hay to Hereford
4) Builth Wells to Hay
5) Above Builth Wells.

The returns have been examined in terms of variation in their absolute magnitude between reaches and in terms of the proportion taken on the lowest reach.

6.2 DISTRIBUTION OF CATCH

Since the monthly mean flows throughout the gauging stations on the main stem of the Wye appear to be very highly correlated, differing only in magnitude. Flow measurements from the Erwood gauging station were used to examine the effect of flow on the distribution of catches in the river system. As flow is log normally distributed, natural logarithms were taken and used as one independent variable in an analysis of covariance. Since the relationship appeared to be curvilinear the square of that variable ($logflow^2$) was taken as the second. The independent variable was the arcsin of the proportion of the monthly catch reported below Ross on Wye. Virtually complete data were available from the period 1944 to 1991.

6.2.1 Results

A plot of the proportion of the salmon rod catch taken below Ross on Wye against Lnflow demonstrates convincingly the effect of flow on the distribution of catch (see Figure 15(a))

Figure 15(a): Proportion of salmon rod catch taken below Ross on Wye against lnflow

The Analysis of Covariance (ANCOVA) (see Table 16) confirms the significance of the relationship and tests whether there are differences between months and years.

Source	DF	SeqSS	AdjSS	AdjMS	F	P
lnflow	1	20.88	1.38	1.38	43.73	<0.005
$lnflow^2$	1	1.41	0.46	0.46	14.70	<0.005
year	47	7.86	8.15	0.17	5.50	<0.005
month	8	2.32	2.32	0.29	9.20	<0.005
Error	356	11.23	11.23	0.03		
Total	413	43.70				

Term	Coeff	Stdev	t-value	P
Constant	1.44	0.11	13.07	<0.005
lnflow	-0.50	0.07	-6.61	<0.005
$lnflow^2$	0.05	0.01	3.83	<0.005

Table 16: Analysis of Covariance for catch and flow

The relationship between catch and flow is negative but the slope decreases marginally with increasing mean flow. The two flow variables alone account for 51% of the total sum of squares. There were significant differences between months and between years and, since there is no reason to suspect systematic bias in the data, the estimates of their adjusted means (estimates of their values if the flow had been equal to its mean) are shown in Figures 15(b) and 15(c) with confidence intervals (p = 0.01).

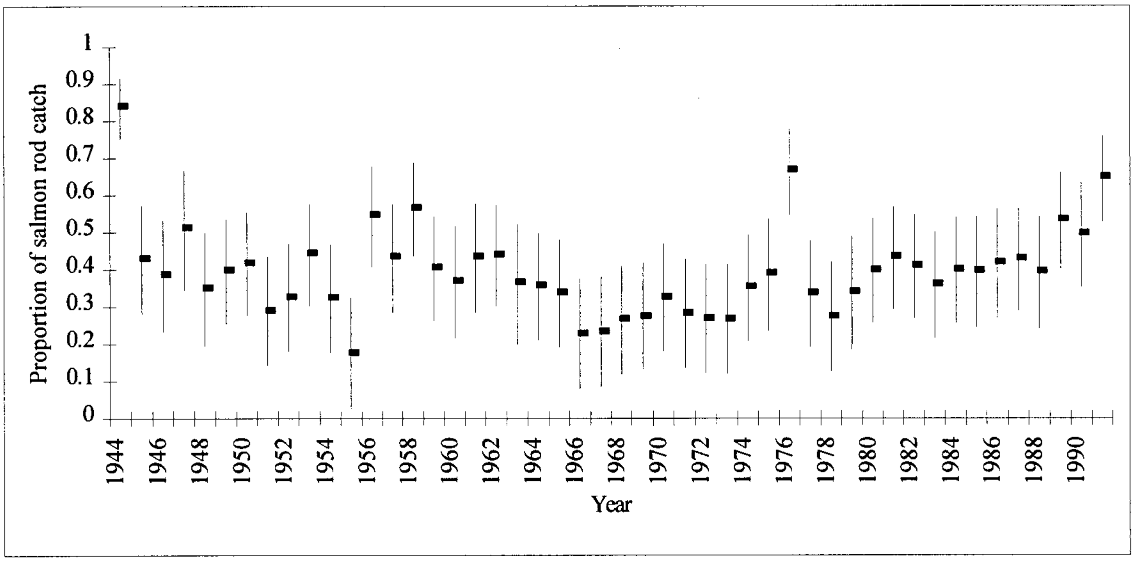


Figure 15(b): Adjusted means from ANCOVA model showing proportion of salmon catch taken below Ross (annually)

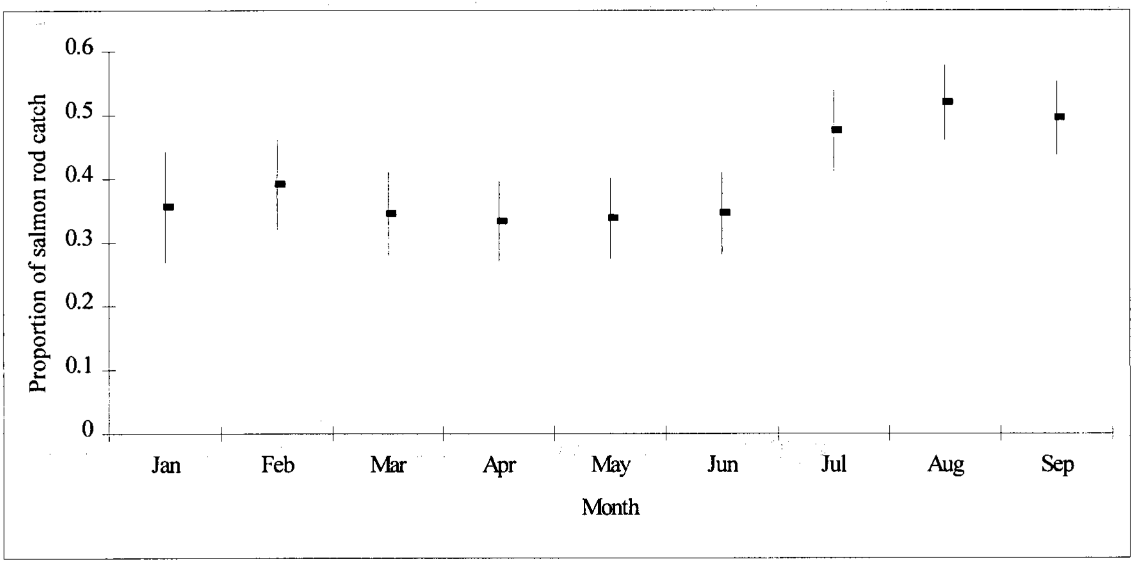


Figure 15(c): Adjusted means from ANCOVA model showing proportion of monthly salmon catch taken below Ross (monthly)

6.2.2 Discussion

A comparison of the annual adjusted means demonstrated few individual differences between years but there is an obvious upward trend starting from somewhere in the mid 1960s. This may reflect a change in the pattern of effort or age class composition. For example, it is known that multi-sea winter fish have declined in the catches during this period and the summer running grilse have increased (Potter and Solomon 1992). If anglers are responding to the presence of fish in the lower part of the river rather than further upstream in the drier summer months this upward trend would be expected. It is also possible that there has been a general redistribution of effort because of the change in age class composition of the run and the recent history of dry years.

There are also significant differences in the adjusted monthly means with July to September being higher than March to June. These differences are more difficult to interpret and while the observed differences could be attributed to differences in behaviour between grilse and multi-sea winter fish a disproportionate increase in effort below Ross over and above that further upriver is also a possibility. There is some correlation between flow and the monthly main effects and between flow and the annual main effects so a basic lack of fit of the model cannot be ruled out at this level of precision. However, the relationship between the proportion of fish caught below Ross and flow is strong regardless of other effects and there can be no doubt that flow affects the annual distribution of catch if not the actual total.

6.3 THE CATCH / FLOW RELATIONSHIP BY REACH

The reported catch from March to October for the top and bottom areas of the river demonstrate that a relationship exists between catch and flow taken from the gauging station at Erwood but the residual variance about any regression line that may be fitted is large and in all probability other factors are involved (see Figures 16(a) - (b)).

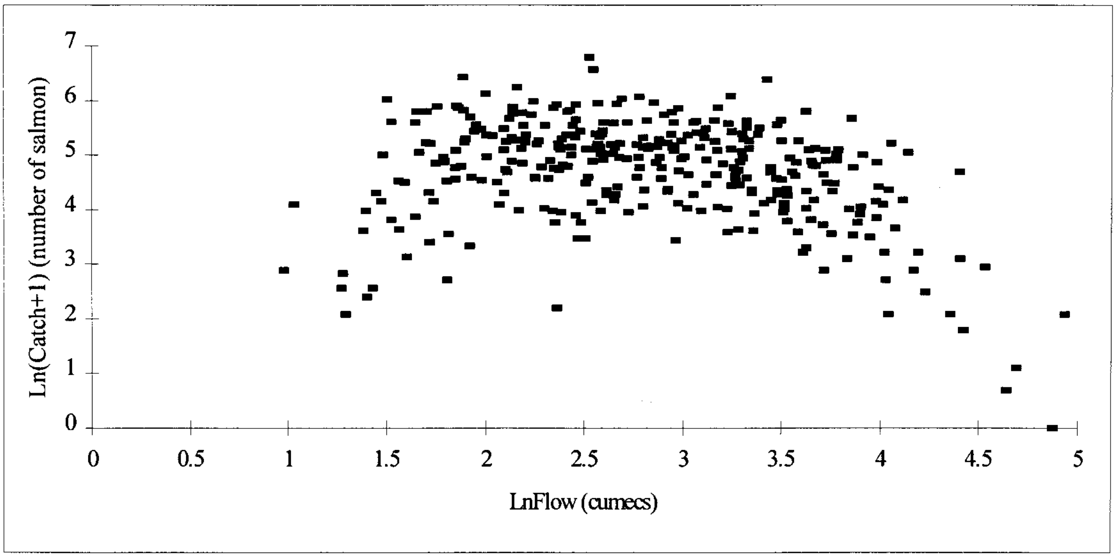


Figure 16(a): R.Wye - Relationship between salmon catch above Buith and flow

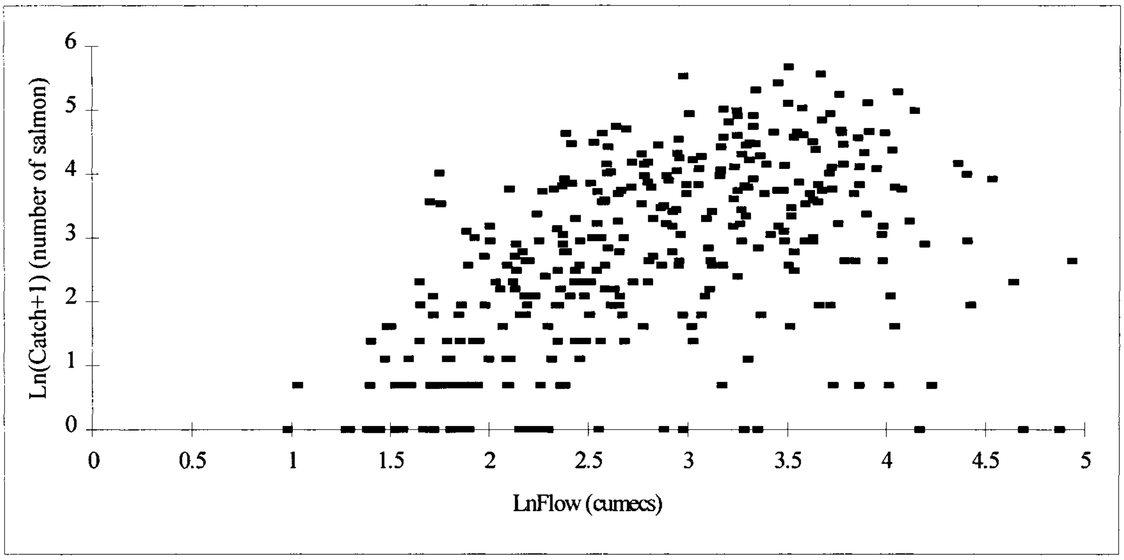


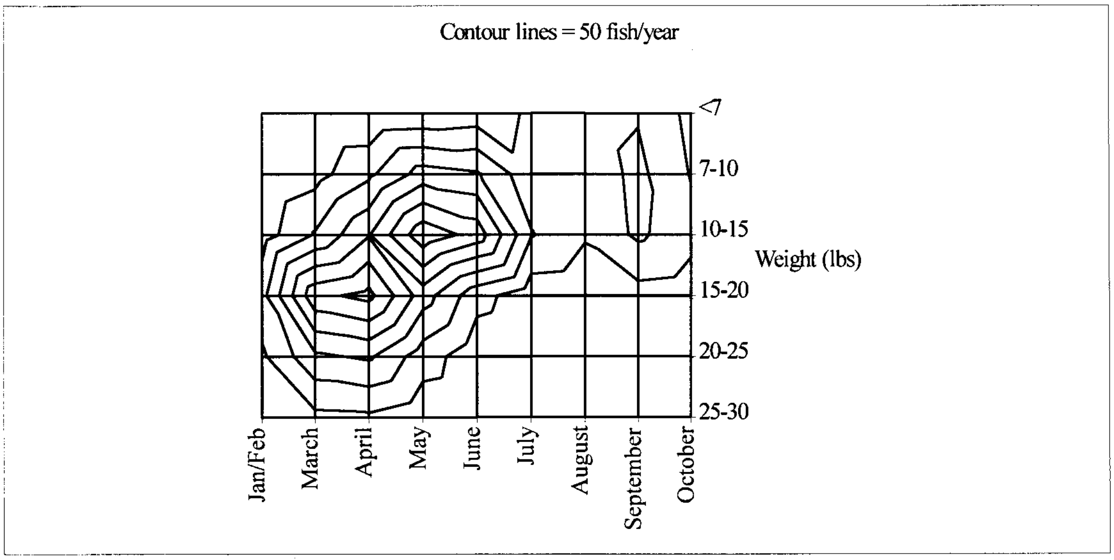
Figure 16(b): R.Wye - Relationship between salmon catch below Ross and flow

An ANCOVA model using lnflow and $(\ln flow)^2$ at Erwood as the covariates was used for modelling the monthly catches for the years 1944 - 1991. Since it was considered likely that the analysis may reflect the difference in run timing of the three major age classes present in the Wye system, three combinations of monthly catches were used:-

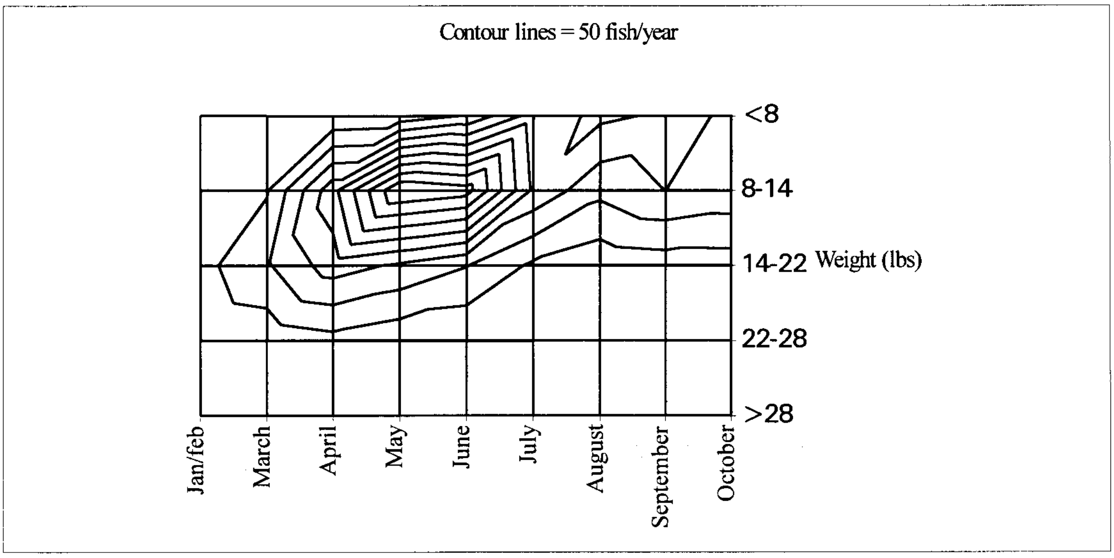
1)	March + April	Corresponding to 3SW
2)	May + June	Corresponding to 2SW
2)	July + August + September	Corresponding to grilse

Such a comparison must be speculative but an examination of the temporal distribution of weights of salmon caught by rod and line revealed a pattern which it was felt supported such a split. Even if these three periods do not reflect the age classes accurately it was felt to be a worthwhile exercise to demonstrate the possibilities of the technique with better data.

Contour graphs presented in Figures 17(a) and 17(b) show the changes in distribution of weight classes before and after 1977 and support the above reasoning despite the fact that the two graphs have different scales for the ordinate due to a change in the recorded size classes at that time.



Figures 17(a): Contour plot of the weight distribution of salmon rod catches for the River Wye (1944-1977)



Figures 17(b): Contour plot of the weight distribution of salmon rod catches for the River Wye (1978-1991)

As a result of an annual effect being meaningless, each season in each year was therefore considered as a main effect in an analysis of covariance. The analysis of variance table (See Table 17) demonstrates the dependence of catches on flow and between areas. The season main effect highlights the combined differences between the three monthly groups as defined and the interaction term demonstrates how these effects vary between the five areas.

Source	DF	SeqSS	AdjSS	AdjMS	F	P
flow	1	460.04	174.36	174.36	289.60	<0.005
flowsq	1	511.55	133.62	133.62	221.93	<0.005
area	4	785.88	743.6	185.9	308.76	<0.005
season	143	1107.18	1107.18	7.74	12.86	<0.005
area*season	572	726.23	726.23	1.27	2.11	<0.005
Error	958	576.79	576.79	0.60		
Total	1679	4167.67				

Table 17: Analysis of variance of catches on flows

The model accounts for 86% of the total sum of squares and all terms were very highly significant but the correlation between the adjusted means for the five areas varied and was generally not high although as can be seen from the following matrices (Table 18(a)) of the correlation coefficient the correlation between neighbouring areas was better. The most noticeable deviant figure in each case being that for the lowest area below Ross on Wye.

March/April

	Above Builth	Builth-Hay	Hay-Hereford	Hereford-Ross	Below Ross
Above Builth	1				
Builth-Hay	0.76	1			
Hay-Hereford	0.75	0.93	1		
Hereford-Ross	0.67	0.86	0.86	1	
Below Ross	0.28	0.34	0.30	0.59	1

May/June

	Above Builth	Builth-Hay	Hay-Hereford	Hereford-Ross	Below Ross
Above Builth	1				
Builth-Hay	0.83	1			
Hay-Hereford	0.74	0.80	1		
Hereford-Ross	0.46	0.47	0.68	1	
Below Ross	-0.39	-0.33	-0.13	0.26	1

July/September

	Above Builth	Builth-Hay	Hay-Hereford	Hereford-Ross	Below Ross
Above Builth	1				
Builth-Hay	0.86	1			
Hay-Hereford	0.84	0.78	1		
Hereford-Ross	0.66	0.63	0.72	1	
Below Ross	0.35	0.35	0.55	0.73	1

Table 18(a): Correlation coefficients between adjusted means for each area by season (p=0.01 r=0.25)

The adjusted means for each area by season could not be considered to be the most economical presentation of the data so a Principal Components Analysis was carried out on the adjusted means with the following results (Table 18(b)).

March/April

	PC1	PC2	PC3	PC4	PC5
Eigenvalue	3.6399	0.8704	0.3358	0.0913	0.0625
Proportion	0.728	0.174	0.067	0.018	0.013
Cumulative	0.728	0.902	0.969	0.987	1

Variable	PC1	PC2
Above Builth	0.437	-0.26
Builth-Hay	0.497	-0.189
Hay-Hereford	0.491	-0.246
Hereford-Ross	0.494	0.162
Below Ross	0.276	0.9

May/June

	PC1	PC2	PC3	PC4	PC5
Eigenvalue	3.0667	1.2992	0.2978	0.2043	0.1319
Proportion	0.613	0.26	0.06	0.041	0.026
Cumulative	0.613	0.873	0.933	0.974	1

Variable	PC1	PC2
Above Builth	-0.518	0.177
Builth-Hay	-0.528	0.123
Hay-Hereford	-0.527	-0.143
Hereford-Ross	-0.385	-0.553
Below Ross	0.166	-0.792

July/September

	PC1	PC2	PC3	PC4	PC5
Eigenvalue	3.6227	0.874	0.22	0.1739	0.1093
Proportion	0.725	0.175	0.044	0.035	0.022
Cumulative	0.725	0.899	0.943	0.978	1

Variable	PC1	PC2
Above Builth	-0.468	-0.394
Builth-Hay	-0.456	-0.398
Hay-Hereford	-0.486	-0.104
Hereford-Ross	-0.46	0.327
Below Ross	-0.353	0.754

Table 18(b): Eigenanalysis of the Correlation Matrix

In each case only those Principal Components (PC1 and PC2) accounting for more than 10% of the variance were considered accounting between them for 90%, 87% and 90% respectively of the variance of which the first eigenvalues accounted for 73%, 61% and 73%. In all three cases the first principal component appeared to represent a weighted average of all five areas and could therefore be considered as an overall measure of availability while the second component clearly contrasted upper and lower areas. The scores for the first principal component are in Figure 18(a).

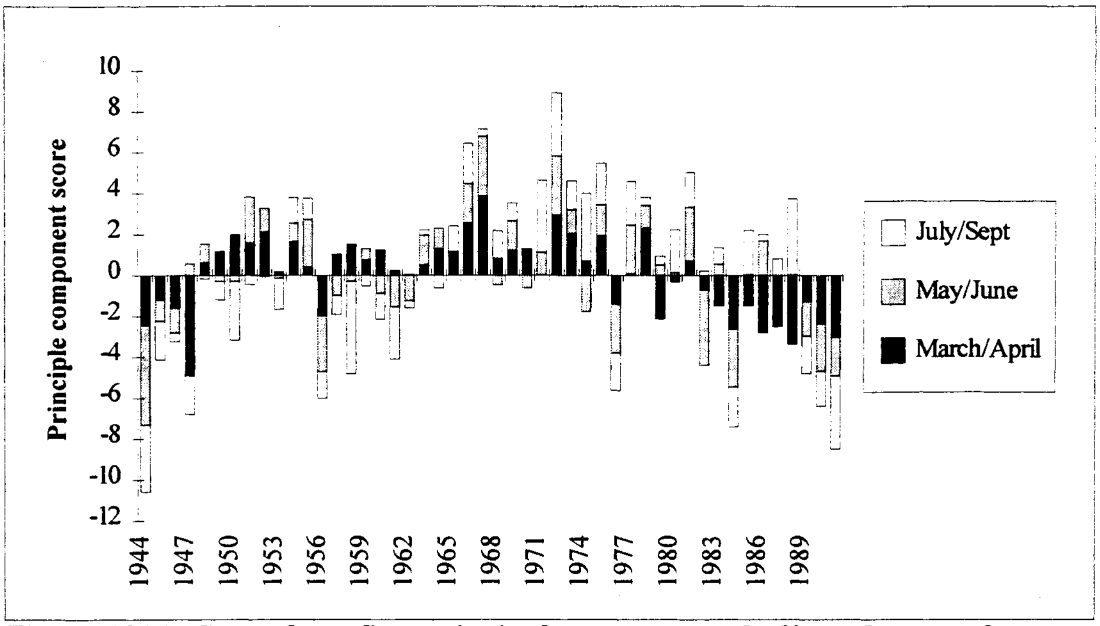


Figure 18(a): Score from first principal component of adjusted means from ANCOVA on the five Wye areas

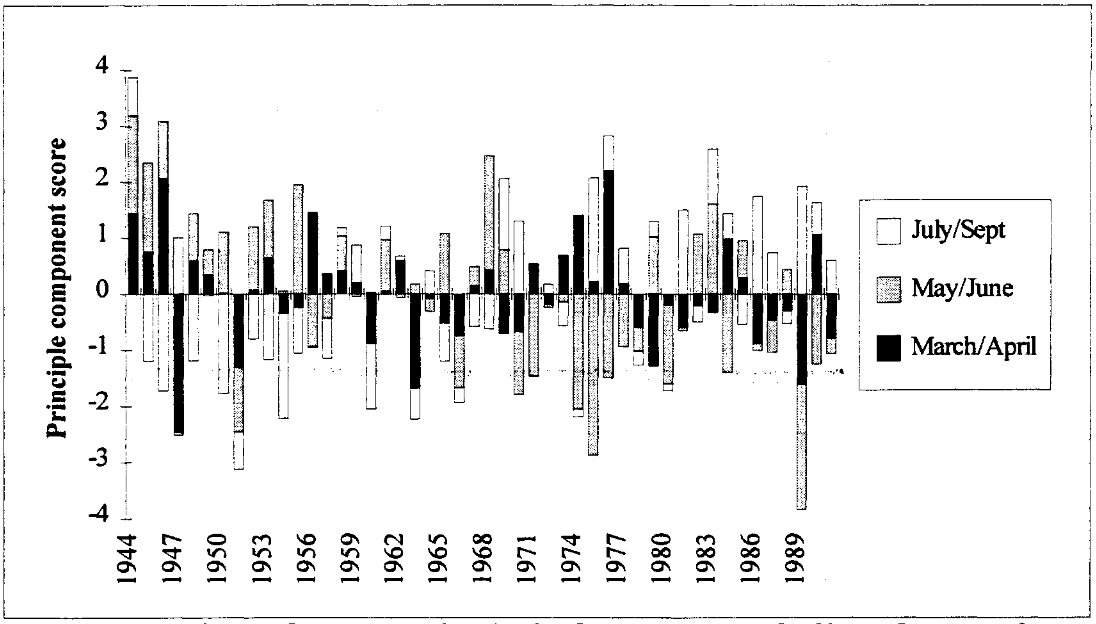


Figure 18(b): Score from second principal component of adjusted means from ANCOVA on the five Wye areas

A similar chart for the second component, (see Figure 18(b) demonstrates the shift in catches from the spring to the autumn during the period examined. However, for the three seasons respectively the scores are negatively correlated with the mean flows for those periods. The respective correlation coefficients being -0.87, -0.60 and -0.60 thus despite the presence of flow as a covariate in the model it appears that flow remains a source of variance between the adjusted means catches for each area. This may be due to the use of only one source of flow data but the possibility that the original ANCOVA model did not account for all the effect of flow cannot be discounted. An improvement in the model would probably be achieved by using flow data from gauges in each area or alternatively rearranging the model so that flow is nested within the area effects to give a different flow equation for each area. Time constraints did not allow this improvement to the model to be tested.

6.4 RELATIONSHIP OF NET CATCH WITH ROD CATCH AND FLOW

Net catches from the River Wye were also examined by the analysis of covariance (ANCOVA) technique but it was apparent that the reported catches had diminished greatly in all months during the time period under examination and that this source of variance swamped all other sources. The likely main cause of this decline was a diminution of effort. To account for this the data were detrended by expressing each observation for each month as the difference from an eleven year moving average of the natural logarithm of the observations. The same technique was also utilised on the two lowest reporting areas for rod catches in order to allow a comparison between the adjusted means derived from analyses of net and rod catch. This also removes any trend due to variation in the numerical strength of individual age classes but does not remove short term variations due to the effect of flow on catches. The seasons were chosen as before except for the third season which consisted of data from July and August only (see Table 19(a)-(c)).

