

Flow Regimes: Do extreme drought flows affect salmonid egg survival?

1 The Issue

On the 7th January 2005 a large flood event occurred in the Eden Catchment in Cumbria. Within a period of 24 hours, a massive cloudburst unleashed the equivalent of two months' rainfall. The Environment Agency said it was believed it to be the worst deluge since 1882. The city of Carlisle, located at the downstream end of the catchment, was the worst affected area.

It is easy to see the impact of such large scale flooding on homes and land that lie on the floodplain and to see the subsequent human cost. It is less easy to ascertain the environmental consequences of such large scale floods and their impact on instream life.

Eden Rivers Trust was interested in using electrofishing survey data to assess whether varying flood return values have an impact on subsequent salmonid fry densities, following the flood event in January.

2 What Was Known Before

Salmon and trout bury their eggs in gravel dug out pits in the river bed between the months of October and January. The fertilised eggs are covered over with gravel and the eggs remain buried in these redds until March. It has been demonstrated that floods which occur after salmonids have spawned can destroy developing eggs and reduce recruitment (Jowett I G & Richardson, J, 1989). Salmonid eggs become eyed 40 days after they are laid and it is prior to the eyed stage that mechanical shock (impact, pressure, vibration) has the most impact on the eggs (Crisp, 2000). Physical disturbance of the redd will cause exposure of the eggs making them susceptible to being washed out and hence subsequent death.

In some tributaries of the River Dyfi in Wales an average of 27% of sea trout redds were washed out during spates (Crisp, 2000). Gravel stability is critical during egg incubation period as high flows in spate conditions can destroy the redd and kill the developing eggs. It has been shown that over 40% of salmonid eggs buried at 15cm and all eggs buried at shallower depths could wash out in a spate of 10-20 years return period (Crisp, 1989).

The depth at which eggs are buried in the gravel is dependant on the size of fish (larger female fish bury eggs deeper) and is dependant on species. Brown trout have an egg burial range of 8-25 cm and salmon have a burial range of 13-30 cm (Crisp, 2000). The depth of sediment disturbance can be expected to increase with increased peak discharge and/or duration (Olsen, D.A.; Townsend, C.R., 2005).

In New Zealand work has been carried out on the effect of a major flood on instream habitat and trout populations. Jowett and Richardson's (1989) results showed little alteration of the instream habitat and although there was evidence of scouring of pools there was little change in the runs and riffles. It was noted that the effects of the flood were more severe on river banks and bankside vegetation than on the instream habitat. Jowett and Richardson (1989) found that post flood brown trout numbers had decreased with the greatest decline occurring in small fish (10-20cm); larger fish being more able to cope with higher water velocities. Ottaway & Clarke (1981) recorded a reduction in juvenile trout but not salmon. This reduction in trout was due to displacement caused by spates during first feeding fry emergence. These studies, however, did not examine the impact of the flood on fish eggs buried in the riverbed.

Results from comparison of Environment Agency macroinvertebrate routine monitoring sites before and after the January 2005 floods (Prigg, 2006) showed no great depletion or modification of faunal diversity or organism abundance two months after the flood. Their results

showed that by autumn 2005 most of the nine sites exhibited an increase in number of families, this was most likely due to habitat improvement caused by the flood de-silting the gravels.

3 What Was Done

An electrofishing survey of salmonid fry densities was undertaken, throughout the Eden catchment, between 9th July and 22nd September 2005, using the methodology described by Crozier & Kennedy, (1994).

A total of 290 sites were surveyed:

- 167 sites were fished as 5-minute preferential fry habitat
- 53 quantitative sites were fished, using a 3-run depletion method

These were combined with 70 sites surveyed by the Environment Agency. The Environment Agency sites were calibrated so they were directly comparable with Eden Rivers Trust's density estimates. Salmonid fry population densities were assigned classes using a five-tiered system (Table 1).