Source	DF	SeqSS	AdjSS	AdjMS	F	P
flow	1	3.35	0.62	0.62	2.66	0.11
year	35	23.28	22.80	0.65	2.79	<0.001
season	2	0.76	0.34	0.17	0.72	0.49
year*season	70	39.39	39.39	0.56	2.41	0.00
Error	107	25.01	25.01	0.23		
Total	215	91.79				

Term	Coeff	Stdev	t-value	P
Constant	0.39	0.25	1.57	0.12
flow	-0.14	0.09	-1.63	0.11

Table 19(a): Analysis of Variance for net catch

Source	DF	SeqSS	AdjSS	AdjMS	F	P
flow	1	6.98	8.62	8.62	19.36	<0.001
flowsq	1	36.25	8.49	8.49	19.07	<0.001
year	35	45.93	47.08	1.35	3.02	<0.001
season	2	2.41	2.49	1.24	2.79	0.07
year*season	70	56.35	56.35	0.81	1.81	<0.001
Error	106	47.20	47.20	0.45		
Total	215	195.11				

Term	Coeff	Stdev	t-value	P
Constant	-3.33	0.61	-5.47	<0.001
flow	2.91	0.44	6.62	<0.001
flowsq	-0.58	0.08	-7.49	<0.001

Table 19(b): Analysis of Variance for rod catch below Ross

Source	DF	SeqSS	AdjSS	AdjMS	F	P
flow	1	12.25	22.55	22.55	75.53	<0.001
flowsq	1	57.18	20.63	20.63	69.10	<0.001
year	35	48.32	44.71	1.28	4.28	<0.001
season	2	1.55	1.26	0.63	2.11	0.13
year*season	70	43.64	43.64	0.62	2.09	<0.001
Error	106	31.65	31.65	0.30		
Total	215	194.58				

Term	Coeff	Stdev	t-value	P
Constant	-6.48	0.74	-8.76	<0.001
flow	4.63	0.53	8.69	<0.001
flowsq	-0.78	0.09	-8.31	<0.001

Table 19(c): Analysis of Variance for rod catch between Hereford and Ross

The model relating the detrended net catch to flow accounted for 73% of the total sum of squares while those for the detrended rod catch below Ross and between Ross and Hereford accounted for 74% and 85% respectively. Detrended rod catches are influenced by flow and demonstrate a strong second order dome shaped relationship with flow but net catches decrease linearly with increasing flow. However, in the analysis of covariance for net catches, flow did not represent a significant variable because of its contribution to the interaction term. This can be tested by means of an F test on the Sequential Sum of Squares or by regression analysis omitting main effects and the interaction term (see Table 20).

Source	DF	SS	MS	F	P
Regression	1	3.35	3.35	8.09	<0.01
Error	214	88.44	0.41		
Total	215	91.79			

Table 20: Analysis of Variance for regression of net catch on flow

It was expected that the adjusted means for the net catch analysis would be positively correlated with the adjusted means of the rod catches because if net catches increase due to an increase in salmon abundance, unless the cropping by nets exceeds that increase, rod catches will also respond positively. This is because regardless of the exploitation rate of the nets, an increase in total population will still give an increase in population above the nets if the exploitation rate does not increase with the population. The following matrix of correlation coefficients (Table 21) demonstrates this, but the correlation coefficients between the adjusted means for the net catch and the adjusted means for the rod catch below Ross were not large and significance levels correspondingly low (R = 0.32 at p = .05, R = .41 at p = 0.01).

	n1	r1	h1	n2	r2	h2	n3	r3	h3
n1	1.00								
r1	0.37	1.00							
h1	0.26	0.54	1.00						
n2	0.32	0.25	0.15	1.00					
r2	-0.08	-0.07	0.02	0.47	1.00				
h2	0.02	-0.21	0.47	0.16	0.39	1.00			
n3	-0.26	0.01	0.04	0.16	0.25	0.09	1.00		
r3	-0.18	-0.11	0.03	0.16	0.44	0.21	0.32	1.00	
h3	-0.06	-0.21	0.00	-0.28	0.14	0.42	-0.29	0.38	1.00

(n = net, r = below Ross, h = Ross to Hereford, 1 - 3 = March/April, May/June and July/ August respectively)

Table 21: Matrix of correlation coefficients for adjusted mean net and rod catches.

For rod catches there were also correlations between neighbouring areas and neighbouring seasons with the exception of the relationship between the March/April and May/June seasons for rod catches below Ross. It should be noted that the relationship between the adjusted means for rod and net catches is positive.

This relationship can also be demonstrated by introducing the detrended net catch into an analysis of covariance of the detrended rod catch below Ross. In summary, (Table 22) using the net catch as a covariate is not significant. The interaction term accounts for the variance attributed to the "net" covariate and if a test of significance is carried out on the Sequential Sum of squares then a significance level of less than 0.01 is obtained.

Source	DF	SeqSS	AdjSS	AdjMS	F	P
flow	1	5.27	9.22	9.22	46.58	<0.001
flowsq	1	43.86	11.59	11.59	58.58	<0.001
Net	1	6.85	0.71	0.71	3.58	0.06
year	35	11.89	11.53	0.33	1.66	0.03
season	2	2.50	2.14	1.07	5.41	0.01
year*season	70	18.58	18.58	0.27	1.34	0.09
Error	105	20.78	20.78	0.20		
Total	215	109.73				

Term	Coeff	Stdev	t-value	P
Constant	-3.45	0.61	-5.69	<0.001
flow	2.97	0.43	6.82	<0.001
flowsq	-0.58	0.08	-7.65	<0.001
Net	0.17	0.09	1.89	0.06

Table 22: Analysis of variance of detrended rod catch below Ross

The model relating the detrended net catch to flow accounted for 73% of the total sum of squares while those for the detrended rod catch below Ross and between Ross and Hereford accounted for 74% and 85% respectively. The latter showed relatively high levels of correlation between their adjusted means but not with those from the net catch model.

The correlation between the adjusted means for net catches and rod catches provides support to the hypothesis that they represent an index of availability, particularly as the response of the two methods of catching salmon to flow are so different. However, as has been demonstrated the correlation between them is low. As the correlation is positive it suggests that both methods of fishing are taking a percentage of the same stock. However, it can be shown that the difference between the adjusted means for nets and rods below Ross is strongly and negatively correlated with the actual net catch. in addition, the adjusted means for rods below Ross and between Hereford and Ross are similarly but less well correlated (see Table 23(a) and 23(b)):-

Source	DF	ADJ	SS	MS	F
Net catch	1	15.72	15.72	103.33	0.00
season	2	1.02	0.51	3.35	0.04
Error	104	15.82	0.15		
Total	107	32.53			

Covariate	Coeff	Stdev	t-value	P
Net catch	-0.69	0.07	-10.16	<0.001

Table 23(a): Analysis of Covariance for difference of adjusted means (Ross - Nets)

Source	DF	ADJ	SS	MS	F
Below Ross	1	3.51	3.51	10.10	0.00
season	2	6.01	3.00	8.64	0.00
Error	104	36.14	0.35		
Total	107	45.70			

Covariate	Coeff	Stdev	t-value	P
Below Ross	-0.31	0.10	-3.18	<0.001

Table 23(b): Analysis of Covariance for difference of adjusted means (Hereford to Ross - Below Ross)

The apparently obvious conclusion that such a negative relationship between contiguous catching areas on the river demonstrates a reduction in stock by exploitation on the lower beat, can also be interpreted as a simple difference in availability due to the fish not reaching the higher beat. If the numbers of fish in each beat are related to the overall abundance and their distribution between the two beats is affected by flow then a negative correlation will follow.

A worked example using Minitab with ANCOVA techniques to determine the effect of flow on salmon rod catch for the River Ribble is presented in Appendix 3.

7.0 THE NW HISTORICAL DATA SET OF SALMON CATCH RETURNS

7.1 INTRODUCTION

Although several rivers can be analysed in the same model almost inevitably amongst those considered to be salmon rivers the larger rivers have larger catches and generally larger flows (Schaffer and Elson 1975). Therefore the differential between catches on different rivers is confounded with the effect of flow and accuracy in the separation of the flow effect and the difference between rivers is lost. In this study the rivers chosen were the first four for which flow information became available (River Derwent, River Hodder, River Lune and River Ribble). There was no obvious point on the temporal scale where a division could be made between predominantly grilse and predominantly 2SW salmon so the seasons have not been split to give annual effects corresponding to grilse and MSW salmon. The adjusted means for months and years are shown with confidence intervals of p= 0.01 in Figures 19(a)-(f).

7.2 RESULTS

7.2.1 Analysis of the effect of flow on catch

Analysis of variance was undertaken for the effects of flow on catch. The results from these analyses are presented in Tables 24(a) - (d).

R.Derwent

Source	DF	SeqSS	AdjSS	AdjMS	F	P
lnflow	1	122.22	5.27	5.27	17.45	<0.001
lnflowsq	1	0.40	1.57	1.57	5.18	0.03
month	4	51.40	48.97	12.24	40.51	<0.001
year	12	12.29	12.29	1.02	3.39	<0.001
Error	46	13.90	13.90	0.30		
Total	64	200.21				

Term	Coeff	Stdev	t-value	P
Constant	0.72	0.55	1.30	0.20
lnflow	1.88	0.45	4.18	<0.001
lnflowsq	-0.21	0.09	-2.28	0.03

Table 24(a): Analysis of variance for the effect of flow on catches for the River Derwent

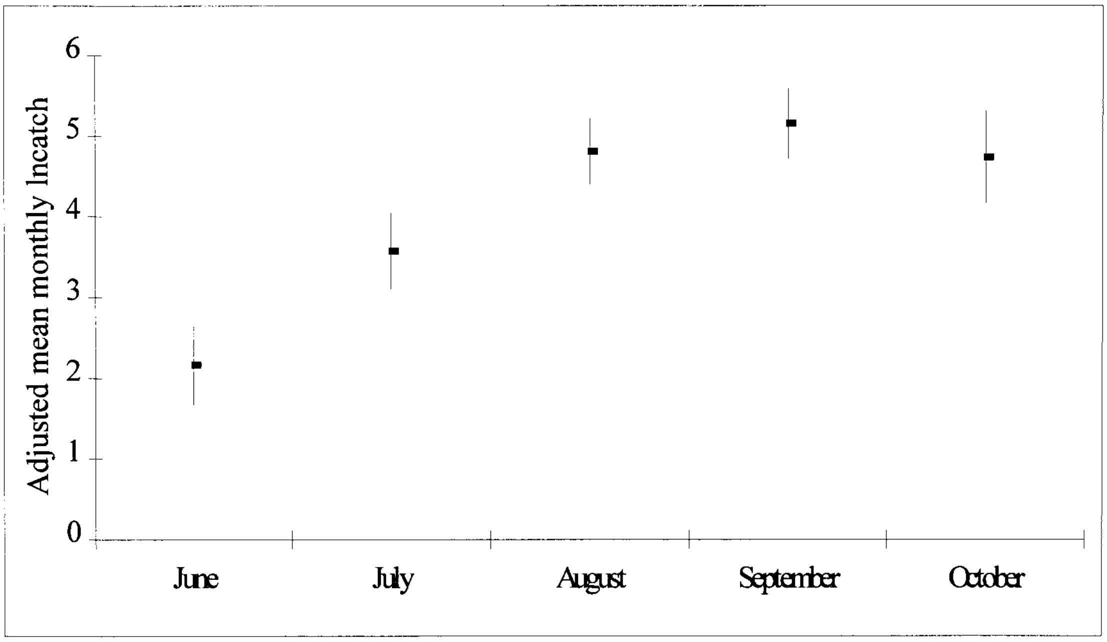


Figure 19(a): R. Derwent - Monthly mean catches adjusted to mean flow for period 1978-1990

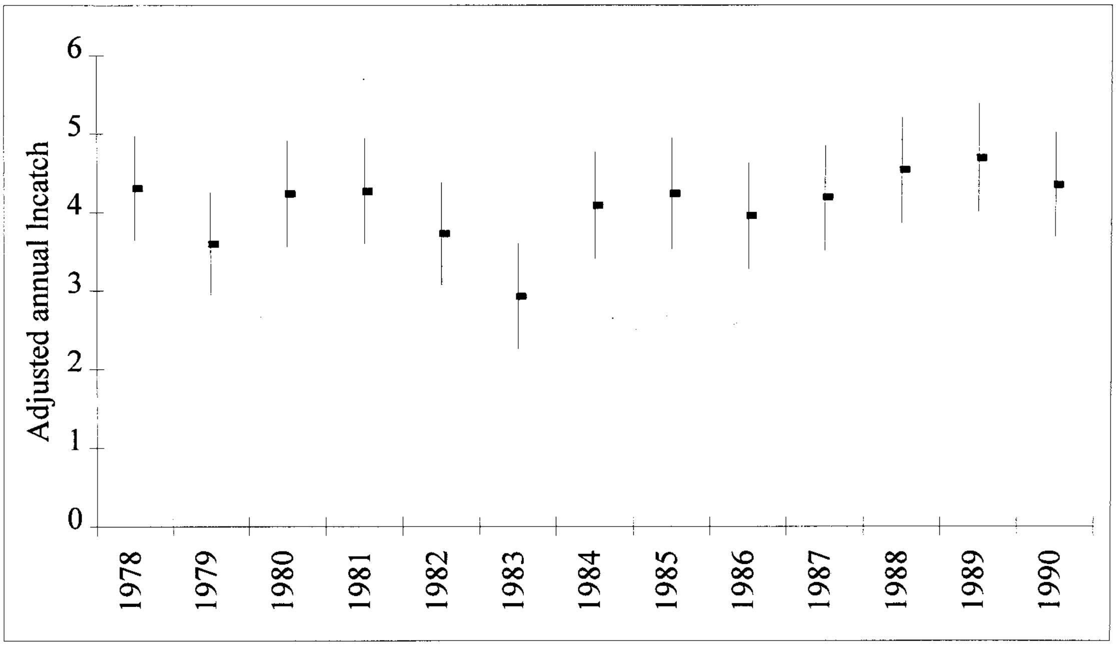


Figure 19(b): R.Derwent- Annual catches adjusted to mean flow for period 1978-1990

R.Hodder

Source	DF	SeqSS	AdjSS	AdjMS	F	P
lnflow	1	82.16	1.35	1.35	3.46	0.07
lnflowsq	1	1.31	0.21	0.21	0.53	0.47
month	4	37.97	39.88	9.97	25.55	<0.001
year	12	6.85	6.85	0.57	1.46	0.17
Error	46	17.95	17.95	0.39		
Total	64	146.23				

Term	Coeff	Stdev	t-value	P
Constant	1.49	0.29	5.12	<0.001
lnflow	0.66	0.36	1.86	0.07
lnflowsq	-0.08	0.11	-0.73	0.47

Table 24(b): Analysis of variance for the effect of flow on catches for the River Hodder

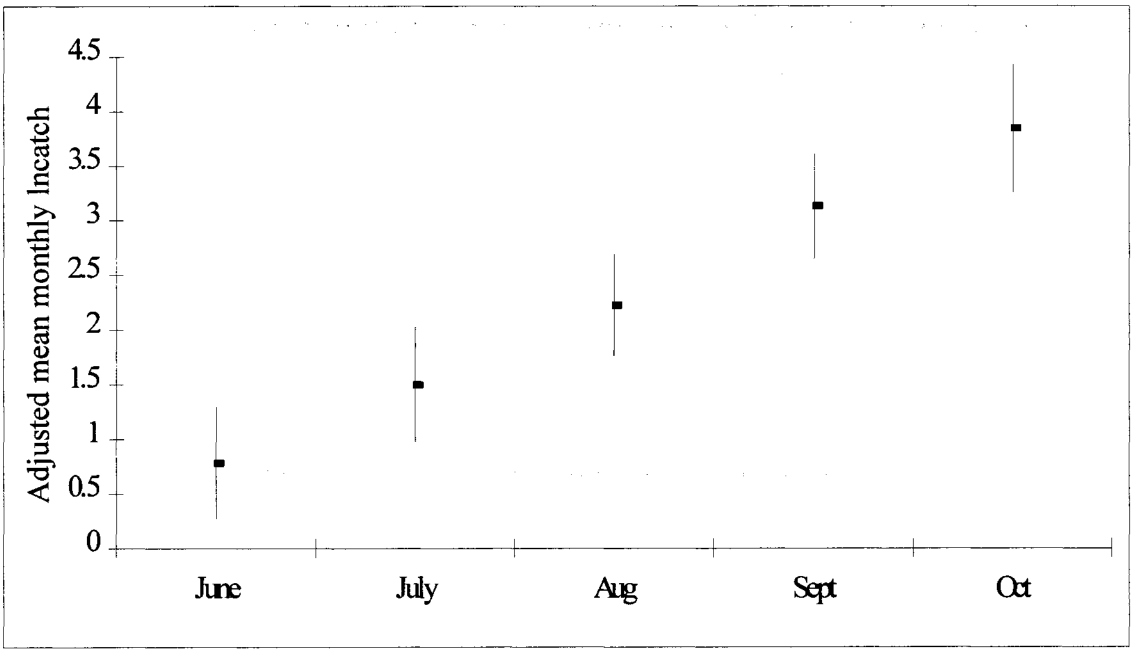


Figure 19(c): R.Hodder- Monthly mean catches adjusted to mean flow for period 1978-1990

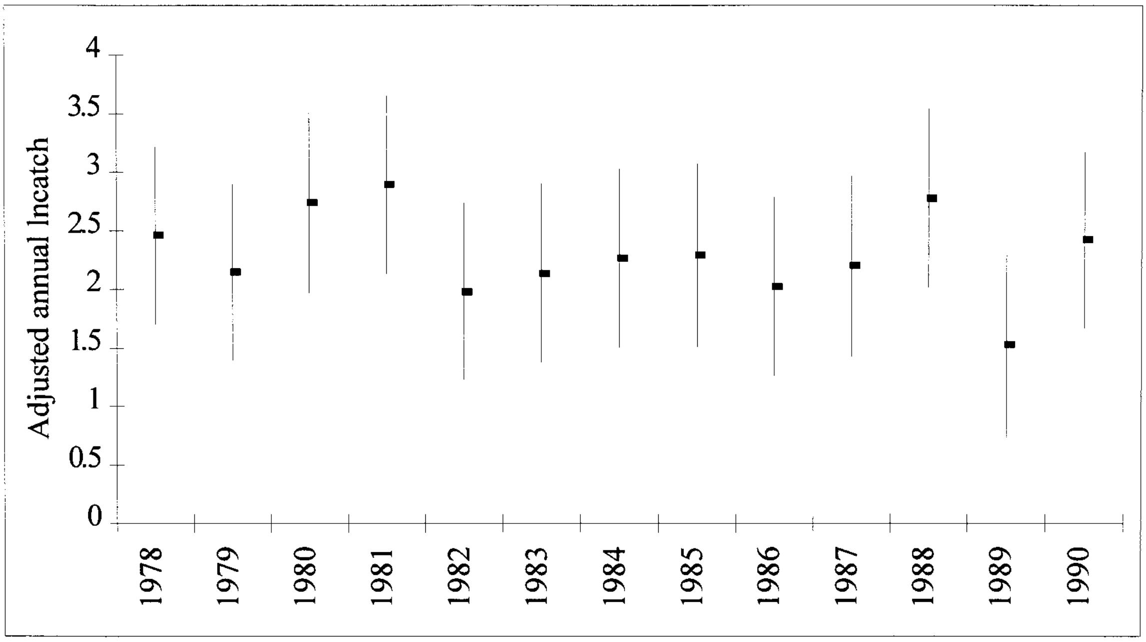


Figure 19(d): R.Hodder - Annual catches adjusted to mean flow for period 1978-1990

R.Lune

Source	DF	SeqSS	AdjSS	AdjMS	F	P
lnflow	1	99.66	4.86	4.86	17.32	<0.001
lnflowsq	1	0.12	2.10	2.10	7.49	0.01
month	4	47.92	45.22	11.30	40.29	<0.001
year	12	24.35	24.35	2.03	7.23	<0.001
Error	46	12.90	12.90	0.28		
Total	64	184.96				

Term	Coeff	Stdev	t-value	P
Constant	0.20	0.64	0.31	0.76
lnflow	2.06	0.49	4.16	<0.001
lnflowsq	-0.25	0.09	-2.74	0.01

Table 24(c): Analysis of variance for the effect of flow on catches for the River Lune

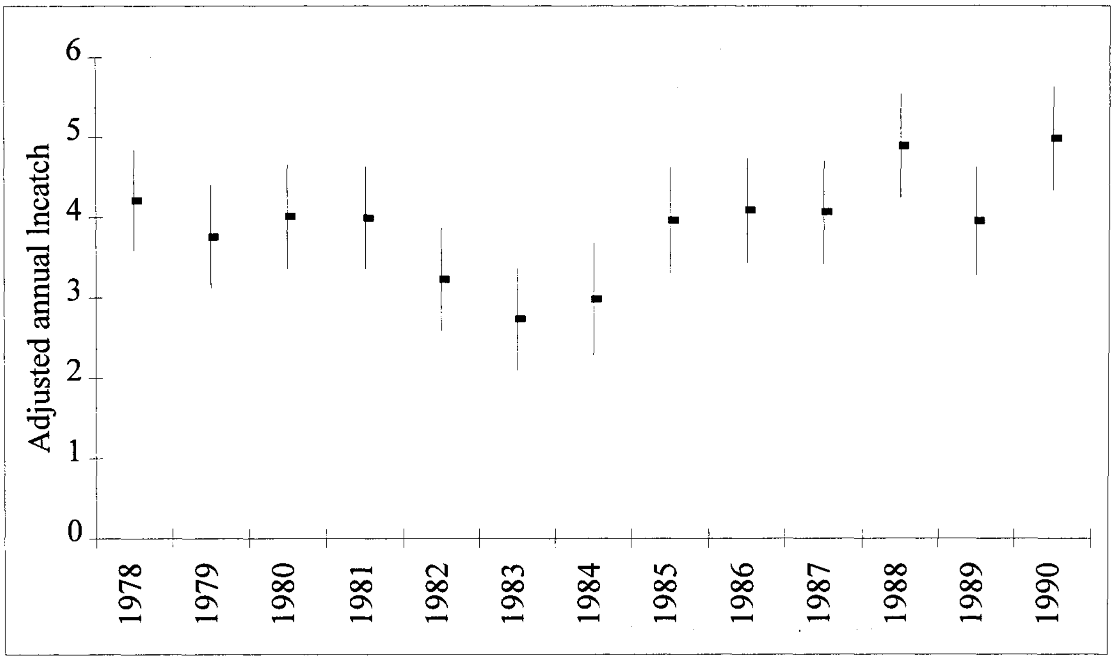


Figure 19(e): R.Lune - Annual catches adjusted to mean flow for period 1978-1990

River Ribble

Source	DF	SeqSS	AdjSS	AdjMS	F	P
lnflow	1	61.88	2.77	2.77	20.72	<0.001
lnflowsq	1	0.08	0.79	0.79	5.94	0.02
month	4	26.85	28.77	7.19	53.87	<0.001
year	12	10.37	10.37	0.86	6.47	<0.001
Error	46	6.14	6.14	0.13		
Total	64	105.33				

Term	Coeff	Stdev	t-value	P
Constant	2.50	0.18	13.57	<0.001
lnflow	0.94	0.21	4.55	<0.001
lnflowsq	-0.14	0.06	-2.44	0.02

Table 24(d): Analysis of variance for the effect of flow on catches for the River Ribble

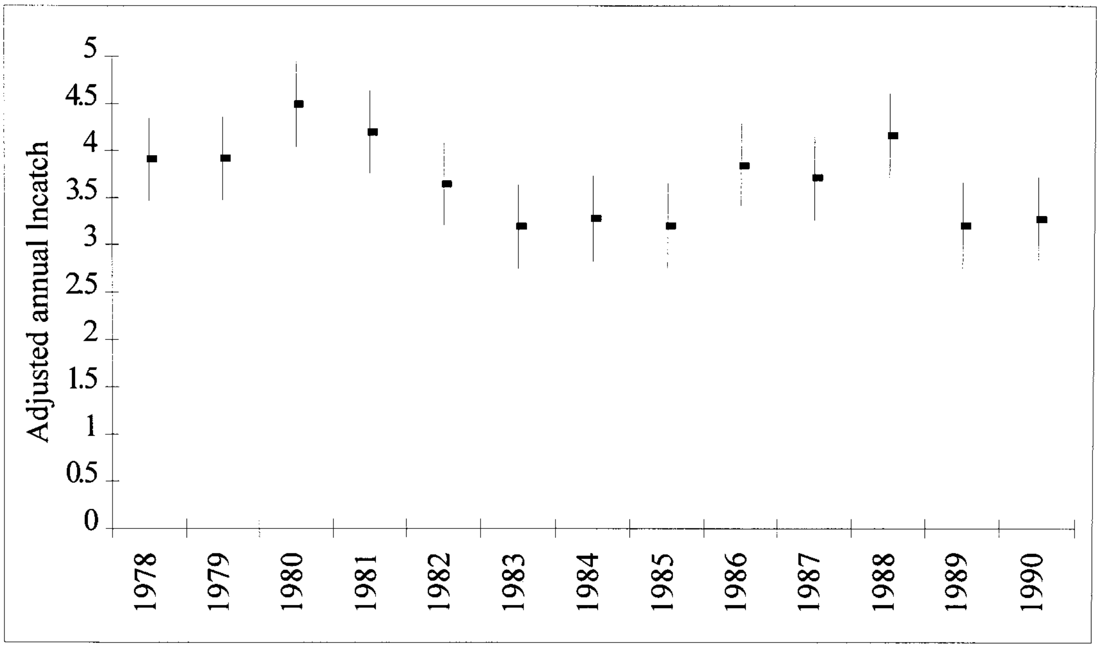


Figure 19(f): R. Ribble - Annual catches adjusted to mean flow for period 1978-1990

Aprahamian and Ball (1995) noted that the catch/flow relationship on the Derwent breaks down in the Autumn. This observation has been tested on all 4 rivers using a nested model which fits a different first order equation for each month. The following Analysis of Covariance (see Table 25(a) - (d)) supports this observation in each case and appear to fit the data as well as the crossed models. However it should be noted that data which can be described by a second order equation can also be described by a series of first order equations when each is fitted over a restricted range of the independent variable. In this case, the mean flows (the independent variable) cover a different part of the second order equation and therefore when the effect of flow is calculated for each month independently a different slope is obtained. Consequently, it is possible that in the autumn flows are such that the second order equation is nearing a maximum turning point. This results in no discernible relationship between catch and flow.

It is also apparent that the contribution of lnflow in the nested model is small compared with that in the crossed model but in contrast the monthly effect is large reflecting the fact that the effect of flow is confounded within the monthly effect (i.e. the differences between months are due to the difference in flow in those months). Thus the nested model in particular should be used with care and is probably not appropriate.

7.2.2 Analysis of Variance for lncatch

R.Derwent

Source	DF	SeqSS	AdjSS	AdjMS	F	P
year	12	22.69	10.45	0.87	3.03	<0.001
month	4	148.14	8.99	2.25	7.82	<0.001
lnflow(month)	5	17.03	17.03	3.41	11.85	<0.001
Error	43	12.36	12.36	0.29		
Total	64	200.21				

Term		Coeff	Stdev	t-value	P
Constant		2.3546	0.47	5.00	<0.001
lnflow(month)					
	June	0.90	0.25	3.52	<0.001
	July	1.28	0.24	5.43	<0.001
	Aug	0.98	0.20	4.82	<0.001
	Sept	0.20	0.33	0.60	0.55
	Oct	0.27	0.47	0.56	0.58

Table 25(a): Analysis of Variance for lncatch for River Derwent

R.Ribble

Source	DF	SeqSS	AdjSS	AdjMS	F	P
year	12	20.23	10.56	0.88	6.15	<0.001
month	4	72.43	7.10	1.77	12.41	<0.001
lnflow(month)	5	6.52	6.52	1.30	9.11	<0.001
Error	43	6.15	6.15	0.14		
Total	64	105.33				

Term		Coeff	Stdev	t-value	P
Constant		2.937	0.18	16.57	<0.001
lnflow(month)					
	June	0.45	0.19	2.43	0.02
	July	0.68	0.14	4.94	<0.001
	Aug	0.52	0.12	4.17	<0.001
	Sept	0.32	0.16	2.01	0.05
	Oct	0.19	0.22	0.86	0.39

Table 25(b): Analysis of Variance for lncatch for River Ribble

R.Lune

Source	DF	SeqSS	AdjSS	AdjMS	F	P
year	12	40.05	20.94	1.75	5.88	<0.001
month	4	116.62	7.66	1.91	6.46	<0.001
lnflow(month)	5	15.53	15.53	3.11	10.48	<0.001
Error	43	12.75	12.75	0.30		
Total	64	184.96				

Term	Coeff	Stdev	t-value	P
Constant	2.1021	0.41	5.16	<0.001
lnflow(month)				
June	0.77	0.26	3.00	<0.001
July	0.79	0.19	4.13	<0.001
Aug	1.00	0.18	5.59	<0.001
Sept	0.30	0.23	1.32	0.19
Oct	0.35	0.40	0.87	0.39

Table 25(c): Analysis of Variance for lncatch for River Lune

R.Hodder

Source	DF	SeqSS	AdjSS	AdjMS	F	P
year	12	15.17	6.36	0.53	1.69	0.10
month	4	109.55	7.03	1.76	5.60	<0.001
lnflow(month)	5	8.01	8.01	1.60	5.10	<0.001
Error	43	13.51	13.51	0.31		
Total	64	146.23				

Term	Coeff	Stdev	t-value	P
Constant	1.8423	0.25	7.39	<0.001
lnflow(month)				
June	-0.55	0.33	-1.66	0.10
July	0.62	0.25	2.52	0.02
Aug	0.85	0.24	3.63	<0.001
Sept	0.74	0.23	3.15	<0.001
Oct	-0.20	0.36	-0.56	0.58

Table 25(d): Analysis of Variance for lncatch for River Hodder

The crossed model was also tested for the River Derwent using the data from June to August only as these were the months that showed significant differences in the full model. Inclusion of the square of the lnflow covariate did not affect the model and so was omitted but the model accounted for 95% of the total sum of squares (see Table 26).

River Derwent

Source	DF	SeqSS	AdjSS	AdjMS	F	P
lnflow	1	20.74	3.74	3.74	33.63	<0.001
year	12	9.80	10.82	0.90	8.11	<0.001
month	2	12.75	12.75	6.37	57.31	<0.001
Error	23	2.56	2.56	0.11		
Total	38	45.84				

Term	Coeff	Stdev	t-value	P
Constant	2.17	0.14	15.00	<0.001
lnflow	0.50	0.09	5.80	<0.001

Table 26: Analysis of variance for catch and lnflow for River Derwent (June-August only)

A plot (Figure 20) of the actual catch for June to August against the adjusted means from the model(with p = 0.05 confidence intervals), when transformed back to the actual figures, demonstrates the difference achieved by correcting for flow.

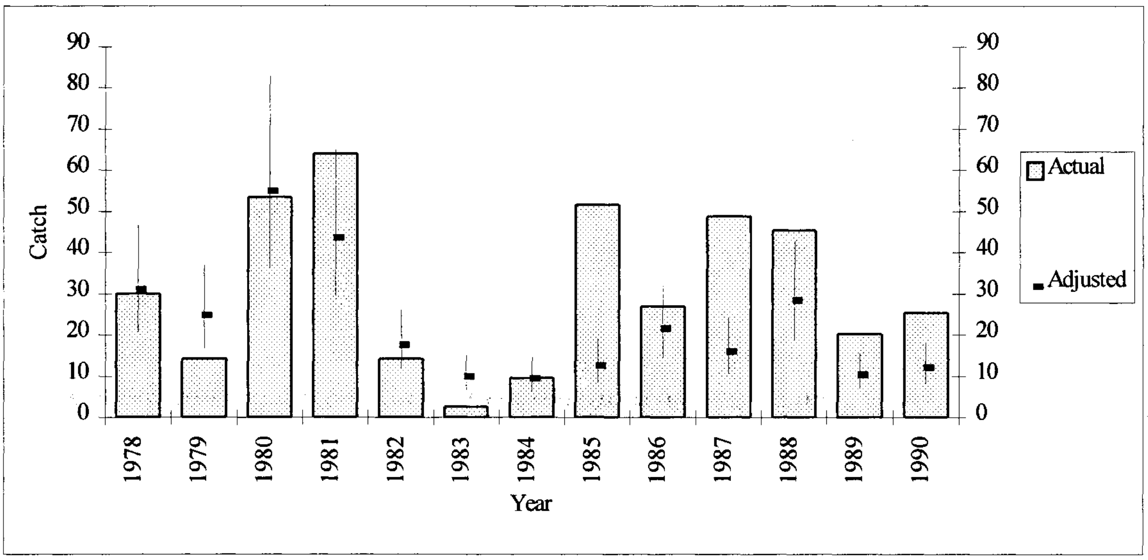


Figure 20: R. Derwent - Comparison of June - August catch before and after adjustment for flow

7.3 DISCUSSION

Examination of salmon catches from the rivers Derwent, Hodder, Ribble and Lune demonstrated strong relationships between monthly catch and mean monthly flow for all four rivers. It is not known if angling effort on these rivers was correlated with flow but in view of the observed behaviour of anglers on the River Wye and the evidence given to anglers by the angling literature it is a reasonable assumption that anglers on these four rivers were successfully selecting times when salmon where plentiful and catchable. If this is the case, unadjusted monthly catch returns are almost certainly a valid measure of abundance in the river.

In theory the model could be used for calculating probable catch levels under a variety of flow conditions but it must be remembered that in such a calculation it is assumed that the monthly effect will stay constant under different flow conditions. This is certainly not the case because the abundance of salmon in the river will depend on flow.

The breakdown of the relationship in October was alluded to in earlier analyses where it was suggested that flows may be sufficiently high at that time of year to allow a constantly high abundance and catchability of salmon. However, another equally likely possibility has been proposed by Aprahamian (pers. comm) in that during October the majority of salmon and sea trout have entered these river systems and therefore the abundance of fish is high and the anglers fish regardless of conditions.

This angler behaviour is supported by observations made on the residuals from fitting the River Wye effort models. It was noted, particularly on the upper reaches, that after some but not all spates, angling effort and catch rates remained high for several days after flow levels had dropped to levels at which angling success was usually low. No tests were undertaken to determine the frequency of this behaviour or the validity of the observation. In view of Aprahamian's supposition it is considered worth reporting because it may have an important bearing on the estimation of comparative spawning escapement from one year to the next. For example, if it assumed that angling effort in October is always maximised because anglers are targeting an abundance of fish in the river and the catchability of salmon and sea trout remains constant, it follows that in the short term the October catch reflects spawning escapement and may lead to a relative index of abundance.

The annual indices of abundance (Annual catch adjusted to mean flow) for the four rivers was not compared directly. However, examination of the charts of these indices reveals similarities between the Ribble, Lune and Derwent and possibly the Hodder. The first three are geographically close (the fourth is a tributary to the Ribble) and demonstrate very similar patterns of flow on a monthly basis. As such it is not unexpected that their catches vary similarly but this would not necessarily follow for indices of abundance calculated in this way. This would only occur if, for example, smolts and their subsequent mortality rates varied similarly between the three rivers. It would be reasonable to assume that this should be the case and therefore should be possible to include all three rivers into one ANCOVA model thus allowing interaction terms and the comparison of abundance indices between rivers. Thus there will be wide variation in catches from year to year within the different river systems examined but they will all follow the same pattern unless there are changes in the smolt production between them. This would allow testing of the performance of one river against another and the transfer of targets between a heavily monitored index river and its neighbours.

8.0 CONCLUDING DISCUSSION ON ANALYSIS OF HISTORICAL CATCH STATISTICS AND THE RIVER WYE AND NORTH WEST REGION DATA

8.1 INTRODUCTION

The Agency has a statutory duty to maintain, improve and develop fisheries. Therefore it must know what a particular fishery is yielding in terms of catch. This figure may be totally unrelated to stock, defined as the number of salmon or sea trout returning to that fishery. That figure is important largely for other reasons and in an ideal world would be the basis for regulation of fisheries to achieve maximum yield whether that is defined as catch, income, recreational potential or any other theoretical management concept.

Historically this figure has never been known and in practice may not be calculable or be meaningful in management terms. For example, it is possible to imagine a group of salmon in the sea, comprising a single age class, arriving over a period of time off the estuary of a river. Unless the fish enter the river immediately, (or suffer zero mortality prior to entering the river) the stock that enters the river will be determined by the mortality rate in the sea. Except in the case of netting both variables are outside the control of the Agency. If this argument is extended to a river with an extensive estuary with or without netting it will be seen that the problem becomes even more complex. Thus it would appear that if angling catch reflects the stock returning to a river offshore it is likely to be a happy accident and the best that can be hoped is that angling catch reflects the stock in the river at the time of angling. The work described has demonstrated that much of the variability in catches can be attributed to variation in effort and that this depends to some extent on flow.

A prospective method of estimating indices of abundance has been developed but not tested. This can also be used to demonstrate what might have happened to the catch had the flows been different and to predict the likely effect of reduction in flow due to a proposed abstraction. The method might also be used for the setting of catch targets under different flows.

The method is based on the identification of known sources of variance and in effect correcting the catch data accordingly. It demonstrates that an examination of the raw catch data can be misleading and is not an adequate basis for the setting of targets. Standardisation of data has been used as a tool to aid analysis but has not been highlighted as a primary technique because comparisons have not been made between river systems. If that is required, then standardisation of catch and flow or both may be a necessary part of the method.

8.2 GENERAL MATTERS

The results have been presented throughout this section of report accompanied by comments on their interpretation in order to explain the reasoning for each step of the modelling process but some further discussion is required.

The initial gross examination of the Wye owners effort data indicated that the distribution of angling effort was not identical with the distribution of flow and that with the exception of the lowest beat where a substantial proportion of the effort was recorded at low flows, anglers tended to favour flows near the ADF. Bias is certainly present in the data and has not been removed by the analysis. However, the inferences from the data do not require a high degree of precision, it being sufficient to establish that there are probably differences between the behaviour of anglers between the lowest beat and further upriver and that there are indications that the relationship between effort and flow is probably curvilinear with a maximum point.

A similar investigation of catch and effort was less conclusive. It would appear from the column charts that catch was distributed similarly to effort but there was one notable exception, namely the upper section in the summer months when catch/unit effort was clearly depressed at low and high flows.

The Analysis of Covariance carried out on subsets of the data to minimise bias demonstrated that angling effort regardless of whether it is measured by hours/day or hours/week is related to flow. It also demonstrated that the weekly measure was statistically better to handle as with the longer time scale both variables and catch were nearly normally distributed (after logarithmic transformation) thus obviating more robust Analysis of Variance models. Although it was not attempted with these data due to time limitations, it would seem sensible to repeat this type of analysis using effort measured in days (or visits) because hours as a unit may be unnecessarily precise and less likely to be recorded. Also there is the possibility of the existence of a different behaviour pattern between the holiday angler and the expert. A day ticket angler is likely to fish all day to get his money's worth whereas the local expert with a season ticket is more likely to fish for shorter periods when he judges conditions to be right. It is difficult to foresee how this might affect any analysis and therefore the problem should be explored further.

The investigation of weekday variations in effort was inconclusive despite indications on 'Reach 2', of the River Wye, that effort increased at weekends. On rivers other than the Wye where the angling is less commercial, variations in effort due to variation in angler leisure time may be important and consequently any bulking up of data should take this into account by utilising periods of 7 days or a multiple of 7 days. This will not accommodate bank holidays but with the exception of Easter they usually occur at about the same time each year and consequently from year to year like will be compared with like.

The Effort/flow analysis highlighted the problems of colinearity between certain times of year and flow. For instance spring and autumn tend to provide higher flows than summer and can disguise the effect of flow on both effort and catch.
Therefore it is easy to ascribe high effort and catch in these months to high abundance of anglers and fish rather than high flow.

It was apparent in most of the models investigated that flow was both statistically and practically significant as an independent variable regardless of the time factor. Since much of the perceived wisdom of angling revolves around the importance of flow, so it is reasonable to assume that in a modelling situation the effect of flow should be accounted for before examining temporal effects. The Minitab ANCOVA programme fits the regression line before calculating the main effects so although the effect of flow tested as not significant in some models, its removal from the main effects made a substantial difference.

The form and statistical significance of the individual models were discussed but the underlying mechanisms have not been considered. The shortage of hard and fast information has, as been shown in the analyses' required a degree of speculation, but it is considered that there is sufficient circumstantial evidence to proceed.

It does seem reasonable to hypothesise that the stimulus for migration increases with flow so the following alternative hypothesis is proposed:- "The greater number of fish responding to higher flows may simply be a reflection of the distance into the sea that the plume of fresh floodwater extends, thus influencing salmon in the sea."

If this model of salmon movement applies to other rivers it is possible to envisage a scenario whereby a flood attracts all or most salmon within its range of influence in the sea and a pulse of salmon enter and start to migrate up the river. Further salmon arriving in the sea offshore then wait until a further flood occurs so that the abundance of fish increase with time. The picture is complicated on large rivers with large estuaries because some salmon undoubtedly move into these areas on flows other than floods but probably do not penetrate far upstream.

Solomon and Potter's data (1988) have demonstrated that salmon in the river soon stop and are usually not triggered to continue their upstream passage until the occurrence of another flood. They have also shown that salmon catchability is closely connected with the occurrence of high flows both for new entrants and those fish which have been in the river for some time and that their catchability declines sharply after a period of 10 to 20 days after a high flow event.

The only logical reason for the pattern of angler effort and catch reported by the Wye owners seems to be that anglers on the Wye fish more frequently when their chances of catching salmon are highest, in other words when raised flow conditions have increased the availability and catchability of the fish. If this is the case it is not unexpected that catch appears to be positively correlated with flow on those rivers examined.

Due to the rather doubtful quality of the data in the Wye owners effort data set it is likely that the main and interaction effects are due mainly to changes in reporting levels. There may be real variation in effort between and within years and also short term variation for other reasons which cannot be separated.

The catch/effort and the catch/flow data are less likely to be severely affected by variation in reporting and it should be considered what the significant main effects and interactions are likely to signify. Clearly a river with a relatively stable returning stock of salmon will be likely to show a relatively similar pattern of abundance within each year but this will be modified by the effect of flow on migration. The Analysis of Covariance procedure has certainly modified but not necessarily removed this effect and the adjusted mean squares for interaction demonstrate that there are significant deviations from a constant within year annual pattern even after the effect of flow has been removed.

There are three main reasons why this should occur:-

1) There is in all probability variation in the relative abundance of different age classes returning to the river in any one year and since they return at different times this will show up as an interaction effect.

2) If anglers are responding to their perception of the presence and catchability of salmon then this will almost certainly be shown up in the interaction term as they respond to floods or reports of catches by other anglers.

3) If the response of salmon to flow is a trigger effect rather than progressive with increasing flow, as river levels fall after a spate, abundance and catchability may remain disproportionately high for a few days after a pulse of salmon has entered the river.

Thus regardless of whether the catch/effort or the catch/flow model is used it is likely that the adjusted fortnightly means reflect the average pattern of abundance of salmon throughout the season given that the flow remained constant at the mean calculated for the covariates i.e. the fortnightly abundance corrected for flow. The interaction effects reflect departures from this pattern. The varying levels of catchability are likely to be confounded (i.e. not separable) within the effect of flow or effort when used as a covariate and it may even be similarly confounded within the annual main effects. In theory because the annual run of salmon is made up of different age classes of salmon migrating at different times annual main effects are only likely to be meaningful if all age classes are more or less abundant than usual. However, if the catchability of salmon in the river is revived with each rise in water level those salmon in the river during a year in which spates were frequent are much more likely to be caught than those salmon in the river during a dry year. It follows therefore that a high and statistically significant annual adjusted mean may reflect a year of high catchability and therefore high exploitation rate besides just a year in which all age classes were superabundant.

Such considerations as these can only be explored with a high quality data set taken on a river with a counter so that the estimates from the model can be compared with actual observations of abundance.

The analysis of the historical data set from the R.Wye is also instructive. The model demonstrating the dependence on flow of the proportion of the angling catch taken below Ross is particularly striking and pertinent because the distribution of catch is shown to vary widely with very high proportions below Ross being taken at low flows. This might merely reflect the variation in effort and therefore catch with flow between beats as noted on the Owners effort data. The observation fits a scenario of anglers responding to the presence of salmon which, while they may enter the lowest beat on low water levels, do not penetrate further upstream and are therefore caught in substantially greater numbers on the lowest beat than elsewhere.

However the shape of the relationship between catch and flow on the lower beat is similar to the other beats namely increasing to a maximum at moderate flow levels and thereafter decreasing which suggests that at very low flow levels salmon are not entering the river even as far as the reach below Ross.

The analysis for all areas is revealing in that the adjusted means for each area are positively correlated, one with the other, but neighbouring areas were more closely correlated. This suggests that throughout the river system the distribution of catch and therefore in all probability the distribution of salmon is affected by flow. The Principal Components Analysis supports this interpretation and the resulting scores for the first Component probably represent the best estimate of overall abundance of salmon entering the river system. To some extent this hypothesis is supported by the analysis using the net catch but here flow as used in the model only explains a relatively small part of the variance in catches. There are doubts regarding the success of the detrended moving average technique in allowing for long term variation in effort by the nets. In the lower reaches of the river and the estuary the movement of salmon into the river may be controlled by other factors e.g tides. The fact that the calculated adjusted means of rod catch below Ross were positively correlated with the adjusted means calculated from the net catch but negatively correlated with the actual net catch are most likely to reflect differences in spatial distribution. However, it remains a possibility that the net catch significantly reduces the number of fish available to the rods in the river. Some form of model relating the indices derived from rod and net catches with the actual catch might be a route for estimating the exploitation rate. However, a similar relationship was not observed between the two lowest rod catch reporting areas examined and since the net catches on the R.Wye are of the same order as the rod catches it might have been expected. This is another area which has not been examined in detail but might yield further interesting results.

It is considered that a full analysis of the historical data set in the NW region and the counter data available for some of the rivers in that region would be a valuable test of the hypotheses developed above. An initial examination has shown that there are differences from the Wye data but flow is still an important factor in controlling catch in the early summer on four of the North West rivers.

It seems unlikely at present that there is sufficient information to give a final definitive answer because in general the number of salmon involved is much smaller than on the Wye and more robust models may be required. However, it would appear that an adequate range of data exists to repeat much of the above work, test some of the hypotheses and assumptions and develop a data collection system with close statistical control.

Two major problems were encountered throughout the present contract which have prolonged the analysis and influenced confidence in the results. These are data collection and handling.

8.3 DATA COLLECTION

The R.Wye historical catch/effort data was selected for this study because it appeared to be the best data available in the industry but they are a classic example of the result of uncontrolled data collection. No doubt the planning of the survey was adequate but it appears that the level of effort applied to collecting the data varied within the time scale of the study resulting in introduction of bias and creation of unbalanced data sets.

Catch/effort information can be treated as being no different from opinion poll or marketing data. Statistically the problems are identical, namely to account for how people behave or perform by attributing the overall variance to different sources. This is normally achieved by stratifying the data and to some extent this was done on the Wye in that the river was divided into a number of different beats. Unfortunately the level of reporting was not maintained at a constant level throughout the period of data collection. Consequently, there is the possibility of bias in the data from differences in effort due to temporal variations in flow and differences in the efficiency of effort due to variation in the individual efficiency of anglers. The first source can be tackled to some degree by care with the analysis, the second source can only be dealt with by obtaining more information from the anglers reporting their catches. The latter may or may not have been considered when the survey was set up and is not an easy problem to solve for future studies but is very relevant. It is well established that a relatively small number of anglers are responsible for a large percentage of the catch whilst the majority catch nothing. In a study of catch the latter are irrelevant except in so far that their presence on the river may diminish the catch of the more expert angler.

Despite such problems and reservations about the data set and in some cases its failure to meet the Analysis of Variance criteria it is possible to propose hypotheses for examination on a future data set which should be collected to overcome the problems which have been encountered with the present data set.

There can be little doubt that angling effort varies with flow and that this is a second order relationship with a maximum point at moderate flow conditions. The subsequent downward path of the graph almost certainly reflects the increasing difficulty of angling successfully under flood conditions although some anglers still fish and are successful.

The important point at issue is the question why effort should increase with flow at lower flows and the answer to this also seems to result from anglers responding to their perception of availability of catchable salmon. Numerous authorities have demonstrated that salmon tend to migrate into and up rivers on raised flow levels. Solomon and Potter (1992) suggest that the catchability of salmon also appears to be enhanced and may be related to their activity. Therefore effort should be related to flow in the manner described although strictly speaking the relationships of interest are those between effort and abundance and effort and catchability, flow merely being correlated with both.

Daily flows and effort were examined but were considered to be unsuitable for two reasons:

1) The criteria for Analysis of Variance were violated.

2) Unnecessary detail introduced a high variance from other sources. One of these was thought to be variation in effort due to the availability of angler's leisure time on different days of the week which is a problem that leads on to and is closely connected with the efficiency of individual anglers. Although there was little evidence, and that was contradicted on one reach, that the amount of effort increased at weekends it does not seem reasonable that on most rivers there is no increase at times when anglers are more available to fish namely weekends and bank holidays.

If there are times when the probability of success is higher than average then those anglers who can only fish on weekends and holidays are likely to be less successful than those who can and possibly only fish when they perceive that the chance of catching salmon is high. There is therefore the possibility that the distribution of effort and catch for the two categories of angler is widely different. If this is a real situation, then it presents a potentially serious source of bias in the data, not only for the reason outlined, but also because there will be a considerable rise in inefficient effort during the holiday season. The difference in behaviour of the two types of fishermen is critical from a statistical point of view in that the "holiday and weekend" angler is effectively tending towards the provision of a random sample of abundance and catchability while the distribution of the "expert's" effort and catch will follow his perception of abundance and catchability. Either might give an estimate of abundance but combined the data is likely to be misleading.

There is also the problem of anglers fishing for different species which was not encountered in this data set because there are so few sea trout on the Wye. Anglers fishing for sea trout catch salmon, salmon fishermen catch sea trout and some fish for whatever seems to give the best chance of success. The weekend and holiday angler probably fits best into the latter class whereas the expert will almost certainly target whatever species he perceives to be most available. There is therefore reason to stratify the anglers in any survey according to some preconceived judgement concerning their ability and their availability to fish and there should also be a further stratification of their target species.

Catch returns of all salmon and sea trout caught by anglers and netsmen are required by law even if the catch of any individual was nil. In general the level of returns varies widely from a low of around 25% to possibly a local high of 100%. It has been convenient for Fisheries Officers to ignore this and simply publish and base management decisions on those returns received on the tacit assumption that they represented a reasonable index of the total catch. These data are frequently reported or produced as a frequency distribution of those received which, as Small and Downham (1985) have shown, can be used to estimate the total catch.

The standard procedure used in opinion polls or statistical consumer surveys of a similar nature is first to send a reminder and then follow it up with a house visit so that in effect three strata of data are acquired which can be examined for differences and can then be interpolated to those from whom returns were not received. This procedure is expensive and time consuming however, the differences between the three strata are likely to remain constant from year to year in the short term because by and large it is likely that the behaviour of individual anglers with respect to sending in their returns is likely to remain constant. (This could easily be checked from old counterfoils). Thus once a base line had been established the procedure would only need to be repeated (say) once every five years.

8.4 DATA HANDLING

The Agency owns an archive of potentially valuable information that is stored in a variety of formats ranging from hard copy through spreadsheet to small frequently purpose-designed but incompatible databases. It was found that frequently when examining spreadsheets that the number of columns (usually monthly catch returns) varied and the number and order of rivers quoted in the rows also differed. Thus although in theory the data were in a useable and readily accessible form, if it was required to analyse data covering several years and several Agency regions the collation of the data could not be carried out quickly and easily. In general it was not realistic to write a macro to perform the task so it had to be done manually with high consequent cost and risk of data corruption. Data are still being collected and stored in this manner and there is an urgent need for the Agency to structure and quality assure its data collation.

Data are expensive to collect and unless they are stored on a medium from which they are instantly retrievable much of the information that they contain will be lost because no one has the time or the inclination to collate the data by hand. In consequence the Agency has wasted and still is wasting a significant proportion of the fisheries budget.

This is further compounded by the practice of using junior scientific staff to enter the data. In general they are not skilled in data entry and consequently slow and inaccurate. Data entry should be carried out by specialist data entry clerks if necessary contracted in for a specific task; the scientific staff will then be freed to do what they are good at.

8.5 RECOMMENDATIONS

Catch is a relatively easy statistic to acquire and in anglers' eyes is the most important and it appears to be related to abundance. Proper management of stocks cannot be achieved without a full understanding of the biology of both salmon and sea trout and particularly the relationship between abundance, distribution, exploitation and escapement.

The conclusions in this report have been derived from the interpretation of statistical analyses which were carried out on data sets that were not specifically collected for the purpose and whilst it has been possible to test some hypotheses the results have been used to develop others which themselves need to be tested on new data. The following research will check and extend the findings of this work.

8.5.1 Further research

1) Compare the River Lune counter data with ANCOVA derived indices of abundance

2) Examine logbook data from the River Lune and any other suitable logbook data by ANCOVA and any other techniques which may appear suitable to explore the use of logbook data for derivation of indices of abundance and to

   investigate further the possibility of significant variance in catches from "weekend" and "good and bad" angler effects.

3) Repeat ANCOVA on sea trout catches from a sea trout river.

4) Extend analysis on Wye Owners data set to test for continued high effort in low flows when recent catches had been high (i.e. to test the hypothesis "Effort depends in part on catch")

5) Look for evidence of higher exploitation rates in wet years. This might be found in the Wye Owners data set or in the Lune and Dee data and would necessitate further examination of the problem of serial correlation in weekly catches.

6) Application of ANOVA to counter data to derive indices of availability and therefore response of fish to flow.

8.5.2 Data Collection and Handling

1) Continue historical system of returns but rationalise the reminder system. Returns of date and place of capture and weight of individual fish will be required to breakdown the data into age class composition by Discriminant Analysis (backed by a scale sampling strategy).

2) Set up National database of anglers and catches which would be responsible for issuing reminders but not entering data. This should be done locally by data entry clerks advised by local personnel. The database program must be relational as opposed to flatfile regardless of the dictates of the National IS strategy because without the flexibility of a relational database many of its advantages will be lost.

9.0 ESTIMATING TRENDS OF RUNS OF MIGRATORY SALMONIDS INTO RIVERS WITHOUT COUNTERS

9.1 INTRODUCTION

Throughout the United Kingdom and Ireland there are more than 300 significant river basins up which migratory salmonids migrate to reach their spawning areas. However, on only about 30 of these systems have traps or counting devices been installed to estimate the runs of fish over short or long term periods. In the 19th century and up to 1950 it was probably possible to assess the changes in runs surviving the coastal net fisheries by recording the catches by rod fisheries (Grimble 1913) as the rate in change of rod effort was very slow. Since 1950 rod effort has increased rapidly on waters with good public access (Gee & Milner 1980, Small 1991a) and it has become necessary to consider catch per unit effort (CPUE) as an indicator of changes in stock level (Small 1991b). This is confirmed by the historical catch record where nearly 40% of the 30 river systems annual recorded rod catch do not correlate with runs of fish.

As so few rivers are being monitored by fishery independent methods it would be convenient for fishery managers if a means could be devised of estimating the trends of runs of fish into remaining waters from such other records as are available. Monthly catch return data which are amenable to correction for flow variation are only available in relatively short datasets. Longer runs of data exist but consist of annual returns which cannot be corrected in this way but they can be examined for long term trends and corrected for long term changes in effort.

9.2 METHODOLOGY

The methodology described below is based on previous work described in Small & Downham (1985), Small (991a) and Small (1996) and further developed in reports written as part of the Catch Statistics Contract.

9.2.1 General Model

The general model relating Catch (C) with Effort (f), Catchability (q) and Abundance of fish (N), is based on the hypothesis of Paloheimo & Dickie (1964) - 'That for most fish stocks, Catchability (q) varies inversely with stock abundance and geographical area occupied by the stock'. This results in Catch per Unit Effort (CPUE), described by C/f, being curvilinearly related to stock abundance.

The model is usually formulated (see critical review by Crecco & Overholtz 1990, Bannerot & Austin 1983) as:

CATCH per UNIT EFFORT:	**C/f = qN**	**Eqn. 1**	**where:-**
CATCHABILITY	**q = a N ^ b**	**Eqn. 2**	(where -1 < b < 0)
giving	**C/f = a N ^ (b+1)**	**Eqn. 3**	
EXPLOITATION	**C/N = a f N ^ b**	**Eqn.4**	

Flow is not included in the estimating process for annual runs as it has not been found to be a good predictor. Flow data seems to have a marginal use as a predictor with monthly data, though becomes important when considering daily and weekly data.

These equations provide satisfactory fits to the data from 14 fisheries where effort, catch and counts were recorded and 13 fisheries where effort was not recorded but could be modelled.

When the observed trends of runs into 27 fisheries were compared with the trends of runs estimated by the methods described below, the correlations were highly significant (Small 1996).

9.2.2 The Estimating Model

Equation 3 can be transformed to terms of temporal models. The model is based on that described in Small (1996). The estimate of run size is based on determination of three variables: catch, effort and catchability as follows:

ESTIMATED RUN = (CATCH / EFFORT MODEL) / CATCHABILITY MODEL

This model may be derived from both net and recreational catch statistics data. However, due to the sharp decrease of netting effort in the 1990's it may be necessary to concentrate estimates of run based on rod records.