Density Classification	Semi-quantitative (n/5min) Salmon & Trout (Crozier & Kennedy)	Quantitative equivalent (n/100m ²)	
		Carle & Strubb (Eden) for 0+salmon	Carle & Strubb (Eden) for 0+trout
A (excellent)	>23	>60.9	>131.1
B (good)	11-23	29.1-60.8	62.7-131
C (fair)	5-10	13.2-29.0	28.5-62.6
D (poor)	1-4	2.6-13.1	5.7-28.4
E (absent)	0	0-2.5	0-5.6

Table 1 Semi-quantitative electrofishing and its relationship to actual fish densities derived from quantitative electrofishing

The 2005 semi-quantitative electrofishing survey results were then compared with survey data from the previous three years. Changes in trout and salmon fry densities were compared to flood return data, at a catchment and sub-catchment level, to ascertain if there is a relationship between different return periods during the January 2005 flood and salmonid egg survival.

The Environment Agency routinely monitors flow speeds at various locations throughout the Eden catchment. Histograms were produced from this data to show monthly maximum and mean flows recorded across thirteen sites in the Eden catchment from 2002-2005. The Environment Agency used this data to calculate an approximate return period for the January 2005 flood for seven of the rivers in the Eden catchment. Percentage increase in flow of the January 2005 flood over previous maximum flows recorded at various sites within the catchment was also calculated.

The relationships between salmonid fry numbers between years was statistically tested at the catchment scale and also examined at an individual river level for seven rivers in the Eden catchment (Caldew, Dacre, Irthing, Lowther, Petteril and Upper and Lower Eden). For each of these seven rivers, histograms were produced to show mean number of salmon and trout fry per 100m². A Mann-Whitney U test was used to compare fish density between years for each of the different rivers.

The Environment Agency provided ERT with four years of quantitative data on salmon and trout parr (in addition to the salmonid fry data) in the Eden catchment and this has been analysed using a Kruskal-Wallis test to compare the abundance of salmonid parr between 2002 and 2005.

4 Outcome and Results

4.1 Flow data

The highest maximum flow occurred in January 2005 (nearly twice as high as for any other month across all years) with the next highest flow in February 2004 (Figure 3). Although the maximum flow was far greater in January 2005 than any other year, the mean flow in February 2002 was actually the highest of all months for all years (Figure 4). In general the maximum flow measured in a month for a given year is generally 3-4 times greater than the average flows for that period.

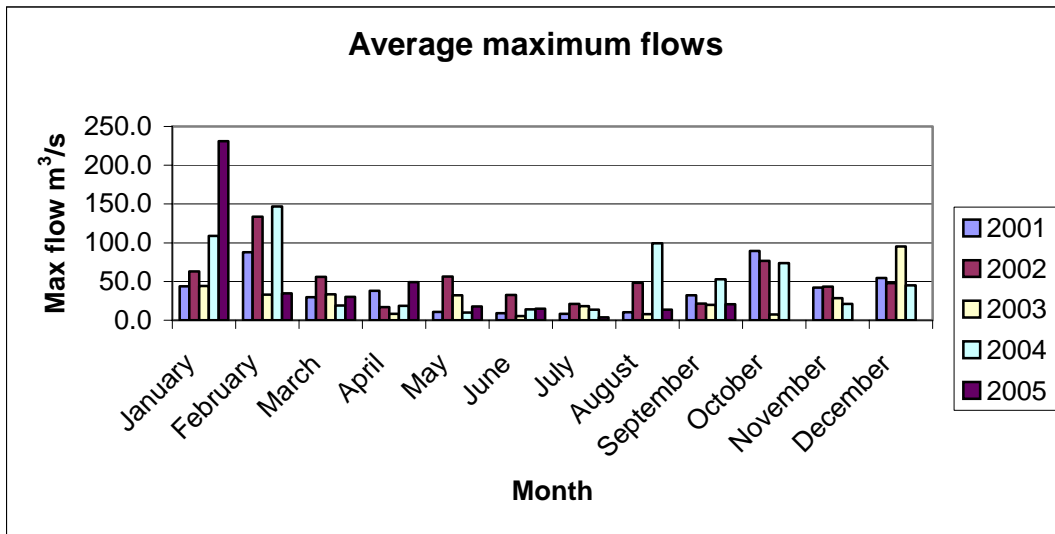


Figure 1 Average maximum flows (EA data) for 13 sites in the Eden Catchment for 2001-2005

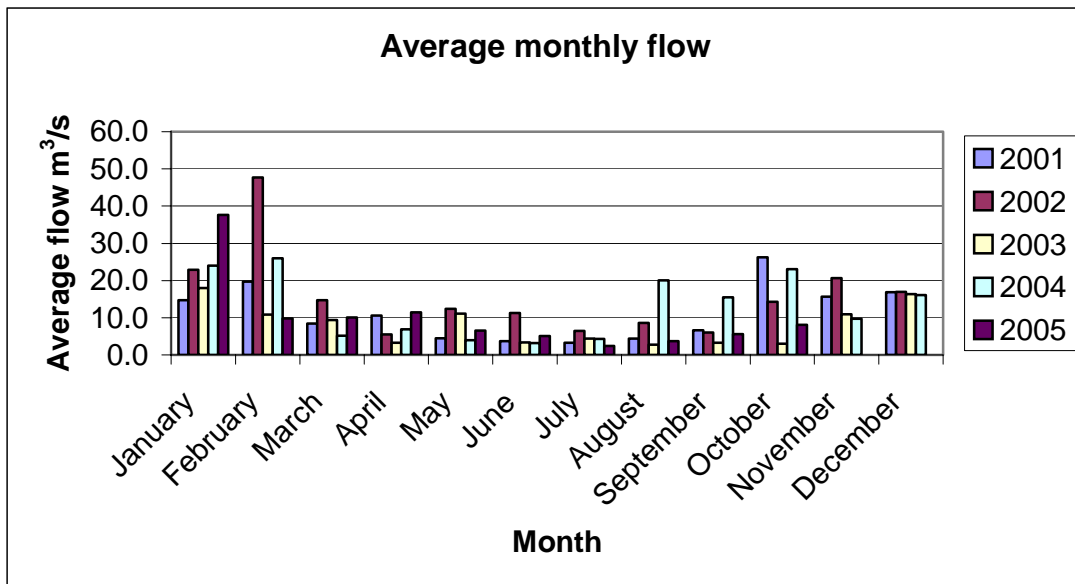


Figure 2 Average flows (EA data) for 13 sites in the Eden Catchment for 2001-2005

Table 2 Flood return periods for the January 2005 flood for different rivers

Catchment and Gauging Station (G.S.) where appropriate		Approximate Return Period of Flood Event January '05	Source of data
Petteril	Harraby Green	100	NW Region Modelling Report
Upper Eden	Gt. Musgrave	<100	Narrative for Flood Event Jan '05
Irthing	Greenholme	75	Greenholme gauged flow and S 105 model
Caldeu	Cummersdale G.S.	25	NW Region Modelling Report
Eamont	Udford	25	River Eamont S 105 Study and gauged data
Lowther		25	River Eamont S105 study and gauged data
Dacre Beck	Dacre Bridge	10	Gauged level data

The actual highest recorded flow data at 13 sites across the Eden catchment shows that during the January flood the flow was between 1000-4000 times greater than the average daily mean for that site with the greatest increase being at Kirkby Stephen on the Upper Eden (Table 3). The January flows are often nearly double that of the next highest flow event (February 2004).

Table 3 Percent increase on long term daily means of January 2005 flood flows

Site	Long Term Average of Daily Means	Highest flow (3 rd) February 2004	Highest flow (7 th or 8 th) January 2005	% increase on mean of January flood
Pooley Bridge U/S, EAMONT	7.9	64.0	88.13	1109
Patterdale Side Farm, GOLDRILL BECK	3.2	29.4	37.74	1164
Udford, EAMONT	15.5	176.3	201.4	1299
Great Corby, LOWER EDEN	37.7	441.6	551.6	1463
Cummersdale, CALDEW	6.7	52.0	130.8	1955
Temple Sowerby, EDEN	14.5	227.1	299.7	2073
Sheepmount, LOWER EDEN	52.3	594.4	1093	2088
US Swindale Intake, SWINDALE BECK	1.0	10.8	22.72	2311
Greenholme, IRTHING	7.8	110.7	180.3	2314
Gt Musgrave Bridge, UPPER EDEN	7.2	96.3	171.6	2371