9.2.3 Calculation of parameters for input into model

Before calculation of the parameters for input into the model the data set over the time period under consideration is normally best split into different time periods and each period analysed separately. e.g. between the peaks of the 1960's and the troughs in the 1970's and 1980's , or before and after breaks in the record such as UDN etc. (see Figure 21). The worked example presented is based on the salmon data set for the River Tweed in Scotland.

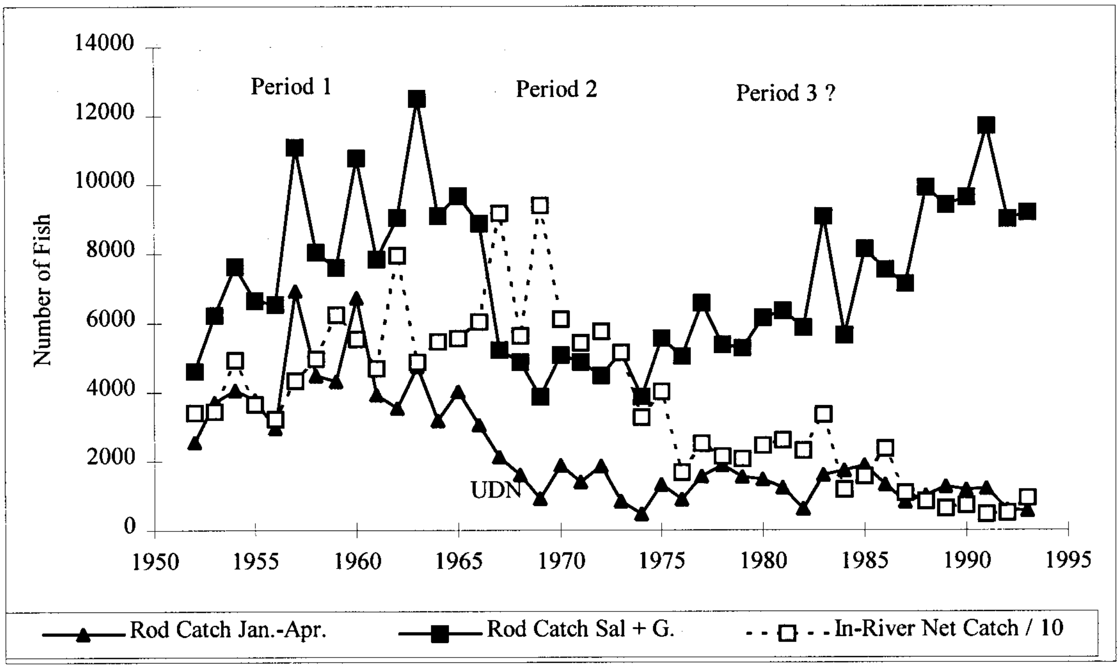


Figure 21: Plots of recorded catch

A) Total Catch

The proportion of anglers (**Pu**) making catch returns has been shown to vary greatly over the period of catch statistics collation (Small 1991a, Solomon & Potter 1992). Therefore adjustments to the catch record are required to estimate total catch as follows:

TOTAL CATCH = Declared catch (0.3/Pu + 0.7) for salmon

TOTAL CATCH = Declared catch (0.5/Pu + 0.5) for all trout

where Pu = the proportion of anglers and netsmen making returns.

The multiplier for nets is the same as those described for rods after testing. However, as the submission of catch returns for nets is usually greater than 70% the use of this correction is seldom required, although under reporting is till likely to occue even with a 100% return rate.

B) Effort

The calculation of the effort component of the model is dependent on the completeness of the available data set. In most cases the effort data is likely to be incomplete or absent altogether in which case it is suggested that some estimate of effort is made.

Complete effort data record

A complete record of effort may be used to provide a direct estimate of effort. This may be in terms of hours fished, day ticket sales etc. Logbook monitoring of anglers may provide an additional useful source of fine detail on angling effort.

Incomplete effort data record

If only an incomplete record of effort is available then estimates of total effort need to be made. There are four main methods of estimating the effort:

1. Use of known benchmark values coupled with a simple linear model for each period of the data being analysed . For example Figure 22 shows for a particular fishery that the total effort for the year 1989 was 41720 rod days (from surveys) and the between year difference in effort was estimated as 860 days.

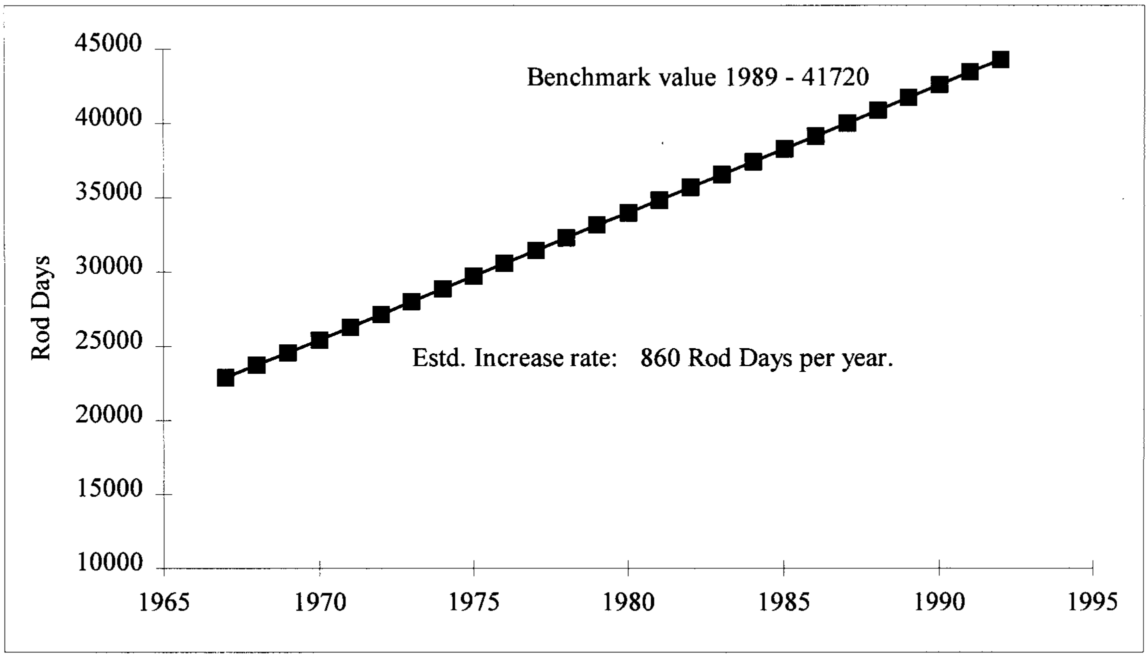


Figure 22: Rod effort model (Period 2 and 3)

2. Effort may be derived from (Total Catch / CPUE) from typical beats or sections of the fishery under consideration.

3. The following formula has been developed from data in Shearer (1992) and Welsh, North-West and Northumbrian and Yorkshire Regions logbook data, for estimating effort:

Rod Effort = E*Rod Catch^F

where E (a constant) ranges from 10-300 depending on the units under consideration and F is approximately 0.5. Estimates of E and F can be obtained from logbook data from the water under consideration.

This model is particularly useful when considering spring runs of fish where effort data are scarce (see Table 27)

Salmon and Grilse			Effort = E *(Rod Catch^F)				
River	**Period**	**Data**	**Unit**	**E**	**F**	**R^2**	**p**
Furnace	1980-92	Annual	Hours	660	0.38	0.65	<0.05
Feeagh	1980-92	Annual	Hours	94	0.77	0.55	<0.05
Bush	1976-80	Monthly	Days	15	0.4	0.42	<0.05
Thurso	1960-86	Annual	Days	120	0.5	0.96	<0.001
Tyne	1994	Monthly	Hours	53	0.77	0.85	<0.0001
		Annual	Visits	300	0.5	0.75	<0.0001
Eden	1991-94	Monthly	Hours	27	0.76	0.7	<0.0001
		Monthly	Visits	12	0.5	0.75	<0.0001
Lune	1991-93	Monthly	Hours	140	0.5	0.86	<0.001
Welsh Dee	1990-94	Monthly	Hours	275	0.5	0.83	<0.0001
Conwy	1982-93	Monthly	Hours	47	0.91	0.78	<0.0001
		Monthly	Visits	12	0.84	0.63	<0.0001
Spring Salmon			**Effort = E + (F*Rod Catch)**				
River	**Period**	**Data**	**Unit**	**E**	**F**	**R^2**	**p**
Thurso	1960-86	Annual	Days	390	4	0.3	<0.001
Tyne	1994	Monthly	Hours	40	25	0.97	<0.001
Eden	1991-94	Monthly	Hours	32	20	0.83	<0.0001
Lune	1991-94	Monthly	Hours	30	2.5	0.3	0.036
Welsh Dee	1990-94	Monthly	Hours	414	63	0.46	0.0002
Conwy	1982-83	Monthly	Hours	50	30	0.7	<0.0001

Table 27: Relationships of rod effort to rod catch

4. Where catch and count are recorded but not effort, the trend of effort can be estimated by the best fit method described in Gardiner (1991).

The following points should be noted regarding calculation of effort from incomplete data sets:

- It has been shown (Small 1992 and 1996) that there has been an approximate linear increase in rod effort between 1960 and 1990 by a factor of 2 on fisheries with restricted access and up to around a factor of 6 on fisheries with easy access.

- Analysis of data sets from about 30 rivers has shown that the rate of increase of effort is not critical for estimating the trends of annual runs into the estuary. The important point for consideration is whether effort is demonstrating an increasing or decreasing trend as this has a marked effect on the CPUE model.

- Individual frequency counts of successful anglers' CPUE may be used to successfully estimate major changes in effort (Small & Downham 1985). This information may be collated from logbook schemes .

- Examination of several years data recorded in logbooks, for rivers in England and Wales, indicates that there are highly significant correlations between monthly logbook rod catch catches and those made on the normal returns to the Agency. This may justify applying models based on logbook data to returns.

With the appropriate adjustments made to estimate the total catch and total effort the first two components of the model can then be divided to calculate catch per unit effort (CPUE). This is provided by the following formula:

CPUE = Total Estimated Catch/Total Estimated Effort

The calculation of CPUE is required to calculate the third component of the model catchability (see Figure 23). CPUE is calculated as follows:

For Salmon **CPUE = Declared catch (0.3/Pu + 0.7) / Effort (derived as above)**
For Sea trout **CPUE = Declared catch (0.5/Pu + 0.5) / Effort (derived as above)**

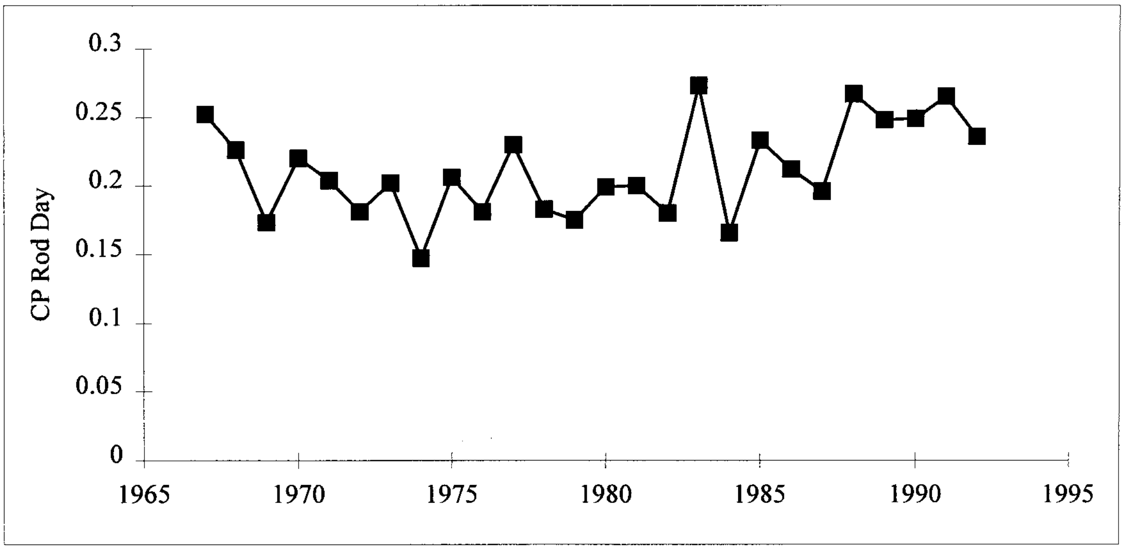


Figure 23: Estimated catch per rod day (Period 2 and 3)

C) Catchablility

Catchability **(q)** is defined by the following model:

Catchability (q) = CPUE / RUN

i.e. the proportion of the total run caught by 1 unit of effort.

Analysis of data from rivers with counters/traps have provided simple temporal models with linear trends for catchability with slopes ranging from (see Figure 24):

+/- (0.10*benchmark catchability) per year
with a mean of 0.035 (S.D 0.02).

It can be shown that the trends and rate of change of rod exploitation normally closely follow those for rod effort. Combining the benchmark values and the temporal change gives the first temporal model for rod catchability upstream of any in-river nets and guidance of the choice of models required.

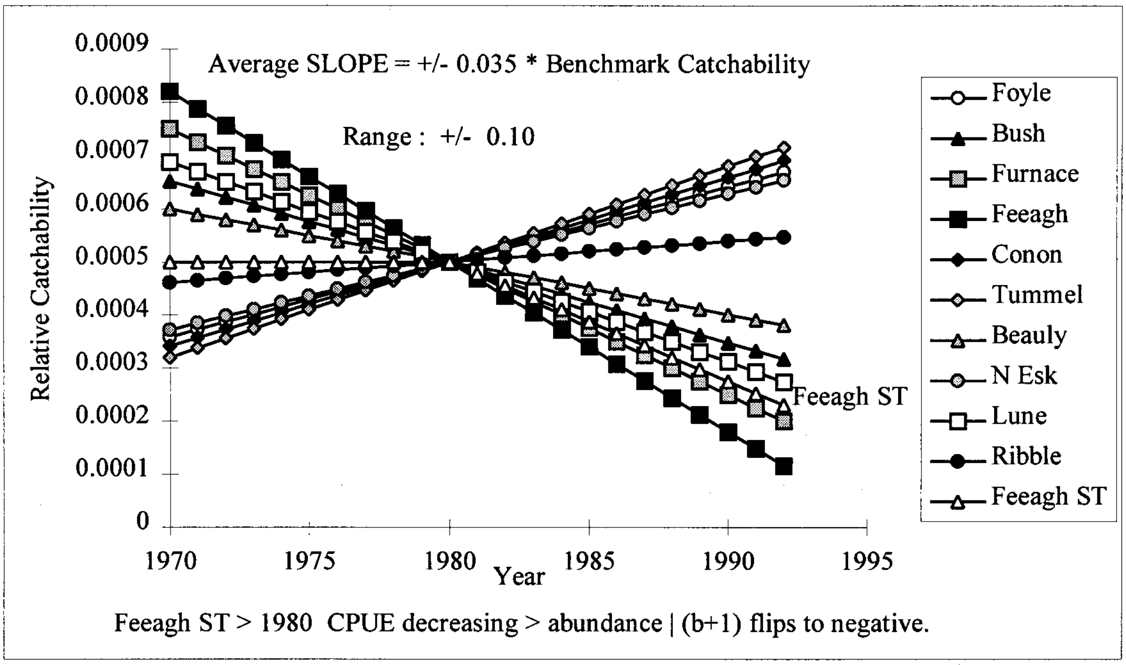


Figure 24: Salmon rod catchability: Slopes of linear models around a common benchmark value

Therefore catchability estimates may be defined by three different models:

1. an increasing catchability model

2. a benchmark catchability value model

3. a decreasing catchability model

Long-term changes of catchability have been shown to increase with decreasing numbers of fish (Small 1991a) or decrease with a dilution of skill resulting from increased numbers of anglers (Peterman & Steer 1981, Small 1991a). If no information is available on the catchability trend then all three models should be constructed on a known benchmark value preferably, but not necessarily, in the middle of the temporal period under consideration. Catchability may also be calculated via the following:

Catchability calculation on rivers with counting devices

If counter data on the river under consideration is available then catchability **(q)** may be calculated by:

i) **q = CPUE / COUNT** (where counter is at or near tide head)

ii) **q = CPUE / (COUNT + CATCH BELOW COUNTER)** (for counters located upstream)

Catchability calculation on rivers with no counting devices

If no counter or mark - recapture data are available the catchabilty (q) benchmark value may be calculated from exploitation rates. Exploitation rates can be found from mark-recapture surveys or suitable mean values obtained from other sources e.g. Solomon & Potter (1992) or Table 28. It should be noted that exploitation rates increase rapidly as abundance falls below 500 to 1000 fish i.e. for > 1000 summer salmon and grisle 0.05 to 0.20 may be appropriate whereas >0.30 may apply to spring fish in recent years.

	Percentage of annual run of fish entering estuary			
	Spring Salmon	Salmon / Grilse		
River	Rods	In-river nets	Rods	Escapement
EAST COAST				
Conon		5	60	35
Beauly	>40	0	11	89
Spey*	31	12	22	66
Ab. Dee	34	0	25	75
N. Esk	15	35	16	49
Tay	33	38	19	43
Tweed*		10	30	60
Coquet		0	28	72
Tyne**		0	20	80
IRISH SEA				
Derwent		0	6	94
Lune	8	28	21	51
Ribble		1	30	69
W. Dee	20	16	8	76
Usk		33	10	57
Severn***		50 - 15	6	44 - 79
SOUTH COAST				
Frome		2	6	92
Tamar	50 - 10	26	10	64
ATLANTIC				
Burishoole Furnace		0	11	89
Feeagh		0	4	96
Foyle	33	80	10	10
Ellidar		0	38	62

Table 28: Estimated exploitation rates and escapement for salmon on a range of rivers for the 1990's

Notes for Table 28:
All values are based on runs into estuaries and observed counts except.
Where two values are indicated, the latter value shows the current value after recent changes in the fisheries.
* Mark-recapture estimates
** Assumed rod exploitation
*** Data from Shrewsbury but does not include the spawning population of the River Teme.

For 'spring' Salmon:
For Scotland Rod catches Jan- 1st May Counts Dec - 1st May
For Ireland, England & Wales Rod catches Jan -15th May Counts Jan - 15th May

The relationship of rod exploitation to abundance is usually expressed as:

C/N = a* f N^b see Eqn. 4

where C/N represents exploitation value and N represents abundance.
Measured values of 'a*f' lie between 0.05 to 20 (Beaumont et al. 1991)
whilst values of 'b' usually lie between -0.25 and -0.5.
Note that Exploitation = Effort *Catchability

To obtain a benchmark value of catchability, a benchmark value of the run needs to be calculated first. This may be obtained by the following formula:

Benchmark value of run = Benchmark value rod catch / Benchmark value Exploitation rate

Once the benchmark value of the run is obtained this value is entered into the following formula:

Benchmark value of catchability = Benchmark value CPUE / Benchmark value of run.

Therefore for catchability three models representing mean, increasing and decreasing catchability are derived:

Model 1: Benchmark value + (0.035*Benchmark value)*(Year-Benchmark Year)
Model 2: Benchmark value of catchability
Model 3: Benchmark value - (0.035*Benchmark value)*(Year - Benchmark Year)

9.3 ESTIMATING TRENDS OF THE RUN

9.3.1 Rod close season runs

For the 27 waters examined the proportion of the total annual run taking place in the rod close season, in non-drought years lies in the range 0.002 to 0.10. In smaller rivers in drought years the proportion may rise to about 0.25, but inclusion of these years in the datasets still produce significant correlations between in-season CPUE and (Total run ^ (b+1)). Therefore the inclusion of the data from infrequent drought years does not significantly affect the determination of trends.

9.3.2 Estimating the trend of runs above estuarine nets (including the close season)

Three trend estimates are calculated using the following formula:

Estimated run = Rod CPUE / Catchability model

This should be calculated for each of the three catchability models to determine which appears the most reasonable fit.

9.3.3 Estimating Historical Trends of Runs of Salmon and Grilse into the Estuary (including the close season)

To estimate the historical trends of runs of salmon into the estuary it is necessary to add the within estuary net catches, if appropriate, to the three trends obtained from the rod data. The plots generated may then be assessed to determine which line or parts of the trend are likely to be reasonable. An example is shown in Figure 25 for the 3 catchability models and all indicate the same pattern for a decrease in the abundance of salmon over the time period.

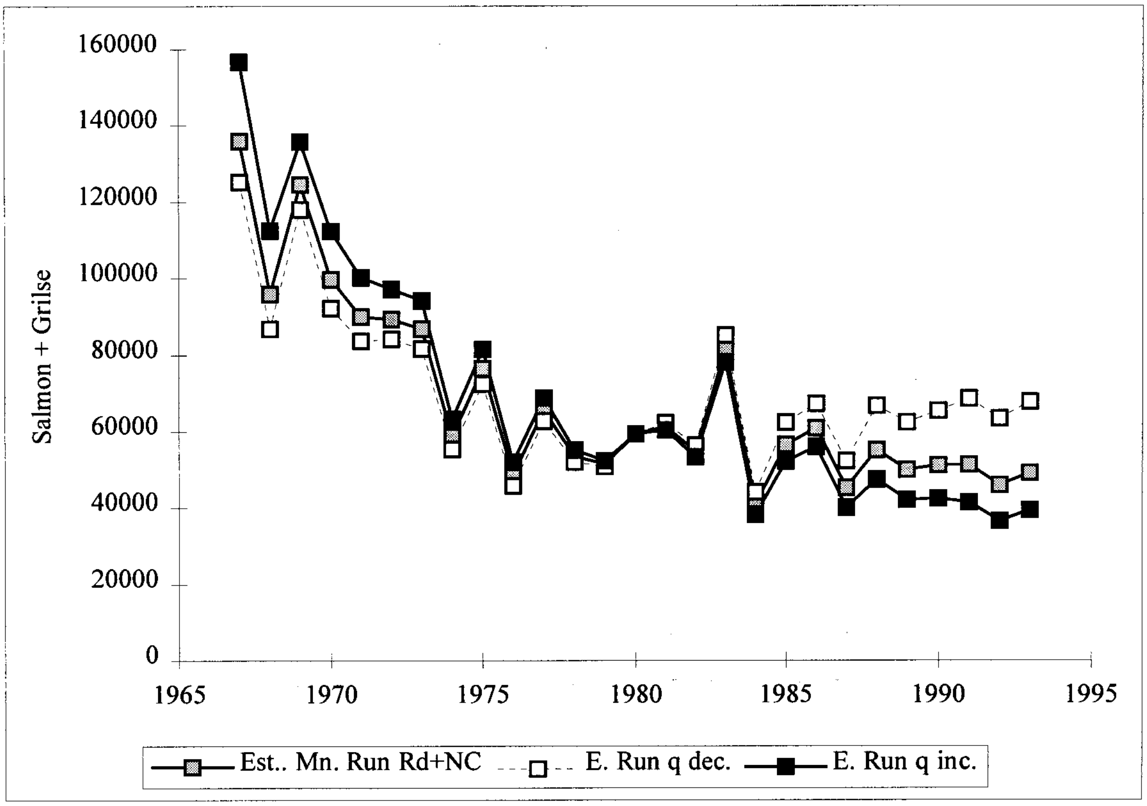


Figure 25: Estimated trends of runs of salmon and grilse into the River Tweed estuary

9.4 ESTIMATING TRENDS OF RELATIVE EXPLOITATION AND ESCAPEMENT RATES

This may be calculated by dividing the following:

- Rod catches
- Net catches
- Escapement

by the assessed best estimate of the run into the estuary (see Figure 26):

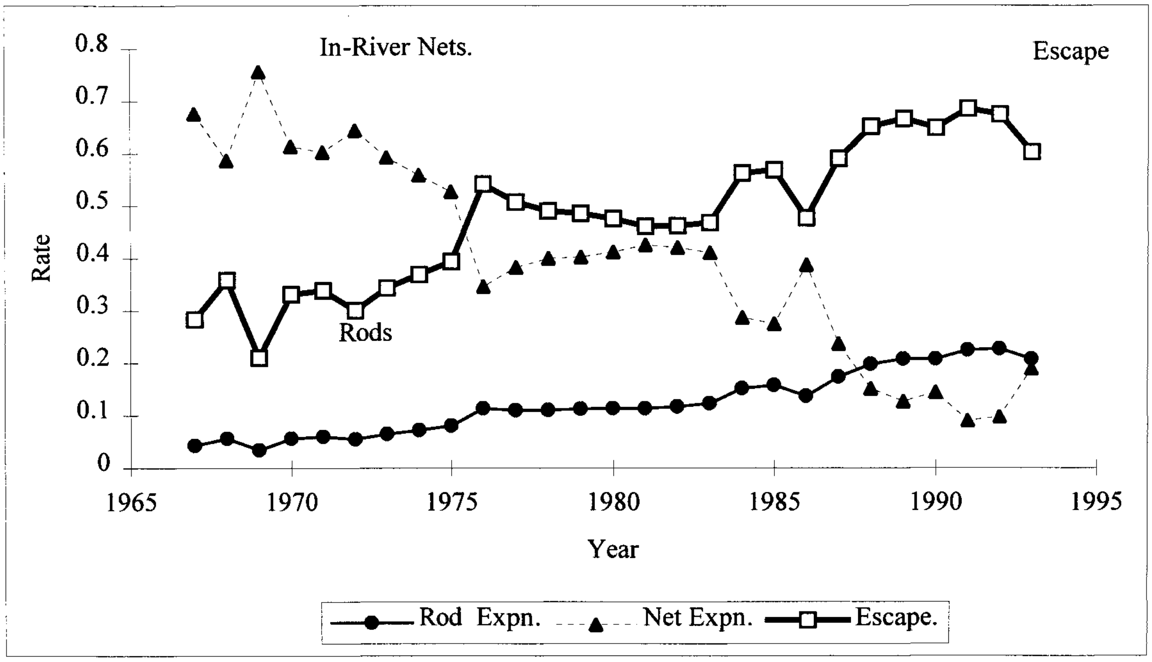


Figure 26: Salmon - trends of relative exploitation and escapement rates: Proportion of fish entering the River Tweed (Periods 2 and 3)

9.4.1 Spawners

Where it is necessary to obtain some estimate of the numbers of spawning fish (e.g. when the counting device is upstream or it is desired to obtain a first approximation to the number of fish running from rod catch data plus the number of spawners) then the following may be method may be tested.

If there is an indication of recent rod exploitation rates, from mark and recapture surveys etc, and ignoring unrecorded losses in the river, the relation of escapement rates to rod catch rates can be determined from the data presented in Table 29.

Proportions		Ratio	
Fish available	Rod exploitation	Escapement	Escapement / Rod catch
1	0.01	0.99	99
1	0.05	0.95	19
1	0.1	0.9	9
1	0.2	0.8	4
1	0.3	0.7	2.33
1	0.4	0.6	1.5
1	0.5	0.5	1
1	0.6	0.4	0.67
1	0.7	0.3	0.43

Table 29: Relationship of rod catch rates to escapement rates

Examination of 15 data sets, from waters with tidehead counts, show that the mean values of ratios over periods of about 5 years are close to the approximate values in Table 25.

Where there are no benchmark values of exploitation, trial estimates of spawners may give some guidance on the temporal trends of rod catchability models.

9.5 USE OF MONTHLY DATA TO ESTIMATE WITHIN SEASON RUNS

Similar methods can be applied to the estimation of within season runs.

9.5.1 Salmon: rod CPUE and catchability

In the years under consideration, salmon runs, rod effort and catches, tend to increase as the season progresses, (Aprahamian 1993, Small 1996 & 1997), both authors provide temporal models for the proportions, for salmon and sea trout angling.

Examination of logbook and day ticket data from rod fisheries in the United Kingdom indicates that during the latter half of the season, there is a significant ($p<0.01$) relationship between cumulative monthly counts of salmon, where a counter is at or near tidehead, and whole river CPUE. Where the rod data comes from a fishery immediately adjacent to the counter, the relation is with monthly counts. This takes the form:

Monthly Cum.Count (or Count) = C*(Monthly rod CPUE ^ d)

The exponent 'd' tends to 1.0 and when the unit of rod effort is 100hr, the coefficient 'C' had a value of 1600 for the Welsh Dee 1991-93, a range of 500-1500 for north west English rivers 1991-94, approximately 500 for small Irish rivers 1980-90, and the range 50 - 200 may be suitable for Scottish waters similar to the Beauly and Tummel 1991-94.