Harraby Green, PETERIL	2.2	21.2	53.45	2427
Bampton Grange, LOWTHER	2.0	41.7	73.11	3694
Kirkby Stephen, UPPER EDEN	2.6	45.6	98.94	3851

4.2 Salmon and Trout fry numbers within the Eden Catchment

4.2.1 Catchment-wide comparison

Salmon Fry

The overall salmon for an average of all sites (including EA data) surveyed in the catchment is shown in Table 4 (as number of fish per 100m²). Average number of salmon fry was greater in 2005 (post flood) than 2002 or 2004. 2003 has the greatest average number of salmon fry over the catchment compared to any other years although the variance is also the greatest compared to other years. A boxplot showing the mean values, including standard error and standard deviation, for salmon fry across the catchment is shown in Figure 3.

Table 4 Salmon fry descriptive statistics for 2002-2005

Salmon fry	2002	2003	2004	2005
Number of sites	300	232	234	260
Mean no per 100m²	23.91	46.15	14.20	32.22
Median	12.15	16.99	6.62	10.91
Standard Deviation	31.26	64.66	19.42	54.47
Variance	976.91	4180.66	377.15	2966.78

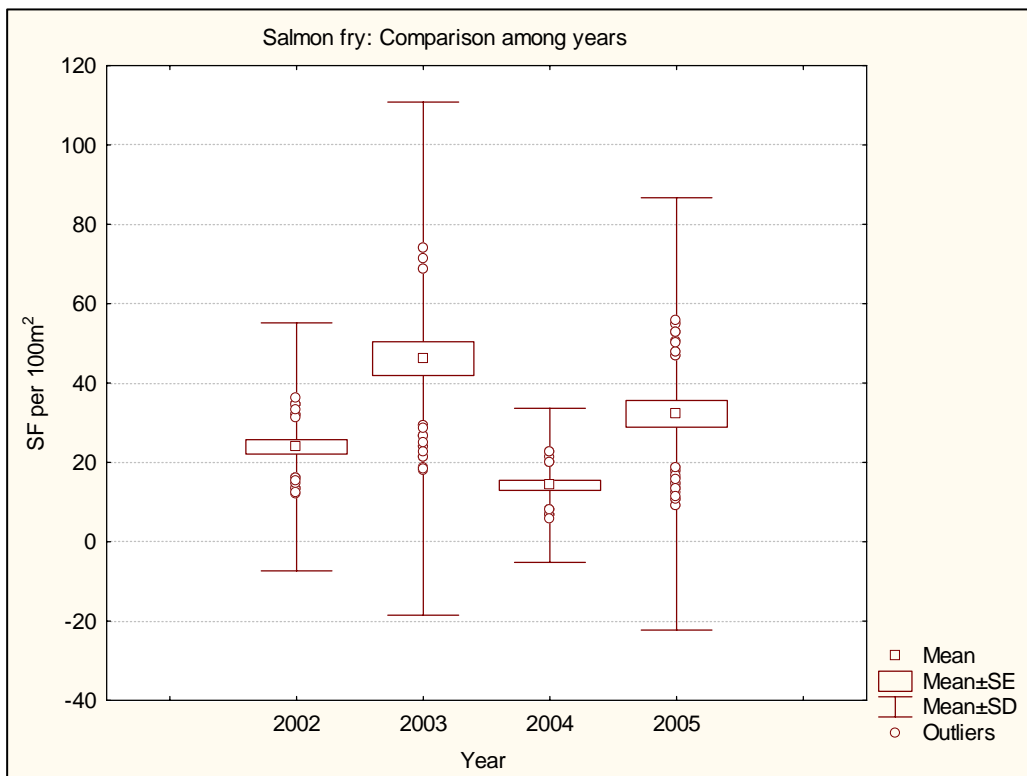


Figure 3: Average salmon fry per 100m² - comparisons between years.

2004 salmon fry numbers per 100m² were significantly lower than all other years sampled over the Eden catchment as a whole (Table 5). The number of salmon fry per 100m² in 2005 (the post flood year) was only significantly different to the densities recorded in 2004 and these numbers were greater in 2005. Salmon fry numbers in 2003 were the highest recorded for the four years and this was statistically significant over fry numbers in 2002 and 2004.

Table 5 Mann-Whitney U test comparisons for salmon fry between years. *=P<0.05, **=P<0.01 and ***=P<0.001

SALMON FRY per 100m2				
				Indicates significant difference
YEAR	2002	2003	2004	2005
2002		0.027*	0.002**	0.782
2003	0.027*		0***	0.074
2004	0.002**	0***		0.003**
2005	0.782	0.074	0.003**	

Trout Fry

The overall n/100m² for trout fry for an average of all sites surveyed (including EA data) in the catchment was lower in 2005 than all previous years surveyed (Table 6). Mean trout fry numbers across the catchment as a whole were greater in 2003 than all the other years surveyed. A boxplot showing the mean values, including standard error and standard deviation, for trout fry across the catchment is shown in Figure 4.

Table 6 Trout fry descriptive statistics for 2002-2005

Trout fry	2002	2003	2004	2005
Number of sites	355	325	296	290
Mean no per 100m2	18.03	46.13	12.67	10.66
Median	2.37	16.92	2.82	0.00
Standard Deviation	54.42	68.97	24.88	29.81
Variance	2961.16	4757.51	618.78	888.48