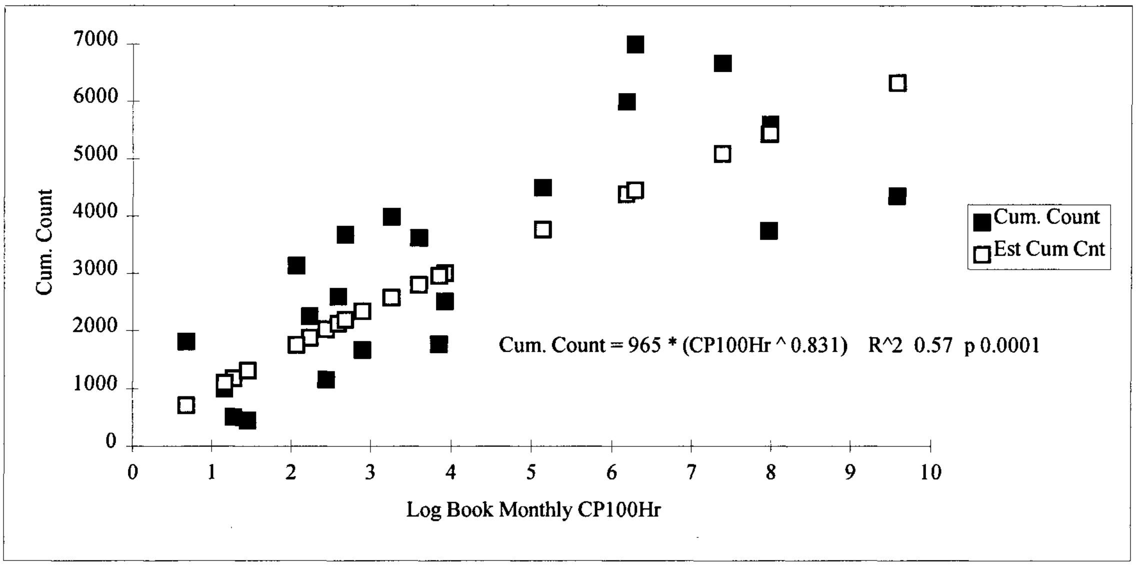


Figure 27: River Lune Salmon 1991-4, Estimate of monthly cumulative count from logbooks (June-October).

Figure 27 illustrating the relationship for the River Lune logbook data and cumulative counts for 1991-94, is typical of the datasets examined.

Due to the uncertain nature of low counts and rod catches in the early months of recent angling seasons, rod catchability can be expected to be high and variable. Temporal models tend to show a rapid decrease from January to May or June, then level off at a near constant value to the end of the season. (Aprahamian 1993, Small 1995 & 1997).

Jan to May or June **Monthly Rod Catchability (q) = a - (b*Month)** where Month is 1 to 6

May or June to Oct **Monthly Rod Catchability (q) = c.** where c is a constant.

For numerical values see Small (1997)

Applying the Rod Catchability Models to the logbook patterns of CPUE produces estimates of monthly cumulative counts which are highly significant correlated to the measured values.

9.5.2 Correlation's of flow and angling parameters

Aprahamian (1993) quotes a number of studies which have documented the influence of flow on the catch of salmon, and found that for the months after May in 1991 on the Derwent, Kent and Lune, salmon catch and effort were significantly correlated (5% level) with flow but not with CPUE. In respect of sea trout he found that flow did not influence any parameter.

When the correlation analyses are extended to other years and waters, (Small 1997), Aprahamian's finding for salmon, are largely confined for logbook data, but these results must be treated with some reserve. It is noted that the significance of the correlation between in-season flow and counts may vary considerably with period and river, also that annual mean flow may have little influence on any annual mean angling parameter.

9.5.3 Sea trout: Rod CPUE

Fishing success

As for salmon anglers, most anglers fishing for sea trout are unsuccessful. This pattern is typical of the rivers where sea trout (fish < 1360g) are counted separately, mostly located in North West England, namely the Ribble, Lune, Leven, Kent and Derwent.

Whereas salmon runs, rod effort and catches, in the years under consideration, tend to increase as the season progresses (Aprahamian 1993, Small 1997), sea trout runs commence about May, peak about July, then decrease to October. Angling effort and catches follow the same pattern.

In-season rod effort models

It has been shown, Small (1997), that counts, catches and effort for sea trout tend to be negatively correlated with flow, therefore anglers probably plan their fishing in the light of their knowledge of the presence of fish in the river.

As with salmon angling there are significant relations between logbook rod effort and catches. Typical regressions are:

LUNE: Monthly rod hours = 28.7*(Rod catch ^ 0.63)	R^2 =0.71	$p<0.0001$
KENT: Monthly rod hours = 51.5*(Rod catch ^ 0.59)	R^2 =0.63	$p<0.0001$

9.5.4 Relation of CPUE and catchability to abundance of fish

Where there are sufficient monthly counts i.e. on the Lune, Leven and Kent, these relationships are significant, whether abundance is measure by counts or cumulative counts. Therefore it seems that sea trout data also satisfy the original hypothesis stated in section 9.2.1. However, it should be noted that there may be some underestimation of sea trout counts because the efficiency of the counter varies with fish size (Aprahamian *et al.* 1996).

9.5.5 Rod catchability (q)

Temporal in-season patterns of rod catchability based on catch / 100hrs and counts, cumulative counts or fish available, have been analysed for the Lune, Kent, and Leven Small (1997) and indicate that the value based on counts are variable on the Lune and show some tendency to increase markedly through the season, whereas the Kent and Leven values tend to decrease. The trend of values from cumulative counts on all three rivers, is slow to decrease in October.

Temporal models

If required the numerical models for the three rivers can be found in Small (1997)

9.5.6 Comparison of estimated counts of sea trout with recorded values

Estimated monthly counts and cumulative counts for the Lune were calculated by dividing CPUE by the appropriate model q, for comparison with the recorded values. Although the model for Q Cum. Count would appear to be more consistent, it became apparent that the estimates for counts are a better fit to the recorded values, R^2 of 0.2 and 0.5 respectively.

However, a similar calculation for the Kent gives the opposite result, the estimated cumulative counts being the better fit, R^2 of 0.51 and 0.16. The Leven estimates of monthly counts are not significant (R^2 = 0.1); the estimated cumulative counts being the better fit (R^2 = 0.33).

It would seem that further investigations are needed to determine which set of models are most suitable for estimation of runs from logbook data. In the meantime if estimates of runs are required from logbook CPUE, the results from both types of model or mean values for Q Count and Q Cum. Count might be investigated.

9.5.7 Relation of statutory returns data to logbook data

All the logbook datasets from rivers in south Wales to Northumbria showed that for both salmon and sea trout, there is a highly significant near linear relationship of monthly logbook catches and recorded monthly statutory returns, Small (1997).

This may indicate that it is possible to apply the patterns of models derived from logbook data to recorded or adjusted rod catches in order to estimate trends of annual and in-season runs of fish on rivers where traps or counters are not installed.

9.6 DISCUSSION

"*We know that the model assuming fixed parameters will be 'wrong' in the strict sense, i.e. it will make numerical predictions that are not precisely correct. therefore the issue in choosing a model.....is not whether it is right or wrong. Rather, the practical issue is deciding which simplifying conveniences are good enough......given whatever limited historical information is available*" Hilborn and Waters (1992)

The methodology described is used to demonstrate the trends within the data set and is not suitable for providing estimates of absolute numbers. This results from the model requiring a parameter as volatile as CPUE, (which may arise from two estimated values) to be divided by a small number (Catchability) which may lead to large errors in estimates for small changes in values. Therefore the method is more useful at providing indications of a change in the population over a long-time scale. All estimates of run size should thus be treated with caution and where available should be backed up with local knowledge and surveys. Therefore, the development of teams of scientists committed to long-term studies on specific systems is likely to be beneficial due to an increase in understanding of a river system with time. This information on each river should be widely disseminated and available to Agency staff.

The key to obtaining reasonable estimates of trends lies in the choice of models for the trends of catchability, and where required effort. The values shown in Table 1 of observed exploitation rates, and local knowledge may help, but trials of high positive and low negative rates of change in effort combined with high positive and negative rates of change in catchability will indicate practical upper and lower bound models.

It can be seen that the described method is reliant on estimated components to calculate an estimate of the trend in run size. The model has therefore identified the deficiencies within the present methods of catch statistics data collection. Accurate measures of catch, effort and counts (for validation purposes) are required to fulfil the potential of the model.

If the data and models are entered into a spreadsheet for a particular water, then altering the rates of change in rod effort and catchability, will quickly establish how sensitive trends of runs and exploitation, are to the changes.

The significant correlations between logbook catch data and statutory returns catch records are potentially valuable. They may be a consequence of the logbook volunteers and the persons making the bulk of the returns, being largely the same anglers. It has also been noted that the number of logbooks completed in the fourth year of the scheme has decreased. Has the enthusiasm of volunteers subsided and how long will this source of information be available? It is recommended that consideration is given to logbook scheme which will perpetuate the current enthusiasm to ensure this value data source is maintained.

Gross trend changes may be detected by this method over a relatively short period. However, it should be considered as to whether more subtle changes in trend, which may be potentially deleterious may be detected over the short term to allow reactive management of the fisheries.

If trends are identified to show a decline in estimated runs over, for example over a 5 year period then this may be sufficient evidence of problems in the salmon population or river conditions. The analysis of trends may therefore be sufficient to assess the performance of the river.

On many rivers without counting devices, sufficient logbook data are now available to determine likely year to year variations within season runs of salmon and sea trout. Where logbooks have not been issued, the variations might be estimated by applying suitable models for effort and catchability, derived from analyses of logbook data, to statutory returns of rod catches which have been adjusted for changes in the proportion of anglers making returns.

It is unlikely that fish counting systems will be established on all rivers. However, if groups of rivers can be shown to behave in a similar way, then selected type rivers with counters installed may be used to assess performance of the group. Estimates of run size may then be undertaken by the method described for other rivers within such a classification grouping to assess their performance.

9.7 RECOMMENDATIONS

1) Teams of scientists should be formed committed to long-term studies of specific river systems.

2) On river systems where counting devices are unlikely to be installed, mark-recapture surveys should be carried out on both salmon and sea trout, at intervals of 4 or 5 years, in order to establish the order of magnitude of runs or changes thereof.

3) Administration of rod licence issue for migratory fish, should include a means of identifying which licencees make statutory return of catches. The returns should require records of rod effort in terms of rod days or hours.
This would require databases of migratory salmonid anglers to be established. Individual anglers could be coded, along with their catch returns, by licence number. A bar code type system may be useful for this purpose.

4) As logbooks are a valuable source of information their issue should be continued, but consideration given to obtaining a more statistically random distribution, possibly combined with a reward for completion of the required details.

10.0 CLASSIFICATION OF MIGRATORY SALMOIND RIVERS

10.1 INTRODUCTION

Catch statistics data for catches of migratory salmonids by nets and rods have routinely been collected by the Agency (formerly the National Rivers Authority and Regional Water Authorities) since 1975 but in some regions earlier data is available. The collated data for England and Wales are published annually, along with regional based reports, which in addition break the catches down into monthly figures. The quality of the data appears variable between regions depending on the methods of collection and use of reminders for the submission of catch returns (MAFF 1995). The methods of collection and vigour of collection have varied temporally, thus creating inconsistencies within the historical data set. However, this data set remains the main historical record of migratory salmonid catches in England and Wales and has been used for undertaking the analyses in the present project.

The aim of this work was to examine the historical catch statistics data, and to determine whether environmental and physical factors enabled a broad classification system for rivers to be established based on annual catch data. The development of such system would allow comparison of the performance of a number of rivers within a group of the classification and also enable objective choice of index rivers.

10.2 METHODS OF EVALUATION

Annual catch statistics data was supplied by MAFF. In addition annual catch statistics reports for the Agency Regions were also obtained which included a monthly breakdown of the annual figures. Preliminary examination of the data sets revealed that they varied in timescale between and within regions and individual rivers. To examine the overall data and in individual regions, the data sets were truncated to the longest timescale available, avoiding missing values and to include the major rivers in the regions. Several discrepancies were noted between the MAFF and EA data. These included:

1 Data were more detailed in the MAFF rod catch records for the rivers Ellen, Ehen, Esk and Duddon.

2 Data for more rivers was available in the Agency data set.

3 Minor errors were found in records for the rivers Ehen, Duddon and Cumbrian Derwent and Border Esk

4 Records for the River Eden were of a higher order of magnitude in the EA records, than the MAFF records.

5 Within the commercial catch record a few minor errors were noted, and more

data existed in the MAFF data.

Two techniques were examined for deriving a classification system. Firstly the method developed by Elliott (1992), undertaken for the NRA, for classification of sea trout was re-examined and applied to the Atlantic salmon data sets. The alternative approach adopted was to undertake analyses using Analysis of Variance (ANOVA).

10.3 ELLIOTT'S METHOD FOR SEA TROUT

Elliott (1992) developed a sea trout classification system for all rivers by looking at catch statistics data both spatially (by region) and temporally (by year). This work was undertaken as part of an Agency R&D Contract 404. It was considered particularly important to re-examine this classification system and to determine its applicability to salmon. The methods were therefore replicated for salmon catch statistics data.

Elliott proved that the following relationship could be used both spatially and temporally on sea trout catch data.

$$s^2 = ax^b$$

where
s^2 = variance
x = mean
a,b are constants.

The derived relationship indicates that the data sets follow a normal distribution. The technique was applied successfully by Elliott to both rod and net catch data and demonstrated the following:

- Catches from different rivers in a region varied in a similar manner.
- The variability of catches between rivers and years was dependent on the mean catch. For example the larger the mean catch on a river, the less variation was found between years.

Elliott's classification system used CV% (the coefficient of variation), a measure of the variability of the data, to determine a river's type. Six different river categories were derived from this classification. These categories were:

1. The size of catch on a log scale was split into 3 annual catch bands (i.e. <105 fish, 105-1000 fish and >1000 fish).
2. The classification produced 3 temporal variability classes i.e. high variability (CV>86%), medium variability (CV 50-86%) and low variability (CV<50%).

The Elliott methodology was examined to test its usefulness and robustness during which several problems were found.

The classification system was determined over different time spans for different rivers, ranging from 14 to 40 years depending on the available data. It was found by investigation that the rivers would shift between the classification categories depending on the timescale of the data used. Several examples could be found of rivers such as the Eden and Derwent /Cocker fisheries that changed from medium to low variability when the temporal ranges were shortened from 27 to 16 years (see Table 30 Example 1). An opposite effect was also observed, such that fisheries of the rivers Leven /Crake and Duddon displayed higher variability, switching from medium to high categories, when the years examined were increased from 14 to 33 years (see Table 30 Example 2).

Example 1 (after Elliott):

Eden salmon data

Years taken	CV%
27	64.6
16	45.2

Derwent/Cocker salmon data

Years taken	CV%
27	67.1
16	37.5

Example 2 (after Elliott):

Duddon sea trout data

Years taken	CV%
14	66.0
33	110

Leven/Crake sea trout data

Years taken	CV%
14	64
33	106

Table 30: Comparison of CV% values obtained using different timescales of catch data

These results suggest that the method is not particularly robust as a classification system, especially with data collected over different time periods. However, if all the data had have been looked at over the same timescale, changes in category could infer some change in the state of the river and possibly relate to a performance indication. The classification categories therefore must have a meaningful determination.

The data was further examined to see if clusterings occurred around any particular scales of CV% or mean annual catch. As Elliott's own data demonstrates, all the rivers appear to be on a sliding scale or simple ordering according to catch. Thus a small river suitable for salmon may appear in the classification next to a large river which is unsuitable. Such a classification is of less value than a method which groups rivers according to some other attribute. Therefore there appears to be some problems in the classification previously derived by Elliott.

10.4 CLASSIFICATION USING ANOVA

Based on re-examination of Elliott's method it was considered unlikely that a simple classification system or method of examining the overall data could be meaningfully determined. With the assistance of Dr David Downham, a statistician at Liverpool University, it was decided to adopt a potentially more powerful analytical approach for examining the data. Two models were derived for analysis, the second of which reverts to the form of the first after the usual logarithmic transformation for stabilising the variance. These models are:

MODEL A: CATCH = CONSTANT + RIVER EFFECT + YEAR EFFECT + ERROR

MODEL B: CATCH = CONSTANT x RIVER EFFECT x YEAR EFFECT x ERROR

The mulitplicative approach is preferable because if the pattern on arrival of each age class remains relatively constant from year to year then a proportional increase in one month resulting from a 'good' year class is likely to be reflected in the same proportional increase in other months. However, the main reasons for the preference of the multiplicative method is that the distribution of mean flows and cacthes appears to be lognormal. Therefore the logarithmic transformation of the multiplicative model has the advantages a stabilising the variance and yeilding a simple additive model which satisfies the assumptions required under the Analysis of Variance.

The ANOVA statistical technique was applied to both models for all the data and regions available. Residual analysis of the data provided a powerful technique for determining if assumptions made on these data were correct. Residual values were calculated by the following formula:

Residual value = Observed value - Predicted value

The following assumptions associated with this new approach were:

- The data were independent
- The data have a zero mean
- The data have a constant variance
- The data were normally distributed (F test)

A range of factors were considered for determination of a possible classification system. These factors included catch size order and river length data (in terms of total river length, numbers of tributaries, etc. for a selection of Welsh Region rivers). River flow was also considered on a limited basis.

10.4.1 Statistical packages and methods used.

The preliminary analyses using Elliott's method were all undertaken using Microsoft Excel for Windows (Version 4.0). However, for statistical testing of the ANOVA method and to take account of missing values in the data, a dedicated statistical package was required. The Use of Minitab for Windows (Release 9) was found to be suitable for this purpose. The General Linear Model in this programme provided all the statistical results required and located outlier values in the data sets.

This programme also proved useful for examining standardised residuals and CUSUM charts and is recommend for use for this type of analysis. However, the data presentation capabilities are superior within Excel and it is suggested that data handling and graphical outputs are more easily created with this spreadsheet package.

The national annual catch statistics database of rod catches was analysed in its entirety for salmon and sea trout rod catches. The analyses were all performed with the overall data set for all rivers for which sufficient rod catch data were available over the same timescale. Because the most extensive river attribute data, in terms of river lengths, were available from Welsh Region this regional subset of catch data was examined over the maximum timescale available (1956 -1990).

10.5 RESULTS

10.5.1 Salmon rod catch data

Only those rivers without more than occasional zero returns, as low cell counts in ANOVA can introduce bias, were selected for analysis and the standard logarithmic transformation was applied to convert model B to the additive form of model A.

Normal probability plots of the residuals from both models are shown in Figures 28(a) and 28(b) and demonstrate the basic unsuitability of model A due to non-normality. Model B also shows non-normality amongst the smallest residuals but they represent a small proportion of the total data set.

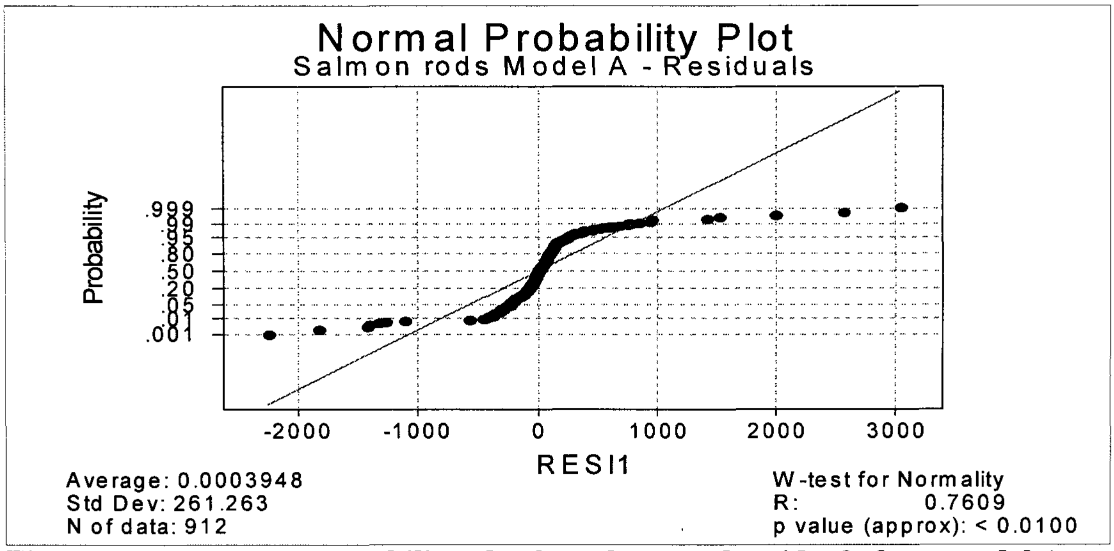


Figure 28(a): Normal probability plot for salmon rod residuals from model A

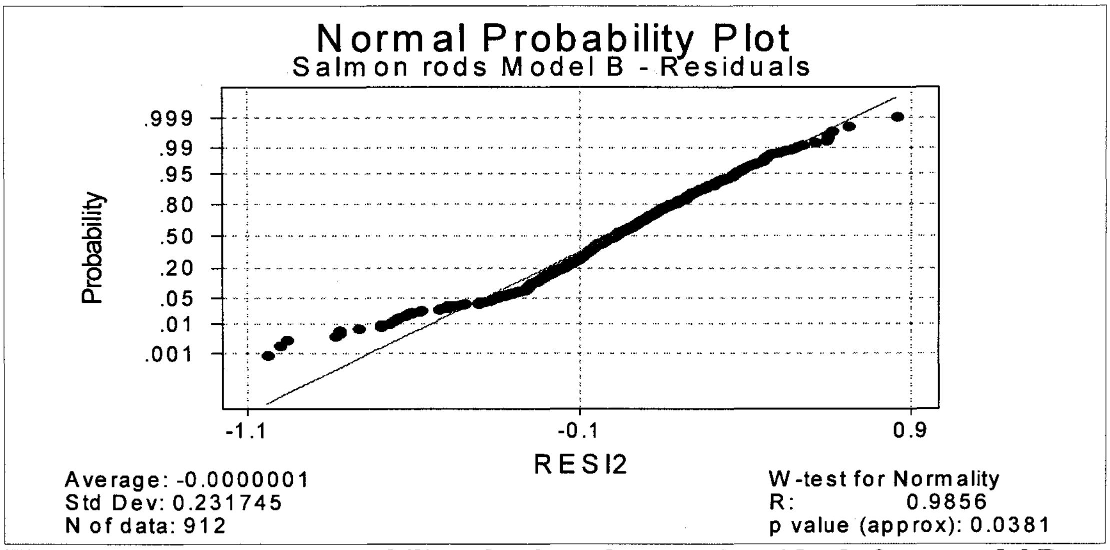


Figure 28(b): Normal probability plot for salmon rod residuals from model B

The analysis of variance table for both models is presented in Table 27(a) and 27(b).

Source	DF	SeqSS	AdjSS	AdjMS	F	P
River	56	$2.54*10^8$	$2.54*10^8$	4533387	61.24	<0.001
Year	15	7692242	7692242	512816	6.93	<0.001
Error	840	62183476	62183476	74028		
Total	911	$3.24*10^8$				

Table 31(a): Analysis of Variance for Model A

Source	DF	SeqSS	AdjSS	AdjMS	F	P
River	56	361.987	361.987	6.4641	110.98	<0.001
Year	15	13.2522	13.2522	0.8835	15.17	<0.001
Error	840	48.9258	48.9258	0.0582		
Total	911	424.1651				

Table 31(b): Analysis of Variance for Model B

Model A accounts for 81% of the total sum of squares while model B accounts for 89% and represents a better fit to the data. Model B was chosen for further examination for this reason and because the lack of normality in the residuals of model A was considered sufficiently serious to introduce bias.

Using the data from all rivers the model demonstrated a very high level of significance of difference in catch between rivers but it also detected a highly significant difference in the annual catch from year to year, the means of which (with confidence intervals calculated as 2 x SE either side of the mean) are shown in Figure 29.

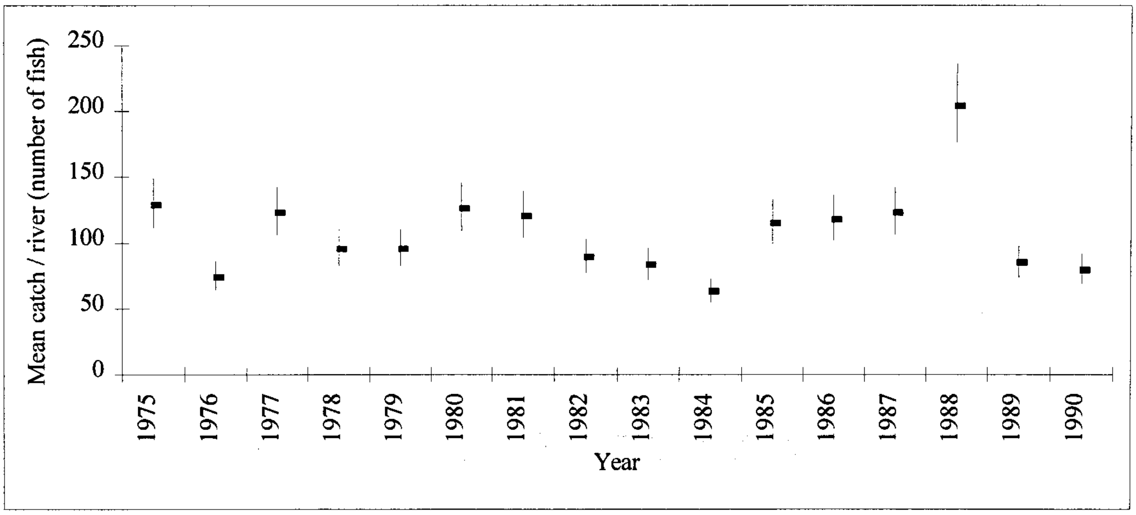


Figure 29: Annual variation in salmon catch calculated from Model B

This suggests that there is a basal level of annual variation of catch which is similar between most of the river systems considered. However, a cursory examination of the data reveals that there are also obvious differences in temporal variation (an interaction effect) between river systems and this can be inferred from the correlation matrix presented in Table 32 showing only those correlations testing as significant at the p=0.05 level.

This apparent difference cannot be tested using Analysis of Variance (ANOVA) because annual catches cannot be replicated but the contour plot of the residuals (Figure 30(a)) from the model with the rivers ordered by catch demonstrates that there are systematic patterns in the residuals which cannot be attributed immediately to any cause.

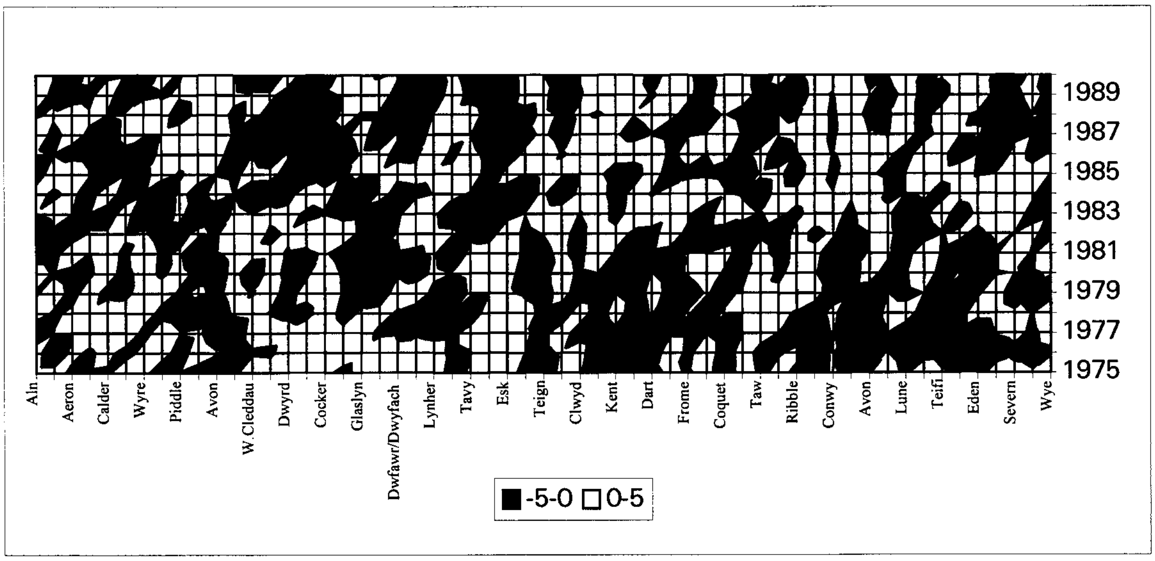


Figure 30(a): Contour plot of residuals from model B with rivers ordered by salmon catch

In order to investigate this further a cluster analysis by average linkage between groups was carried out on the residuals using the cosine of vectors of variables as the distance measure for clustering cases in order to highlight temporal differences rather than simply the size of the catch. This reordered the rivers according to the dendrogram (Figure 30(b)) and produced a more consistent pattern of residuals as shown (Figure 30(c)).

	Erch	Aber	Erne	Axe	Aln	Loughor	Aeron	Dysynni	Calder	Gwyrfai	Wyre	Esk	Piddle	Duddon	Avon	Ellen	W Cleddau	Llyfni	Dwyrd	Plym	Cocker	Leven	Glaslyn	Irt	Dwfawr/Dwyfach	E. Cleddau	Lynher	Ehen	Tavy	Hodder	Torridge	Esk	Lyn	Teign	Clwyd	Wear	Kent	BorderEsk	Dart	Camel	Frome	Fowey	Coquet	Taw	Dyfi	Ribble	Conwy	Exe	Tyne	Avon	Dee	Lune	Tamar	Derwent
Erch																																																						
Aber																																																						
Erne																																																						
Axe																																																						
Aln																																																						
Loughor																																																						
Aeron						.7																																																
Dysynni						.6	.6																																															
Calder																																																						
Gwyrfai						.6		.7																																														
Wyre						.5	.8	.7																																														
Esk						.5	.6	.6																																														
Piddle					.6																																																	
Duddon								.5				.9																																										
Avon														.6																																								
Ellen																																																						
W.Cleddau						.5		.5		.7																																												
Llyfni				.7		.7				.7							.8																																					
Dwyrd						.5		.6		.7							.6	.7																																				
Plym																																																						
Cocker															-.6																																							
Leven							.6	.8			.7	.6		.7					.5																																			
Glaslyn								.5		.6		.5		.6					.6			.6																																
Irt									.5														.5																															
Dwfawr/Dwyfach				.5		.7		.6			.5							7	.5																																			
E. Cleddau	.6			.9													.6	.8	.6						.7																													
Lynher						.5							.6				.5	.6	.6						.6	.6																												
Ehen							.6				.7			.6	.9							.8	.6	.5																														
Tavy						.8	.9	7			.7	.8		.5			.6	.6	.5			.6			.6		.7	.6																										
Hodder			.6	.6																																																		
Torridge										.7							.5	.7	6		.7																																	
Esk															-.6						.7										.6																							
Lyn																							.6																															
Teign							.6					.6		.6	.8						-.5	.5						.7	.7																									
Clwyd					.7		.6				.6												.5	.6			.6																											
Wear																														6																								
Kent								.5						.6	.7							.6	.6					.7					6	.6																				
BorderEsk															.6						-.7											-.7	.5	.6			.6																	
Dart						.7	.6					.7															.6		.8					8																				
Camel											.6			.6					.6			.8						.5																										
Frome							.5				.5		.7		.5												.7		.7					.8					.8															
Fowey				.6	.5													6							.6	5	7		.6		.5				.5					.6														
Coquet					.7								.6		.7					-.5	-.6													.7		.5					.6													
Taw			.6										6					.5											.5	7	.6																							
Dyfi						.8	.7	.7		.7	.7							7				.5	.5		7			.5	.7						.7																			
Ribble			.6								.6		6														.6		.5	.8											.6	.6		.7										
Conwy		-.6																																																				
Exe						.5	.7				.5	.6	.5	.5	.7					-.6	-.6							.6	.7					.8					.8		.7		.8		.5									
Tyne					.6									.7	.9					-.5	-.7	6	.6					.8				-.6		.6			.7	6					.7		.6			.8						
Avon													.7														.6							.6					.7		.8							.6						
Dee						.6	.6	.7		.8	.7						.7	.7	.7						.7	.5	.9		8						.6				.5		7	.5			.7	.5								
Lune							.5	.7			.6			.6	.7							.7	.7					.8	.5				.6	5	.6		.8	.6							.6			.6	.9					
Tamar			.5	.5		.5							.6					.7							.5		.7		.6	.8											.7	.7		.7		.6				.6	.6			
Derwent						.6	.7	.6			.6			.6	.6							.7	.6					.9	.7					5			.5				.5				.6			.7	.8			.8		
Eden															.6					-.6	-.7							.6				-.6	.7				.7	.7											8			.8		.6

Table 32: Matrix showing significant correlations for temporal variation between river systems for salmon

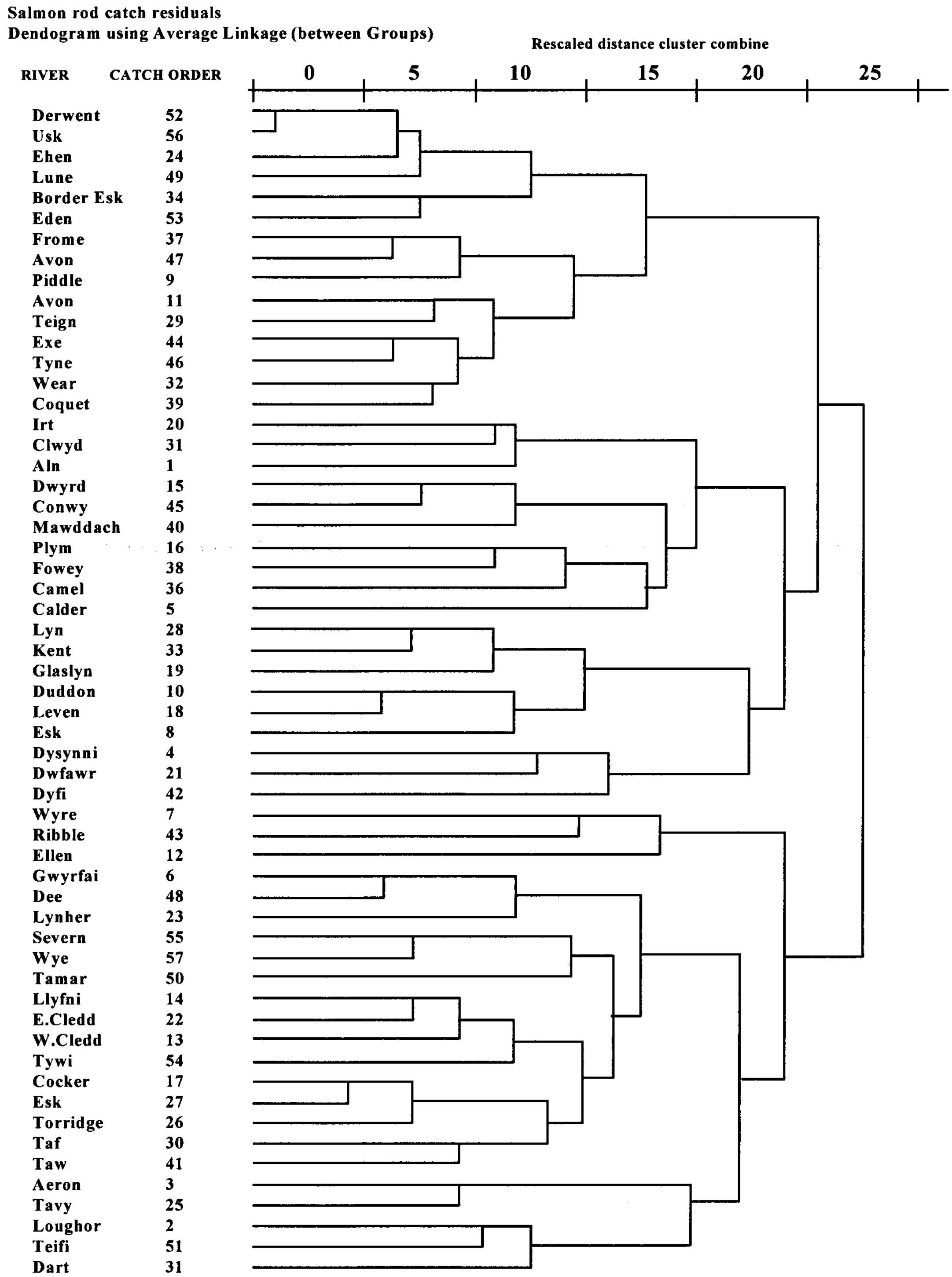


Figure 30(b): Dendrogram of average linkage between groups of rivers for salmon rod catches

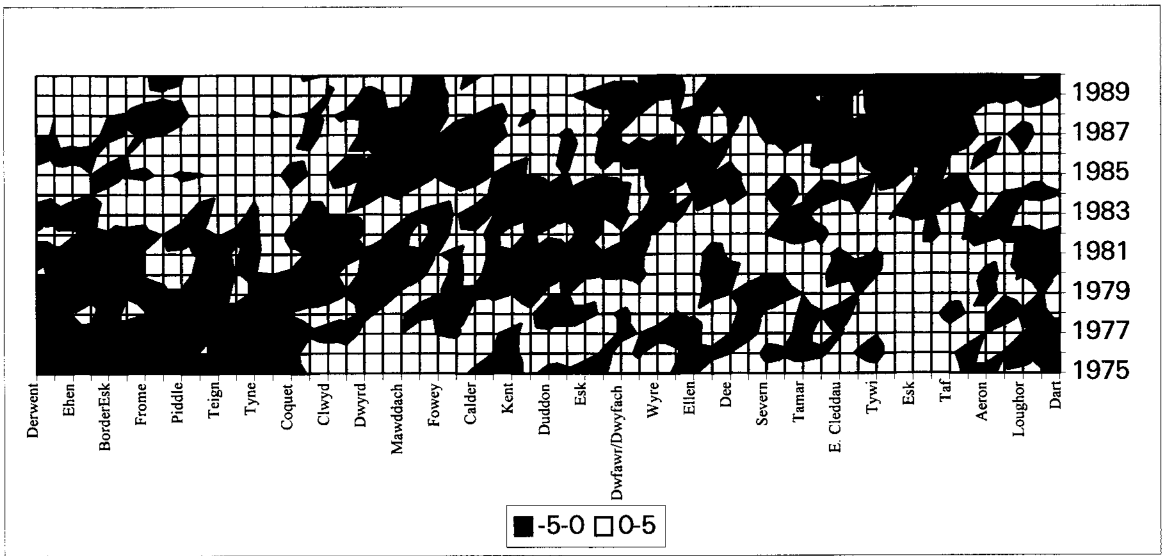


Figure 30(c): Contour plot of residuals from model B with rivers ordered according to the dendrogram presented in Figure 30(b)

There are certain clusters which are obviously related to geographical regions but it is noticeable that there are exceptions to this regional clustering. Both observations may have practical significance.

Whilst cluster analysis groups cases according to their attributes it does not test for significant differences between clusters. This is not possible using other methods subsequent to the analysis because the membership of clusters formed randomly. However it is still possible to examine the extent of differences between clusters using a statistical technique provided the observed differences are not considered as the application of a statistical hypothesis test.

In this instance zscores of $\log_{10}$(catch) for the selected rivers were calculated in order to provide replicates for an analysis of variance testing the interaction between the annual means in the two biggest clusters (see Table 33) (On the dendrogram:- Derwent to Coquet and Irt to Dart).

Source	DF	SeqSS	AdjSS	AdjMS	F	P
Year	15	212.39	220.45	14.70	23.84	<0.001
Clusters	1	0.00	0.00	0.00	0.00	1.00
Year*Clusters	15	84.77	84.77	5.65	9.17	<0.001
Error	832	512.84	512.84	0.62		
Total	863	810.00				

Table 33: Analysis of Variance for zscore of $\log_{10}$(salmon catch)

Expressing the catches as zscores standardises the data by river (see Figure 31) so the difference in means between the two clusters is lost. However, the interaction term between the clusters and years tests significant so the annual means for both clusters are shown with confidence intervals based on 2 x standard error.

It is apparent that the general pattern of annual variation varies little between the clusters. However, the annual means of cluster2 exhibit a downward trend when compared with cluster1 such that in 1975 the zscore of cluster2 was substantially higher than cluster1 but by 1989/90 it was substantially lower. These differences must not be interpreted as statistically significant and the analysis has been included solely to illustrate the effect of cluster analysis in grouping the data.

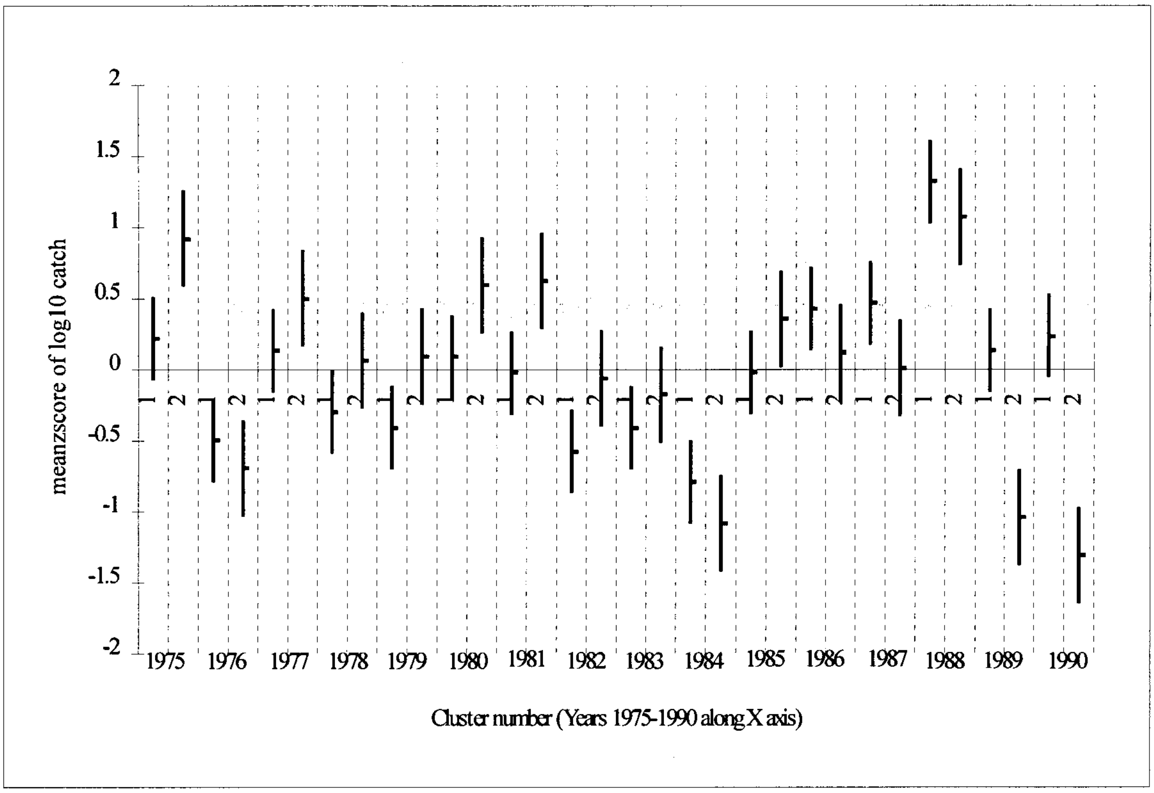


Figure 31: Mean annual zscore of $\log_{10}$ catch by river for two largest clusters

10.5.2 Sea trout rod catch statistics

The identical procedure was followed for selecting and analysing the sea trout catch statistics and model A rejected for the same reasons as for the salmon data.

The Normal plots of residuals are very similar to the salmon data (see Figure 32(a) and 32(b)).

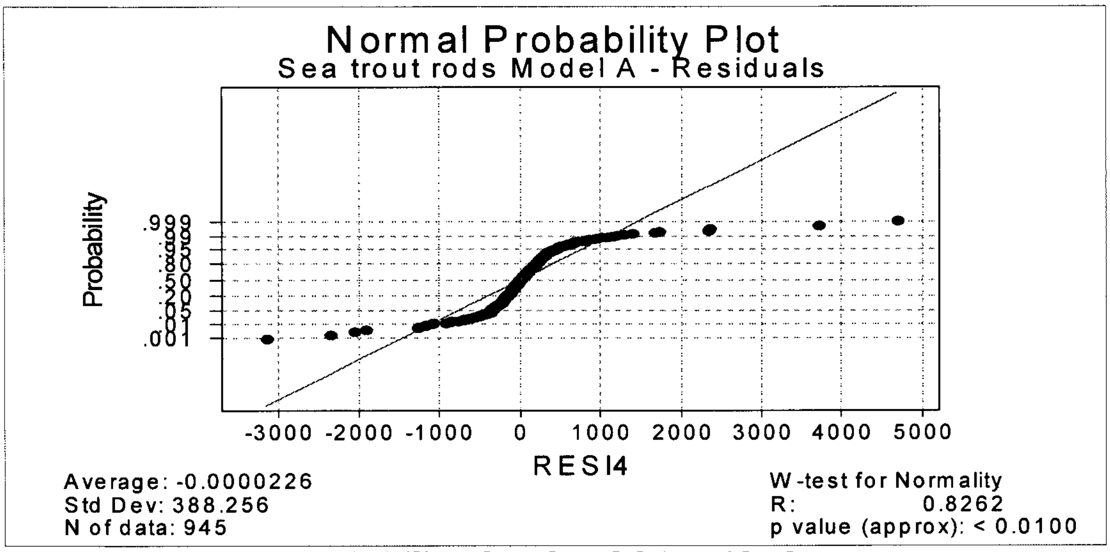


Figure 32(a): Normal probability plot of model A residuals

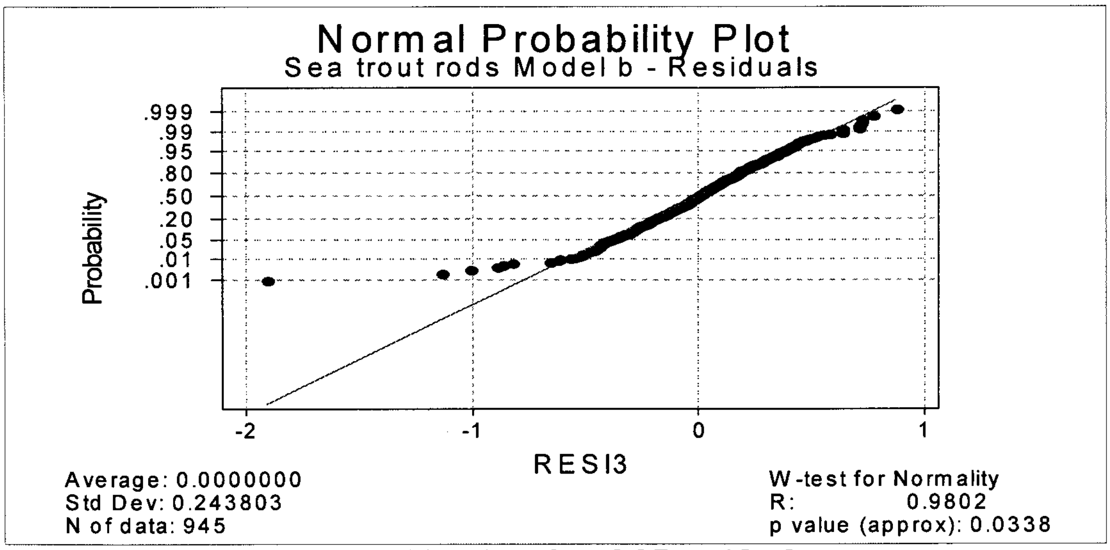


Figure 32(b): Normal probability plot of model B residuals

Analysis of Variance of the data (see Table 34) shows that the logarithmic model accounted for 83% of the total sum of squares. The test for differences between annual effects was highly significant and they are shown in Figure 33 with confidence intervals of 2 standard errors. Most of this variance was attributable to the differences between rivers.

Source	DF	SeqSS	AdjSS	AdjMS	F	P
Years	14	18.07	18.07	1.29	19.97	<0.001
Rivers	62	254.60	254.60	4.11	63.52	<0.001
Error	868	56.11	56.11	0.06		
Total	944	328.78				

Table 34: Analysis of Variance for log10(sea trout catch)

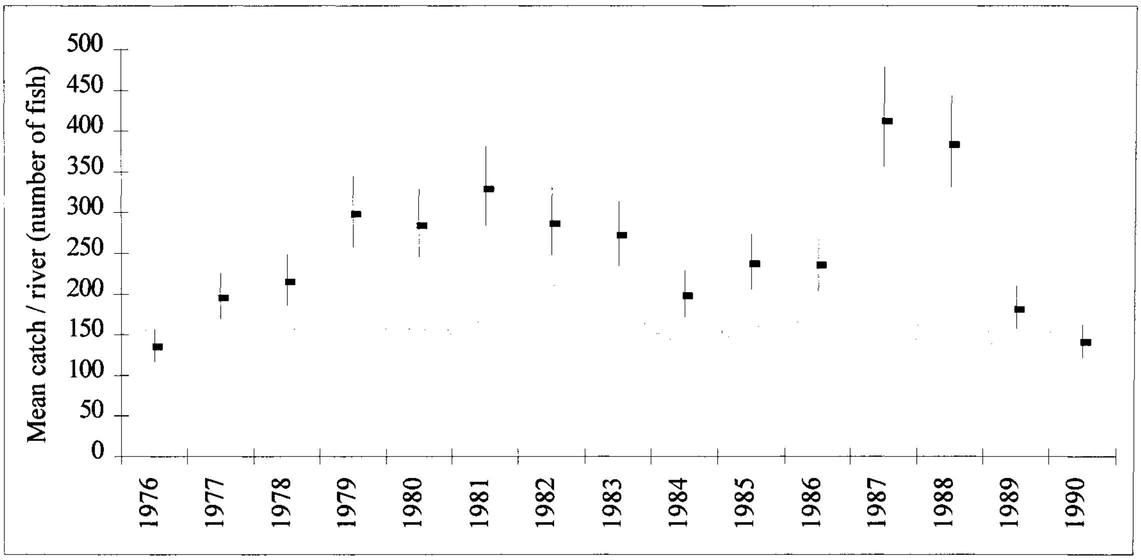


Figure 33: Annual variation in sea trout rod catch calculated from model B

The matrix of correlation coefficients (see Table 35) demonstrates a greater frequency and higher correlation between river systems than for the salmon data.

As with the salmon data when the residuals were plotted on a contour graph of the rivers ordered by sea trout catch as shown in Figure 34(a). There were apparent patterns which were not related to the size of the catch.

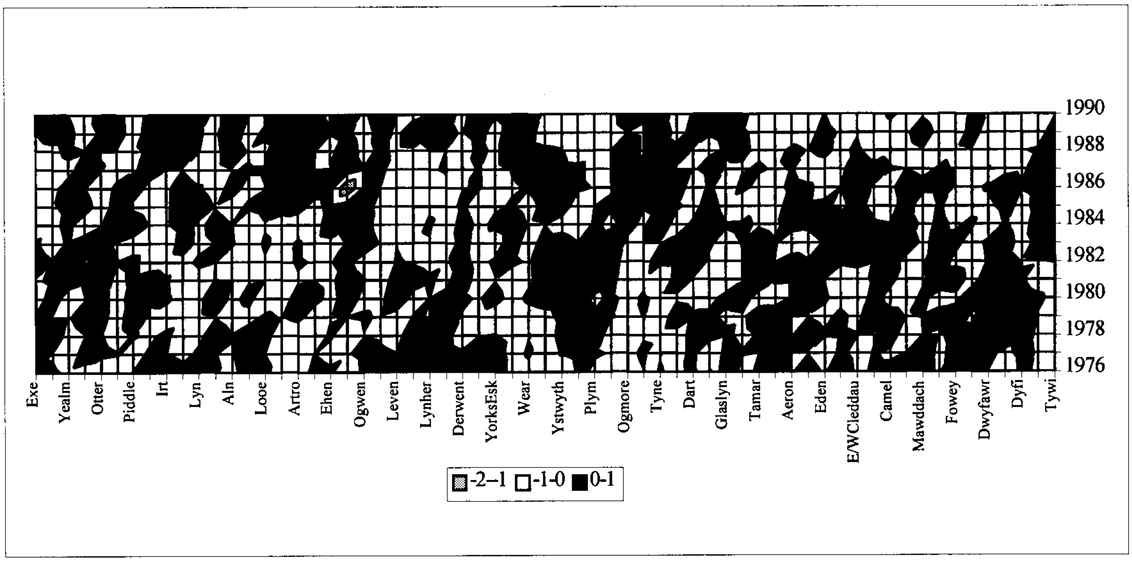


Figure 34(a): Contour plot of residuals from model B with rivers ordered by catch size for sea trout

The cluster analysis was repeated to give the dendrogram (see Figure 34(b)) and it can be seen from the second contour graph (Figure 34(c)) which was prepared with the rivers ordered by their order of appearance in the dendrogram that there are systematic differences in the residuals from rivers in different clusters.

	Ellen	Exe	Wye	Stour	Wyre	Duddon	Yealm	Gwyrfai	Otter	Usk	Piddle	Axe	Irt	Dee	Lyn	Frome	Aln	Esk	Looe	Neath	Artro	Dwyryd	Ehen	Loughor	Ogwen	Dysynni	Leven	Avon/Erme	Lynher	Kent	Derwent	Coquet	YorksEsk	Nevern	Wear	Taf	Ystwyth	Torridge	Plym	Seiont	Ogmore	Conwy	Tyne	Llyfni	Dart	Tawe	Glaslyn	Ribble	Tamar	Tavy	Aeron	Border Esk	Eden	Rheidol	E/WCleddau	Taw	Camel	Clwyd/Elwy	Mawddach	Teign	Fowey	Lune	Dwyfawr	Avon	Dyfi	Teifi	Tywi
Ellen																																																																			
Exe																																																																			
Wye																																																																			
Stour																																																																			
Wyre																																																																			
Duddon	.6																																																																		
Yealm																																																																			
Gwyrfai				.5																																																															
Otter																																																																			
Usk																																																																			
Piddle				.6																																																															
Axe									.5																																																										
Irt										-.6																																																									
Dee			.7			-.7																																																														
Lyn																																																																			
Frome	.6			.8		.6					.6			-.6																																																						
Aln							.5					.7																																																								
Esk										-.6			.6																																																							
Looe								.7																																																												
Neath			.6											.5			.7																																																			
Artro							.5	.6									.5			.7																																																
Dwyryd												.7									.5																																															
Ehen							.5				.7								.5																																																	
Loughor					.7				.7																																																											
Ogwen				.6				.8			.5								.6																																																	
Dysynni			.5									.5					.6			.7		.6																																														
Leven			-.6							-.6			.6																																																							
Avon/Erme								.5											.7																																																	
Lynher					.6			.6	.7		.5	.7				.6								.5				.7																																								
Kent						.5						.6										.5				.6		.5																																								
Derwent				.6							.6														.6	-.5																																										
Coquet												.7					.6			.6		.7				.8				.7	-.5																																					
YorksEsk			-.5							-.6			.6				-.6	.7									.7																																									
Nevern			.5				.6			.7				.6			.7	-.5		.7	.5																																															
Wear									.6			.8					.7			.8	.6	.6				.7				.6		.8		.6																																		
Taf				.6			.6	.6			.6										.8		.5								.6			.5																																		
Ystwyth				.7				.8	.7		.5					.6					.7				.6				.6							.8																															
Torridge								.6		-.6	.5																			.6																																						
Plym				.9				.7	.5		.7					.7			.6						.7				.6		.7					.6	.8	.6																														
Seiont				.7				.8	.5		.6										.6				.7				.5		.7					.9	.8	.6	.8																													
Ogmore			.7							.6				.7			.5			9	.7		.5											.7	.6	.5																																
Conwy								.8													.7				.6					.6					.6	.6	.8	.6		.6	.6																										
Tyne			.6							.7							.7	-.6		8	.6												-.6	.9	.7						.8																										
Llyfni				.6			.6	.8			.7								.6		.7		.6		.6			.5			.5					.8	.7	.5	.7	.8		.7																									
Dart		.7			.6				.6															.6					.7																																						
Tawe			.6		.5															.6	5		.6										-.5	.6		.5	.6				.7		.8																								
Glaslyn																								.5		.6				.5		.6																																			
Ribble	.5								.7			.6					.5				.6	.6							.6			.5		.5	.7	.6	.6			.5		.6	.5	.5																							
Tamar				.7	.6		.5	.8	.5		.6								.7						.7			.7	.8		.6					.6	.7	.6	.9	.8				.8	.7																						
Tavy										-.8								.6	.5								.5	.6	.6				.6					.6	.5				-.6						.6																		
Aeron					.5			.6			.8										.6		.8		.5				.5							.7	.7		.6	.6	.5	.6		.7					.6																		
Border Esk				.5							.8					.7							.6				.5	.5	.6										.7	.5				.7					.6	.7	.7																
Eden	.5				.6		.6				.5							-.5			.5		.6											.7		.7	.6						.7			.8					.5																
Rheidol								.5											.6						.6																			.5					.6	.9		.6															
E/WCleddau			.6				.6							.5					.5	.6			8											.7		.6	.6				.7		.7	.5		.8					.6		.6														
Taw				.7				.7			9					.6									.7				7		6					.6	.6	.8	.7	.8		.6		.7				.6	.8	.6	.6	.7		.7													
Camel	.6			.6	.7			.6	.6		6														.6				7							.5	.6	.6	.8	.7				.6	.7				.8	.6						.8											
Clwyd/Elwy							.5	.6						.6					.5		.5		8		8											.6	.5			.6	.7	.6		.7							.7				.7												
Mawddach												.5										.6						.7	.5	6		6						6				5		.6				.7		.6						.5											
Teign				.6			.6	.7			.8								.6		.6		.7		7				6		7					.8	.8		9	.8		.6		.9					.9		.7	.6	.5		.6	.8	.7	.7									
Fowey				.6				.8		-.5	.6								.6						.7		.5	.7	.7		6							.6	.7	.7				.7					.8	.9	.5	.8		.8		.8	.7		.6	.7							
Lune												.5	.6														.6		6	6																	.7					.5							.6								
Dwyfawr				.6				.8	.6		.5										.6							.7	.7	6						.6	8	.8	7	.8		.7		.8				.6	.8	.6						.8	.7		.7	.7	.7						
Avon				.8				.7			.8					.7			.5				.6		.6				.6		.6					.6	8	.6	9	.6		5		.7					7		.7	.7				.9		.5		.8	.7		.7				
Dyfi	.6							.8			.6					.6		.5										.8	.8	.7							7	.8	6	.6		6		.7				.6	.7	.7	.6	.7				.7	.7		.7	.6	.7	.6	.9	.7			
Teifi				.5				.8			.7								.5		.7		.8		.7				.7							.8	8		.7	.8	.6	.7		.8		.6		.6	.7		.8	.6	.7		.8	.7	.6	.8		.8	.6		.6	.7	.6		
Tywi							.7	.6	.6											.6	.8		.6	.5					.6					.8	.5	.8	7		5	.7	.7	6	7	.6		.7		.6	.6		.6		.8		.8	.5		.7		.7						.9	

Table 35: Matrix showing significant correlations for temporal variation between river systems for sea trout

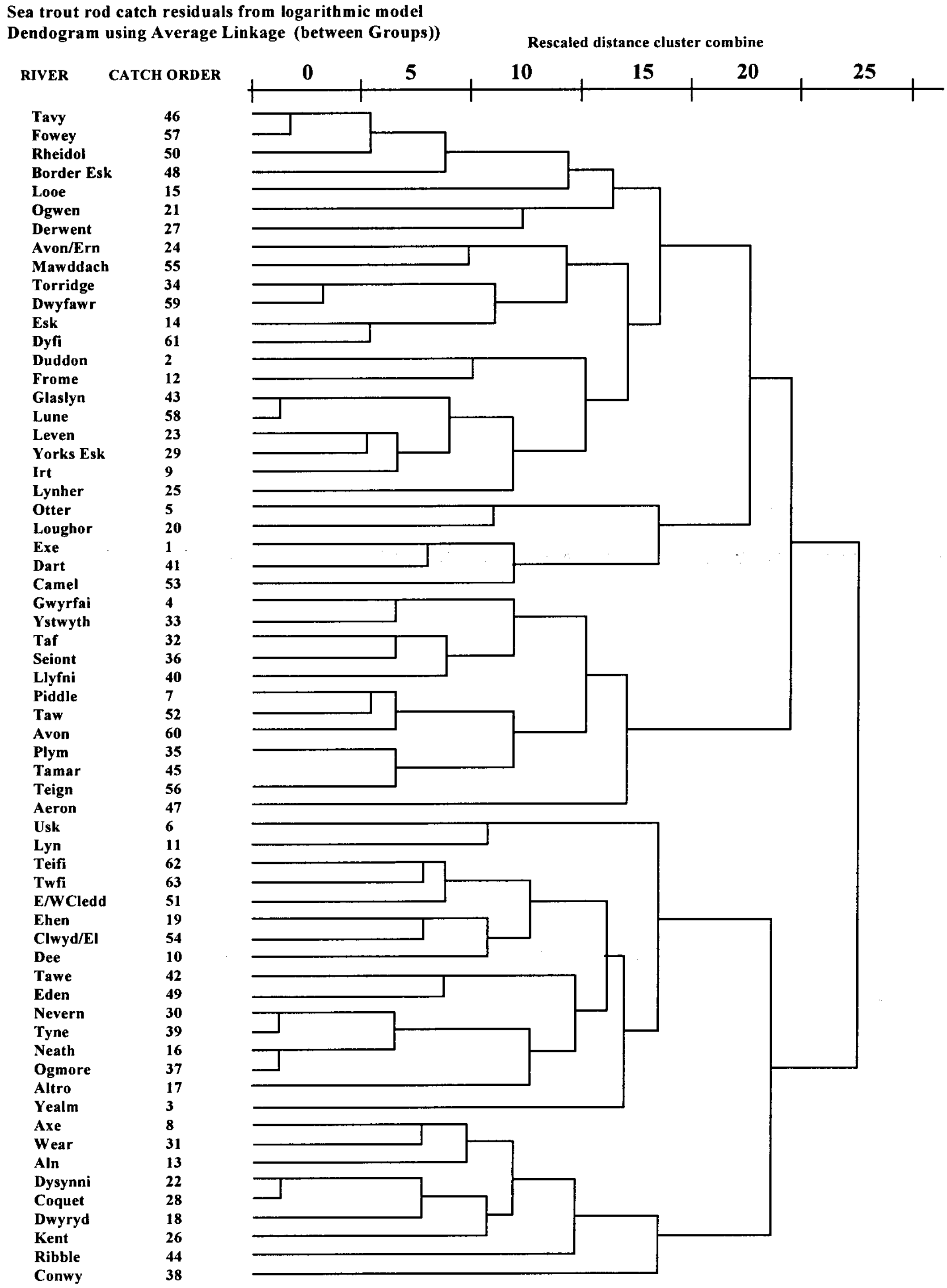


Figure 34(b): Dendrogram of average linkage between groups of rivers for sea trout

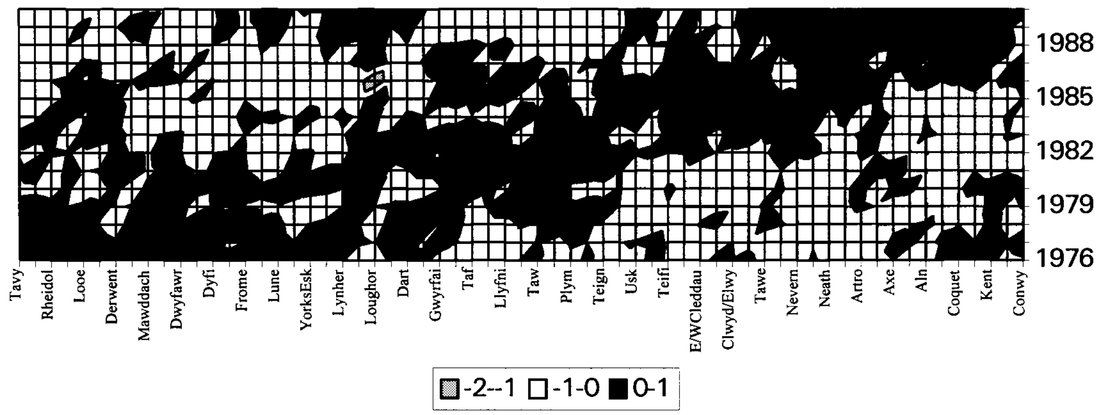


Figure 34(c): Contour plot of residuals from model B with rivers ordered according to the dendrogram presented in Figure 34(b).

The identical procedure to that used for the salmon data was used for the sea trout data to investigate the differences between clusters and in this case it is apparent that the second cluster increases with respect to the first (Figure 35). If it were possible to view the result as a test of significance of the difference some of the differences would be viewed as highly significant and substantial. However, it should be noted that the order of selection of the clusters starts with the selection of the closest pair of cases so the fact that cluster2 for the sea trout data apparently trends in a different direction to cluster2 for the salmon data is irrelevant. The order of selection of the clusters was effectively arbitrary.

Source	DF	SeqSS	AdjSS	AdjMS	F	P
Year	14	239.45	230.45	16.46	27.73	<0.001
Clusters	1	0.00	0.00	0.00	0.00	1.00
Year*Clusters	14	94.39	94.39	6.74	11.36	<0.001
Error	900	534.16	534.16	0.59		
Total	929	868.00				

Table 36: Analysis of Variance for zscore of $\log_{10}$ (sea trout catch)

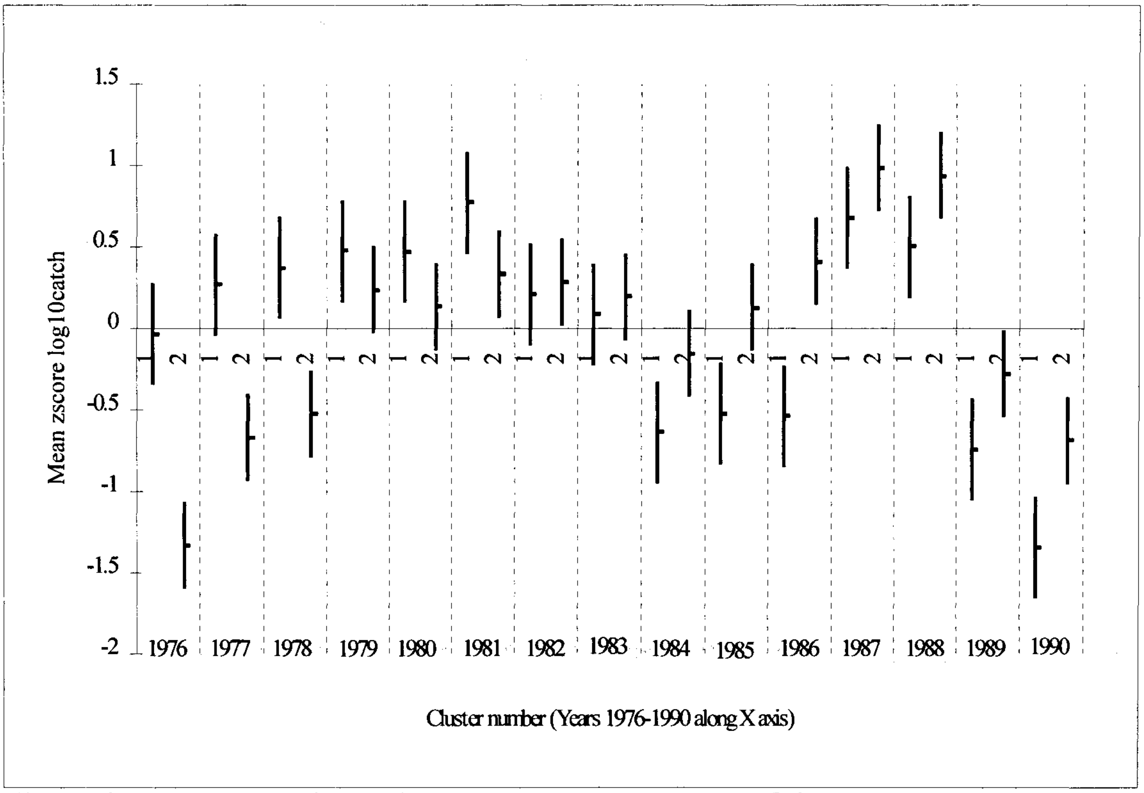


Figure 35: Annual variation in sea trout catch calculated from model B

There is an obvious similarity between the annual effects calculated from model B for both the salmon and sea trout data which has been presented as a scatter diagram (see Figure 36) to demonstrate the relationship ($r = 0.81$; for $p = 0.01$, $r = 0.64$).

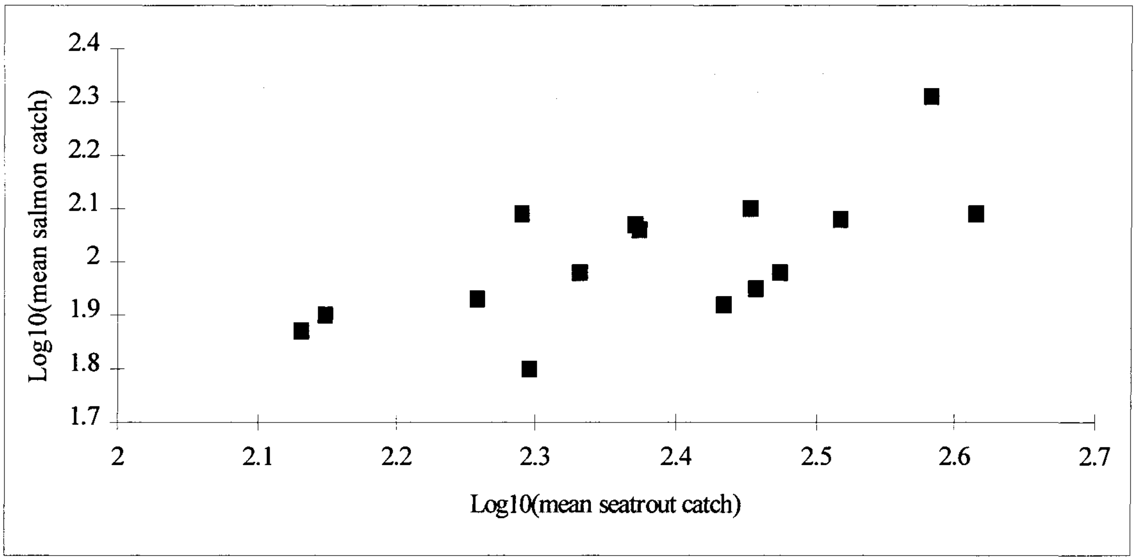


Figure 36: Relationship between mean salmon and sea trout rod catches calculated from model B

Such a correlation is unlikely to occur by chance or, in view of the different life histories of the two species, because of similar production or sea mortality rates. Elsewhere in this report river flow has been shown to be a major factor influencing both angler effort and salmon catch especially in the summer months. Therefore the annual mean effects from the salmon model were plotted against the mean Log_{10}(flow) between June and August for the Ribble and the Wye (Figure 37). Both rivers were not chosen at random but because the data on flows were already available. The mean flows for this period were closely correlated (r = 0.95 for the 15 years considered) for both rivers, as were all rivers in the NW region for which data was available.

The majority of rivers in England and Wales are likely to show similar relationships for flow and catch. If this is found, then the observed correlations of rod catches of both salmon and sea trout for the different rivers listed in Tables 32 and 35 may be due to the dependence of catch on flow for both species.

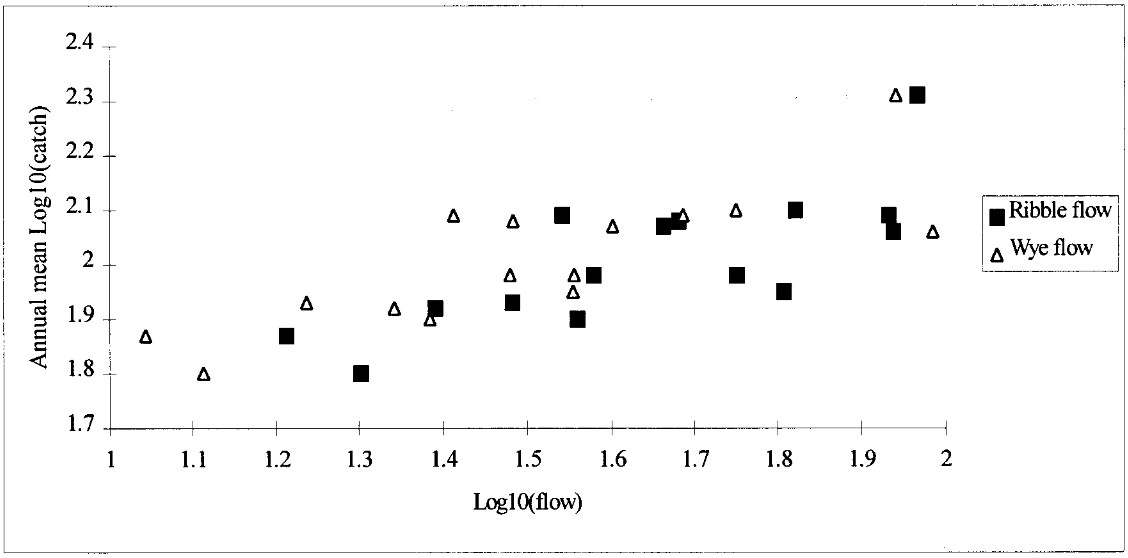


Figure 37: Relationship between Annual mean national catch and flow in two different rivers

10.6 RIVER LENGTH DATA

For the rivers enumerated below the following river attribute data was supplied by the Welsh Region of the Agency :-

- Number of tributaries
- Length of main river
- Total catchment length
- Length of all tributaries (including unavailable lengths)

One further variable were calculated:-

Average tributary length = Tributary length / Number of tributaries

No further consideration was given to "Total catchment length" since it duplicates the information in two of the other variables.

Data was used from the following rivers:-

Aeron	Glaslyn	Ogwen	Teifi
Artro	Llyfni	Rheidol	Tywi
Conwy	Loughor	Seiont	Usk
Dyfi	Mawddach	Taf	Wye
Dysynni	Nevern	Tawe	Ystwyth

Since the variables were highly correlated a Principal Components analysis was carried out on the data for the four remaining variables. The eigenvalues, the proportion of the variance explained and the coefficients of the first three components are presented in Table 37.

Eigenvalue	3.1085	0.6353	0.2472
Proportion	0.777	0.159	0.062
Cumulative	0.777	0.936	0.998

Variable	PC1	PC2	PC3
Tributary length	-0.552	0.215	0.276
Main river length	-0.512	0.118	-0.845
Average tributary length	-0.388	-0.912	0.115
Number of tributaries	-0.532	0.329	0.443

Table 37: Principle component analysis of river attribute data

The first component reflects the size of the catchment but the sign is reversed so that small rivers have large scores and large rivers small scores. The second component appears to be primarily a comparison of average tributary length and the number of tributaries in a river system weighted towards tributary length. Therefore a river with large tributaries will have a small score for PC2. The third appears to be a comparison between main river length and number of tributaries with large rivers with few tributaries giving a small score.

The three principal components were then regressed against the average salmon and sea trout rod catch for the various rivers. The regression equation for salmon was found to be:-

Mean salmon catch = 427 - 407PC1 + 142PC2 - 796 PC3

The statistical results of this regression are shown in Table 38(a).

Predictor	Coef	Stdev	t-ratio	p
Constant	427.29	54.74	7.81	<0.001
PC1	-406.93	31.9	-12.76	<0.001
PC2	142.06	70.56	2.01	0.062
PC3	-795.7	113.1	-7.03	<0.001

s = 238.6 R-sq = 0.935 R-sq(adj) = 0.922

Analysis of Variance

SOURCE	DF	SS	MS	F	P
Regression	3	$1.2*10^7$	4104418	72.1	<0.001
Error	15	853922	56928		
Total	18	$1.3E*10^7$			

SOURCE	DF	SEQSS
PC1	1	9265279
PC2	1	230767
PC3	1	2817208

Table 38(a): Regression statistics of average salmon rod catch against river attributes

The results for the same regression analyses for the sea trout data are presented in Table 38(b).

The regression equation was :-

Mean sea trout catch = 767 -309PC1 + 323PC2 + 1483PC3

Predictor	Coef	Stdev	t-ratio	P
Constant	766.7	139.9	5.48	<0.001
PC1	-309.02	81.54	-3.79	0.002
PC2	323	180.4	1.79	0.094
PC3	1483.4	289.1	5.13	<0.001

s = 609.9 R-sq = 0.745 R-sq(adj) = 0.694

Analysis of Variance

SOURCE	DF	SS	MS	F	P
Regression	3	$1.6E*10^7$	5442490	14.63	<0.001
Error	15	5580042	372003		
Total	18	$2.2E*10^7$			

SOURCE	DF	SEQSS
PC1	1	5343003
PC2	1	1192940
PC3	1	9791524

Table 38(b): Regression statistics of average sea trout rod catch against river attributes

It can be seen for both salmon and sea trout that the regression coefficient of the second principal component does not test as significant at the p = 0.05 level, that the coefficient for PC1 is negative for both salmon and sea trout and the coefficient for PC3 is negative for salmon and positive for sea trout. The Sequential Sums of Squares demonstrate that for salmon PC1 accounts for the largest proportion of the Total Sum of Squares but for sea trout PC3 is most influential. Thus rivers providing a substantial salmon catch are large with a high ratio of main river to number of tributaries and rivers providing a substantial sea trout catch may also be large but must have a low ratio of main river to number of tributaries.

10.7 WELSH DATA SET 1956 - 1990

The historical data set for certain rivers in Wales extends back to 1956 and some of these rivers are included in the river attributes data set. No changes in the procedure to those outlined in section 10.4 for model B were made except that the net catches were converted to $\log_{10}$(catch/licence) prior to analysis to calculate catch per unit effort. Additionally, no further analysis was carried out on the clusters to demonstrate the difference between them. Analysis of variance was undertaken on salmon and sea trout rod and net catches (Table 39(a) -39(d)).

Source	DF	SeqSS	AdjSS	AdjMS	F	P
Years	34	9.8965	9.8965	0.2911	3.64	<0.001
Rivers	10	157.6878	157.6878	15.7688	197.19	<0.001
Error	340	27.1889	27.1889	0.08		
Total	384	194.7732				

Table 39(a): Analysis of Variance for Salmon rod catch

Source	DF	SeqSS	AdjSS	AdjMS	F	P
Years	34	12.0174	12.0174	0.3535	4.15	<0.001
Rivers	11	86.5849	86.5849	7.8714	92.37	<0.001
Error	374	31.8708	31.8708	0.0852		
Total	419	130.4732				

Table 39(b): Analysis of Variance for Salmon net catch_

Source	DF	SeqSS	AdjSS	AdjMS	F	P
Years	36	29.1023	29.1023	0.8084	16.11	<0.001
Rivers	9	55.1941	55.1941	6.1327	122.22	<0.001
Error	324	16.257	16.257	0.0502		
Total	369	100.5534				

Table 39(c): Analysis of Variance for Sea trout rod catch

Source	DF	SeqSS	AdjSS	AdjMS	F	P
Years	34	7.1487	7.1487	0.2103	3.28	<0.001
Rivers	11	99.507	99.507	9.0461	141.2	<0.001
Error	374	23.9614	23.9614	0.0641		
Total	419	130.6171				

Table 39(d): Analysis of Variance for Sea trout net catch

In all four analyses the main effects were found to contain significant differences such that there was significant spatial and temporal variation in the catches of both species by rods and nets. The temporal variation has been demonstrated by plotting the main annual effect means in Figure 38.

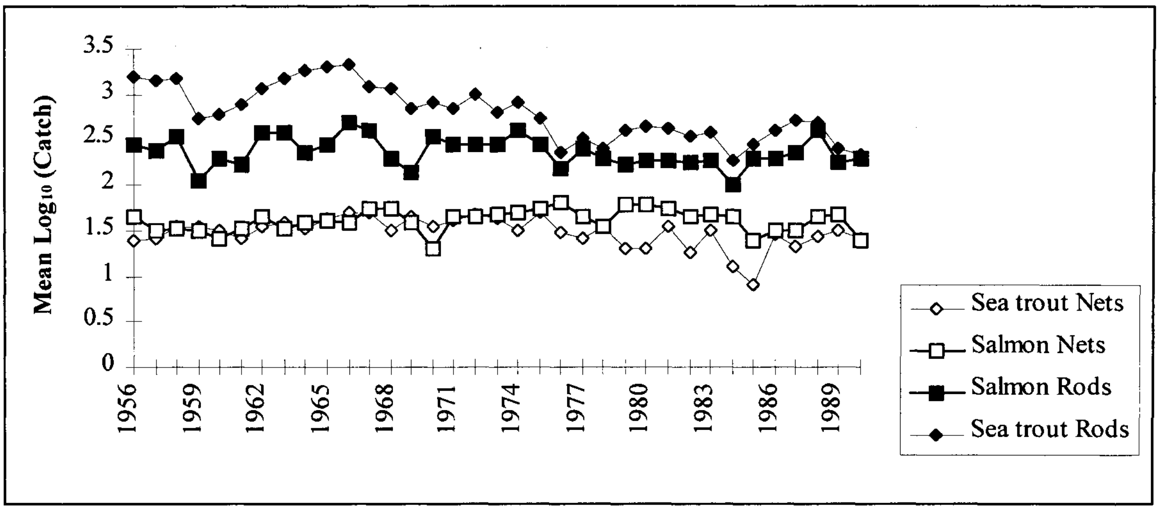


Figure 38: Annual effect means from ANOVA of Welsh rivers

The annual effects were also compared by examining their correlation coefficients which are shown in Table 40. It is apparent that as for the short term data set of all rivers there is a significant correlation between temporal effects for both salmon and sea trout rod catches and for salmon net catches but no relationship was found between sea trout net catches and the other three.

This is consistent with the following composite hypothesis that:

1) The abundance and catchability within each season of salmon and sea trout in a river is largely dependant on flow.

2) The effort expended by anglers, and possibly netsmen, is dependant on their perception of the likelihood of success which is usually based on an assessment of flow.

3) Mean flows in most Welsh rivers are highly correlated.

4) Rod and net catches will be positively correlated if annual abundance is correlated with effort and highly variable.

5) Rod and nets catches sample different components of sea trout populations.

	Salmon net	Sea trout net	Salmon rod
Sea trout net	0.169		
Salmon rod	0.445	-0.042	
Sea trout rod	0.507	-0.08	0.609

p(0.05)= 0.33, p(0.01)= 0.43

Table 40: Correlation Coefficients of Year effects between salmon and sea trout rod and net catches

Cluster analyses were carried on the four data sets and the results are shown in Figures 39(a)-39(d).

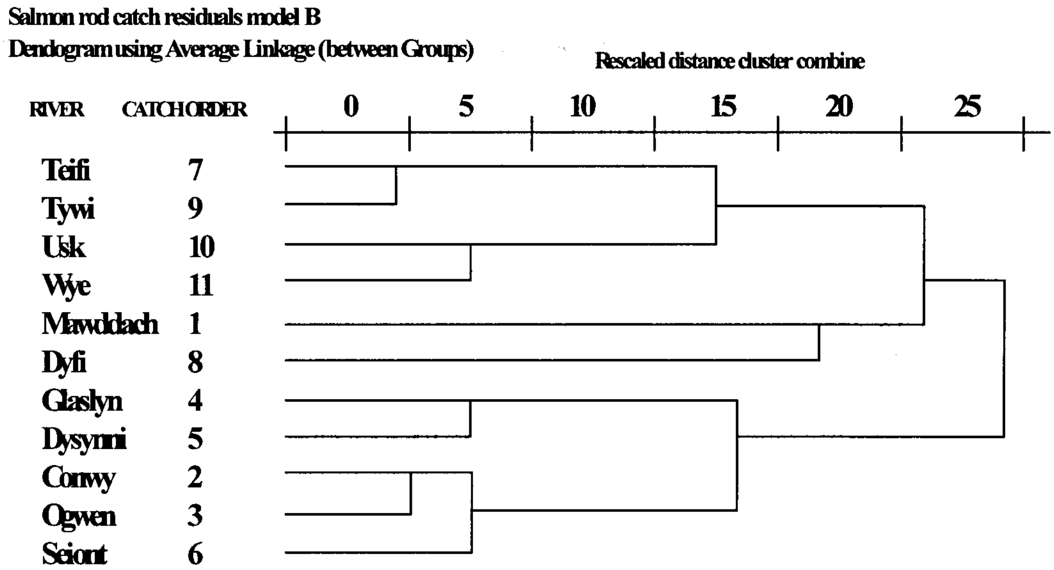


Figure 39(a) Dendogram of average linkage between groups of Welsh rivers for salmon rod catches

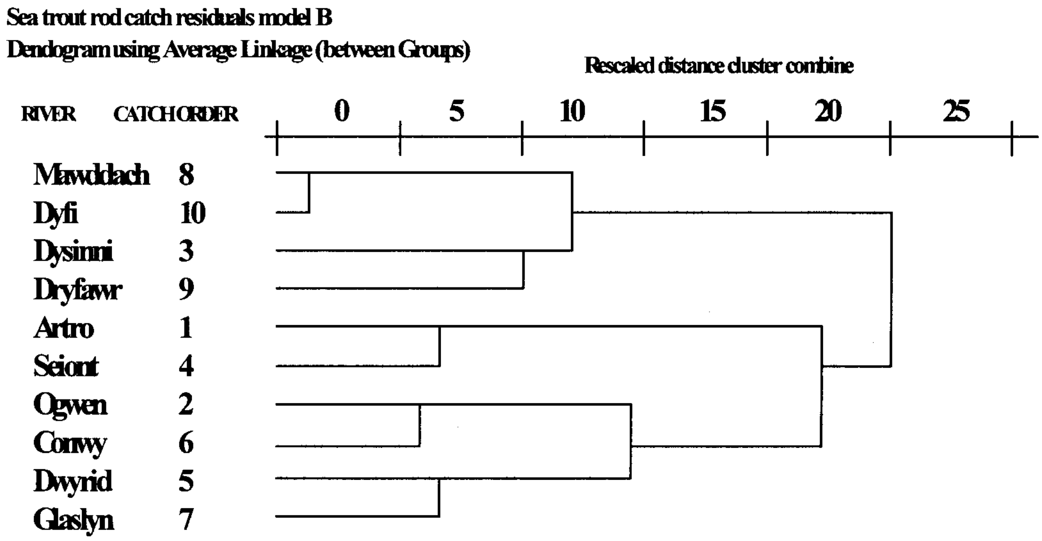


Figure 39(b) Dendogram of average linkage between groups of Welsh rivers for sea trout rod catches

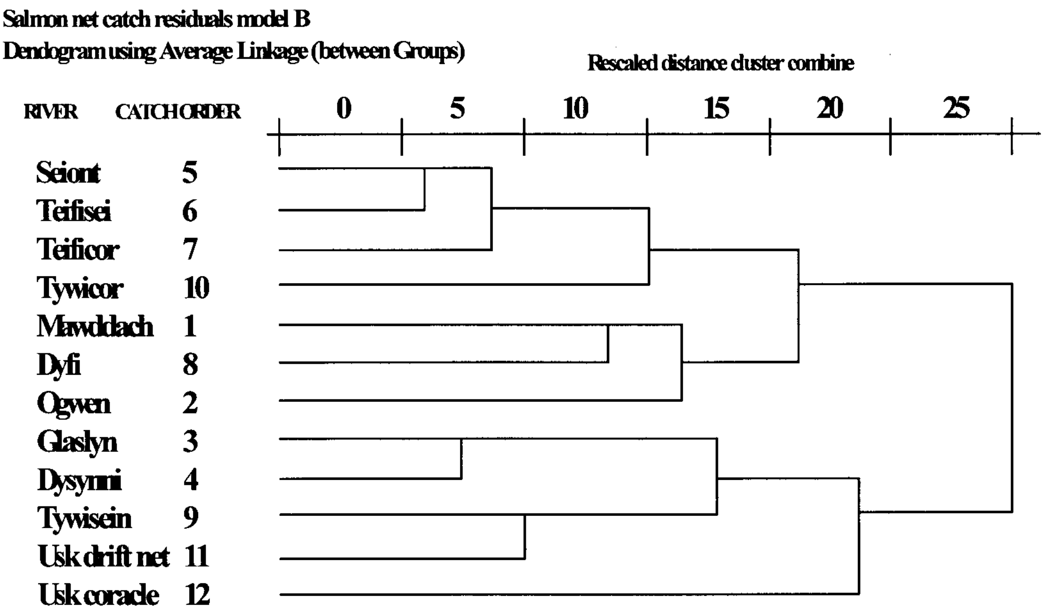


Figure 39(c) Dendogram of average linkage between groups of Welsh rivers for salmon net catches

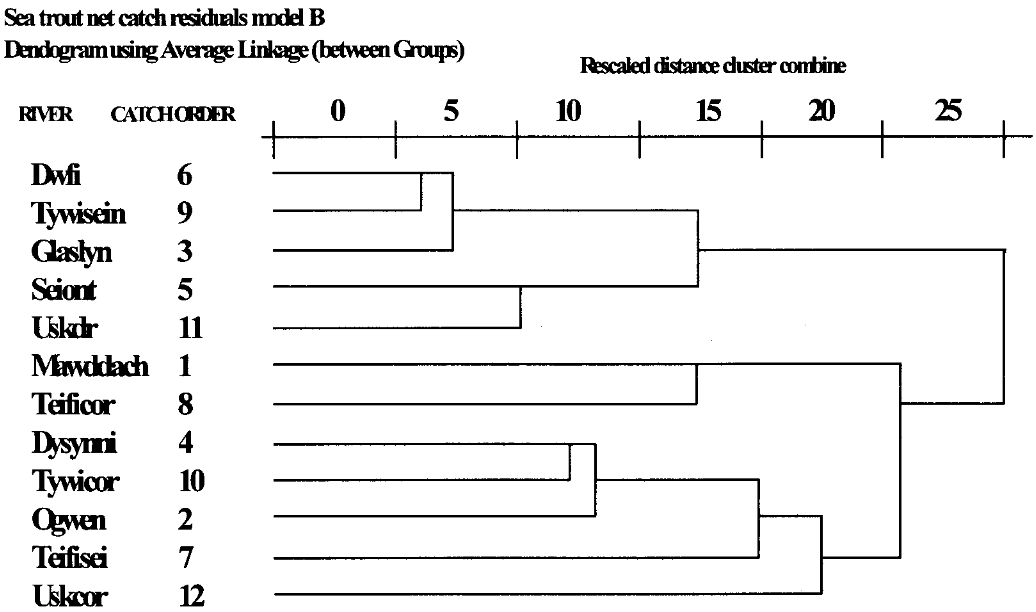


Figure 39(d) Dendogram of average linkage between groups of Welsh rivers for sea trout net catches

There does not appear to be a correspondence between the cluster positions of salmon and sea trout for either rod catch or the net fishery. However, when the salmon rod catch clusters (Teifi - Dyfi =1; Glaslyn - Seiont =2) are plotted against the first Principal Component from the River Attributes data set (Figure 40) some correspondence is apparent in so far that with the exception of the Conwy there appears to be a tendency for the larger rivers to occur in the first cluster.

No comparable coincidence was found with the sea trout rod catch data and the third Principal Component calculated from the river attributes data.

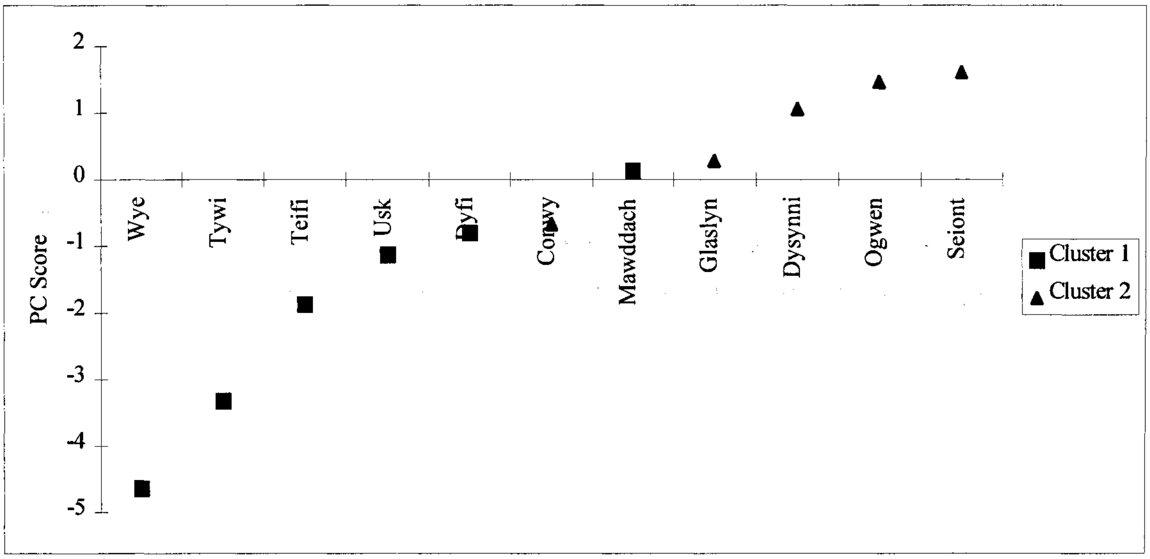


Figure 40: Comparison between PC1 and cluster position of rivers from salmon rod catch analysis

10.8 DISCUSSION

Analysis of the data sets for rivers in England and Wales demonstrated a pattern of temporal variation of catches which was similar for both salmon and sea trout and this appeared to be related to the flow during the months of June, July and August regardless of whether the flow data was taken from the Wye or the Ribble.

The correlation of monthly mean flows in different rivers has not been examined critically other than within the North West Region where data from a number of rivers were found to be closely correlated. In addition the flow for the summer months in the Ribble and Wye are closely correlated. It therefore suggested as a hypothesis, as an explanation of the results, that in the majority of rivers in the data set summer flows are similar and angler effort and success follows the pattern of flow.

It has already been hypothesised elsewhere in this report that salmon anglers match their angling effort largely to their perception of abundance of salmon and sea trout which in turn is related to flow. If this is the case a similarity in pattern of annual catches of salmon and sea trout is likely to follow.

The data set was not examined in detail to determine which rivers departed from the general pattern but the correlation analysis suggests that there are rivers which demonstrate different temporal variation in catches. This could be due to variation in data collection procedures, river size, flow pattern, time of arrival and proportion of different age classes, targeting of different species by anglers or even variation in the spatial distribution of angler effort within different river systems. Some of these variables could be examined using the Analysis of Variance expanded to accommodate regional and size factors, monthly catches and flow as a covariate.

The categorisation of river systems into a classification system can be achieved in a large number of different ways according to what is required from the system. For instance if all that is required is knowledge about the relative magnitude of the total salmon catch of a river the best classification system will be a simple ordering of rivers according to mean annual salmon catch. The fact that in one year a river is third and the next year it is tenth may be used as a relative performance indicator for that river. This will not give any information about the sea trout catch and the comparison may be of little management value because the size and physical geography of the catchments concerned may be widely different or because the annual variation of catch in the rivers concerned is high.

At the other end of the spectrum it may be possible to categorise rivers according to their geographical features or proportion of different types of habitat and thus be in a position to test the catch size against a predicted value based on annual pattern of flow.

Interpretation of the cluster analyses suggests that rivers may be grouped according to the temporal variation in their salmon and sea trout catches. This observation is not useful unless it can be explained and the observed clustering could be a result of any one of the factors described above. However the most likely possibility seems to be that, because catch apparently depends on flow, catch can also be considered as a measure of flow thus all the clustering process may have achieved is to cluster the rivers according to temporal variation in flow pattern. This possibility should be investigated because although this may be an interesting observation it has little value as a basis for classification unless the causative mechanism can be explained. Furthermore until such time the observed relative deterioration in catch in one cluster of both salmon and sea trout against another totally unrelated cluster formed by these analyses must be viewed as a possible artefact of the analysis.

The attribute data of Welsh rivers was limited in extent but still sufficient to demonstrate that for this data set it is possible to identify physical attributes of river systems which provide for high salmon or high sea trout catches. The popular conception is that large swiftly flowing rivers with long main river sections make good salmon rivers and smaller rivers composed of many tributaries and short main stems make good sea trout rivers. The regression analyses of salmon and sea trout catch on the Principal Components derived from the variables measured supported this view. However, the combination of these into the principal components would benefit from greater or more obvious clarity of interpretation. It seems likely that other variables than those available might produce better results and certainly the analysis should be repeated on a larger data set.

The analysis of the longer data set for a limited number of Welsh rivers showed that the pattern of temporal variation for salmon and sea trout rod catches was correlated with that for the salmon net catch; but neither were related to the sea trout net catch. The comparative selectivity of the different methods of exploitation have not been examined but it does not seem likely that during the netting season, the nets in a river system sample a different population of salmon to the anglers. However, in view of the preponderance of whitling in most angling catches this may not be the case for sea trout. If anglers are responding to the abundance of salmon in the river the observed correlations are not surprising. However, if the populations of sea trout exploited by the anglers and the nets are not similar then there is unlikely to be a correlation between the two, since the seledtivity of gear differs in relation to run timing.

The cluster analyses do not appear at first sight to be helpful but local knowledge might supply a reason for the observed clustering. It is interesting that for the salmon rod catches the larger salmon rivers occurred in a different group to the smaller rivers and there is therefore the suggestion that they have a different pattern of temporal variance. This has not been investigated further because it is considered that annual data is not sufficiently detailed to allow the investigation of a phenomenon which is probably related to short term variation in flow.

Cluster analysis tends to be a subjective technique in so far that different measures of distance between clusters and different measures of agglomeration can produce different cluster membership. This is not necessarily a drawback to the value of the technique because there must be some interpretation in the choice of categories for a classification system. It is considered that cluster analysis, as used here, has so far failed to produce a clear lead on which categories are important. If river flow is the main influence on temporal variation in catch, then the clustering process will to a certain extent have grouped rivers according to their flow variation and in theory catches could be adjusted to allow for this. It is likely to be more useful to categorise rivers by comparing their catch of salmon and sea trout with their physical attributes such as length of mainstem in comparison with the number and length of tributaries. Examination can then be undertaken of the differences in temporal variance of both flow and catch between and within the groups.

This approach converges on the HABSCORE method in that the geographical attributes of a river will dictate how much suitable habitat it contains for salmon and sea trout. Examination of the temporal variance in catch may then allow determination of reasons for the variability in different river types.

It seems likely that the smolt production, catch and possibly exploitation rates of salmon and sea trout rivers can be related to geographical factors and therefore it should be possible to group and order rivers according to these variables. Such systems would allow comparison between rivers and therefore assist impact assessments and the targeting of resources.

10.9 RECOMMENDATIONS

The section on Welsh rivers lends support to the hypothesis that the relative production of salmon and sea trout is related to gross river topography. The underlying relationship is much more likely to stem from the relationship between the size and number of tributaries of a river system and the hlding, spawning and juvenile habitats associated with the larger features.

A detailed exploration of the relationships between the physical geographical characteristics of river systems, their patterns of flow and salmon and sea trout catches should be undertaken. This should involve:-

i) Principal Components Analysis of a wider set of river characteristics for a larger range of rivers with the object of defining the subset which accounts for the greatest between rivers variance of salmon and sea trout catch.

ii) Cluster analysis of rivers according to monthly catch of salmon and sea trout in order to obtain subsets of rivers with similar run timings.

iii) Further cluster analysis of subsets obtained from (iii) against seasonal flow in order to group rivers for further examination.

iv) A comparison of basin hydrograph or some other characteristic of river flow pattern with (i), (ii) and (iii) above in order to investigate whether observed differences in catch and run timing is likely to be due to physical habitat affecting production or flow pattern affecting catch.

v) Regression analysis or ANCOVA of selected catch clusters against monthly flow to establish the relationship between catch and flow for a number of rivers or groups of rivers.

11.0 CONCLUDING SUMMARY

11.1 INTRODUCTION

This R&D contract may not have produced a definitive method of analysing and using salmon and sea trout catch statistics to estimate stock size. However, the study has increased the understanding of variability in catches both between and within river systems and has highlighted a number of areas where further research is required. This additional study is required not only to examine the hypotheses formulated in the present work but also because much of the data utilised were of unknown provenance, to check on these findings.

In this summary section the main sources of variation and the models used to identify them are discussed from the viewpoint of stock monitoring and targeting.

11.2 EFFORT

It has been demonstrated that anglers tend to target certain flows in angling for migratory salmonids. Virtually any book on salmon angling will confirm this but the information has never been used by fishery scientists. the most likely reason for this relationship is that the targeted flow brings fresh fish into the river system and anglers know that there is a higher chance of success. In other words effort is related to the anglers' perceptions of the likelihood of success and this may even be influenced by recent catch history. This is important for two reasons.

1. Any measurement of angling effort without consideration of river flow is likely to lead to a misleading interpretation especially if catch per unit effort (CPUE) is calculated. There were indications in the work that CPUE remained relatively constant when measured against increasing flow or effort. Therefore it seems unlikely that in the short-term CPUE reflects abundance.

2. Broadly speaking it is likely that there are two main types of migratory salmonid anglers. There are those who are able to fish when they please and have the opportunity to target the best times and those who lack both experience and opportunity who cannot. The former are probably at the root of the often quoted aphorism that 10% of the anglers catch 90% of the fish. The 90% are most likely to be weekend and holiday anglers. The efficiency of the effort applied by these two categories of anglers is dramatically different and should be taken into account whenever effort is measured or examined.

11.3 FLOW

It is clear from this work that the distribution and size of catch is related to monthly mean flows. However, the underlying relationship is probably between catch and effort which itself depends on the distribution and abundance of salmon which are not responding to a mean flow but the frequency, size and timing of spate conditions. Mean flow is merely a readily available measurement which can be utilised as an approximation of those conditions which affect salmon movement and therefore catch.

11.4 THE ANCOVA MODEL

This model can be used in number of different ways but has not been tested against counter data. Nevertheless it is difficult to conceive of an explanation of the main effects other than that they can be interpreted as indices of abundance. However, the indices relate to the abundance of salmon in a river system which almost certainly depends on the recent flow pattern. The indices are unlikely to reflect either the abundance or availability of salmon outside the river system although this may be possible with data from estuarine nets. Neither do they represent the abundance of the eventual spawning stock or post angling season run although the indices for September and October may relate to the number of spawning salmon in the system.

A further problem with the ANCOVA model is that the time of arrival of different age classes overlaps and the anglers generally fish for a mixed age class stock. Therefore the assumption that there is a relatively constant pattern of arrival of salmon is only relevant prior to the arrival of the grilse run and then only in rivers with few 3 sea-winter salmon or second spawners. this gives rise to a loss of precision in estimating the indices.

It is therefore considered that the main value of this method is to predict the effect on catch of proposed abstraction or river regulation schemes and it will not normally be helpful in estimating returning annual recruitment or residual spawning stock.

11.5 A SIMPLER MODEL WITH WIDER AND MORE FlEXIBLE MANAGEMENT IMPLICATIONS

Even with long-term data sets of semelparous species, such as Pacific salmon the determination of MBAL from a stock recruitment curve gives rise to very wide confidence limits, even at the 50% significance level. Therefore the current spawning targets for English and Welsh rivers extrapolated from the River Bush data are likely to have even larger confidence intervals and great care should be exercised in their use as management parameters until a greater level of precision can be introduced into their calculation.

The determination of spawning and recruitment levels is a prerequisite of salmon management by spawning targets and even this presents major problems.

A possible fallback for the Agency is to define desirable performance bands for the fisheries within their jurisdiction. This suggestion has not previously formed part of this report. However, with the exception of the early spring and possibly October, all the rivers examined demonstrated significant correlations between catch and mean monthly flow if the relationship was examined on a month by month basis. therefore it is possible to fit a regression line to each individual month and examine the residuals (the distance each point lies above or below the regression line) for each year. Each residual contains two elements:

- an element related to the overall availability of salmon able to respond to flows in that month (i.e. abundance in the sea).
- an element related to error.

It is possible to conceive a system whereby these residuals are considered as indices of availability of salmon for each month and thus could be used as the data for examination using a statistical quality control package. This method would lend itself to graphical presentation and could be used as a monthly performance measure for a fishery. It is also possible that with additional information regarding the age class composition and sex distribution for each month that the indices could be combined to calculate an index of stock prior to exploitation.

Further examination of the hypothesis that the October or end of season index relates to spawning stock is required before the two indices could be used in a stock recruitment relationship or even to assess performance of the fishery against a given spawning target.

11.6 CLASSIFICATION OF RIVER SYSTEMS

Only a limited number of data were examined for this study but it seemed probable that salmon catches in most West Coast rivers were correlated as a result of the relationship between catch and flow and the fact the mean monthly flows tend to be highly correlated between these systems. Thus any attempt to classify these rivers according to patterns of catch was more likely to result in a classification according to the pattern of flow. Such a classification would be meaningless in fishery terms unless the effects of flow could first be removed from the data.

Although the data available were limited it does seem likely that a system of classification by physical geography may be possible. From information for the Welsh rivers it appears that catches of salmon and sea trout are highest in large rivers and the relative production of the two species depends in some way on the proportion of main river stem to tributaries.

Therefore catches of migratory salmonids are related to production in the river which is likely to be related to the availability of suitable habitat. The availability of suitable habitat is almost certainly defined by gross physical geography.

Such a classification system would enable direct comparisons between river systems and therefore an examination of relative performance of their fisheries by an extension of the methods described in sections 11.4 and 11.5.

11.7 CONCLUSION

This R&D contract has identified the main variation in salmon catches and has developed or suggested methods by which rivers can be classified in a manner which is meaningful to fisheries management. Further development work is required before these methods can be implemented as standard procedures.

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APPENDIX 1: Migratory salmonid angler creel census forms

SURVEY QUESTIONNAIRE FOR MIGRATORY SALMONID ANGLERS
(The use of catch statistics to determine stock size - 2360(W))

River: LUNE Fishery: 58

Location of angler on fishery (Grid reference: (see map))

Date: 16/7/95 River conditions: LOW FLOW/CLEAR

Weather conditions: OVERCAST

Time started fishing: 11·00a.m

Present time: 2·20pm Total time fished: 3:20

1) What species are you fishing for? SALMON [✓] SEATROUT [ ] BOTH [ ]

2) Do you fish this beat on a regular basis? YES [✓] NO [ ]

3) How do you consider the current river conditions to be for fishing?

GOOD [ ] FAIR [✓] POOR [ ]

4) Do you think fish are present in the area you are fishing? NONE [ ] FEW [✓] MANY [ ]

5) Have you caught any fish today? YES [ ] NO [✓]
(if yes go to question 6, if no go to question 7)

6) What fish have you caught? SALMON [-] SEA TROUT [-]
(enter number in box)

---

7) Why do you fish this beat? PREVIOUS SUCCESS

8) Which other beats do you fish? KILLINGTON
What time of year do you fish these beats? (enter months) JULY - AUGUST
How many days a week do you fish these other beats? ______

9) How many fish have you caught this year?
SALMON 0[✓] <5[ ] 5<10[ ] >10[ ]
SEA TROUT 0[1] <5[ ] 5<10[ ] >10[ ]
(enter number in box).

10) How many fish did you catch last year?
SALMON 0[ ] <5[2] 5<10[ ] >10[ ]
SEA TROUT 0[ ] <5[ ] 5<10[7] >10[ ]
(enter number in box).

11) How many fish have you caught in your angling career?
SALMON [30]
SEA TROUT [20]
(enter number in box).

PILOT FORM

The Use of Catch Statistics to Determine Stock Size ref:2360(w)

Field census form for salmon anglers.

RIVER LUNE FISHERY HALTON TOP BEAT

DATE 2-9-92 GRID REF 516 649

DISTANCE TO NEAREST ACCESS POINT 800m

RIVER CONDITION COLOURED 2½ft UP

PRESENT WEATHER OVERCAST, SHOWERS

TIME STARTED FISHING 08:00 PRESENT TIME 11:05

NUMBER OF HOURS FISHED 3:05

OWNERSHIP OF FISHING RIGHTS NRA

MEMBER OF FISHING SYNDICATE? **(Yes)** No

(Syndicate name LANCASTER ANGLERS)

DO YOU REGULARLY FISH FOR SAMON ON THIS RIVER? Yes **(No)**

WHERE ELSE DO YOU FISH FOR SALMON —

FISHING METHOD SPINNING

DOES METHOD VARY WITH THE CONDITIONS? YES

WHICH METHOD ACCOUNTS FOR MOST OF YOUR FISH? FLY

Beat Information

HOW LONG HAVE YOU BEEN FISHING THIS BEAT? NOT REGULAR

DO YOU FISH SPECIFIC LIES OR COVER THE WHOLE WATER METHODICALLY?

USUALLY LIES.

BEST TIME OF YEAR TO FISH THIS BEAT? OCTOBER

DO OTHER BEATS FISH BETTER AT OTHER TIMES? LOWER BEATS EARLIER.

DOES THIS DEPEND ON WATER CONDITIONS, FISH MOVEMENT OR OTHER?

WATER CONDITIONS

IF YOU COULD FISH ANYWHERE ON THE RIVER WHERE WOULD THIS BE?

LANCASTER ANGLERS OWNED

Angler Experience

HOW MANY YEARS HAVE YOU BEEN SALMON FISHING? 13 YRS

APPENDIX 2: National net catch return forms

EFFORT INFORMATION:

CAPTURE METHOD		EFFORT INFORMATION REQUIRED		
		TIDES	HOURS	NET DRAWS
FIXED NET / TRAP -	Putchers	✓		
	Putts	✓		
	Fixed Seine Net	✓	✓	✓
	T-Nets	✓		
	J- Nets	✓		
	Coops - Esturarine	✓		
	- River (freshwater)		✓	
OTHER METHODS -	Haaf / Heave Net	✓	✓	
	Lave Net	✓	✓	
	Drift Nets	✓	✓	
SEINE / DRAW NET -		✓	✓	✓

For tides:

Indicate the number of tides fished (a tide is from one high water to the next - max two per day). If you did not fish write "0" in the tide column.

The following effort information should be recorded on the catch return overleaf according to capture method.

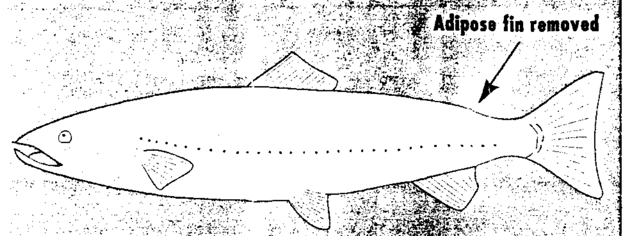
Please complete name and address of licence holder below:

Name...
....

Address..
....
....
....
....

REWARDS FOR TAGGED SALMON AND SEA TROUT

Over the past few years we have released thousands of tagged salmon and sea trout into many rivers. You will not be able to see the tag which is buried in the nose of the fish but to make the tagged fish easily identifiable we have removed the adipose fin. This does not harm the fish in anyway.



Have a good look at any salmon or sea trout you catch - if the adipose fin is missing this is what you should do:

- Dial 100 and ask the operator for "Freephone Fishwatch".
- Tell us your name, address and telephone number.
- Record details of your catch (where, when, size and species of fish).
- Keep the fish or just the head, frozen if necessary, and we will contact you to make arrangements for it to be inspected.

We will pay you a reward if it carries a tag and, of course, you keep the fish. The information obtained from tagged fish is vital in assessing fish stocks, fish movements and the success of our management and stocking activities. This, in turn, will benefit you through better management of fish stocks.

ENVIRONMENT AGENCY

EA Byelaws require you to provide the EA with a catch return at the end of each month, during the fishing season, whether or not you have fished

SALMON AND SEA TROUT CATCH RETURN

This return is confidential and will not be disclosed

Licence No. River / Estuary

Type of net fished : Month 19

					SALMON Number caught in each weight (pounds) category																				SEATROUT No. caught each 1lb wt. cat.										
Date	Day	No. of Tides Fished	Hours Fished	No. of Net Draws	Salmon Total	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 13	13 to 14	14 to 15	15 to 16	16 to 17	17 to 18	18 to 19	19 to 20	20 or over	Sea Trout Total	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 or over
	Mon																																		
	Tues																																		
	Wed																																		
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THIS RETURN MUST BE SENT TO THE AGENCY AREA FISHERIES OFFICE ON THE LAST DAY OF EACH MONTH

For each day: 1) Record date 2) Record effort information as indicated overleaf depending on the capture method. 3)The total number of salmon and sea trout caught and the number of fish in each weight category. If the fish weighs an exact number of pounds, please place in the heavier category i.e 10lbs in the category 10-11lbs. For salmon over 20lbs and sea trout over 10lbs, write individual weights. 4) If no fish were caught write "nil" in the total column.