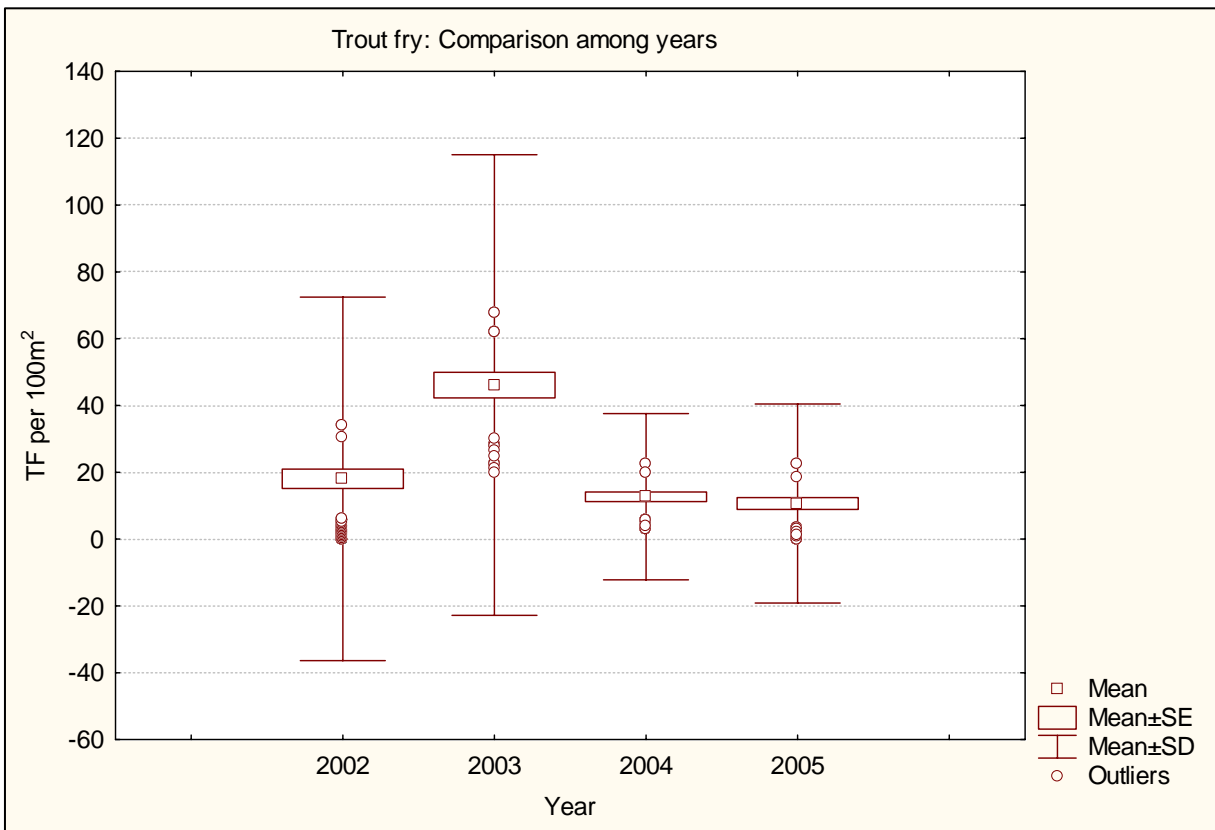


Figure 4: Average trout fry per 100m² - comparisons between years.

2003 trout fry numbers were significantly greater than all other years surveyed (Table 7). Post flood (2005) average trout fry per 100m² was significantly lower on a catchment scale than all other years pre-flood.

Table 7 Mann-Whitney U test comparisons for trout fry between years.

*=P<0.05, **=P<0.01 and ***=P<0.001

TROUT FRY per 100m2		Indicates significant difference		
YEAR	2002	2003	2004	2005
2002		0***	0.331	0.027**
2003	0***		0***	0***
2004	0.331	0***		0.001**
2005	0.027**	0***	0.001**	

4.2.2 River by River comparison

Salmon fry

Figure 6 shows the average salmon fry numbers per 100m² for the seven individual rivers for which flood return values have been given in Table 2. No salmon fry were recorded in the River Petteril in any year and the lower Eden was only sampled in 2003 and 2005. Salmon fry numbers were higher in 2005 than 2004 for all these rivers and 2005 had the highest number of salmon fry compared to all other years in the River Lowther.

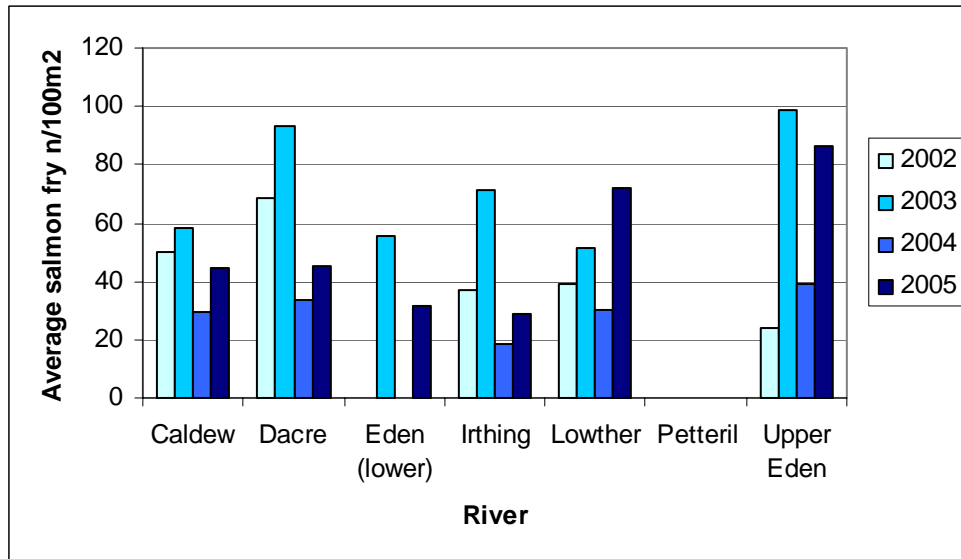


Figure 6: Average salmon fry per 100m² - comparisons between rivers

The only river (out of the seven principal rivers samples) in which salmon fry numbers per 100m² for 2005 differed significantly to any of the pre-flood years was on the Upper Eden where the average fry for 2005 was significantly higher than salmon fry numbers in 2002 (Table 8). For both the Caldew and Lowther there was no significant difference in the numbers of salmon fry per 100m² between any of the sampled years.

Table 8 Mann-Whitney U test comparisons for salmon fry between years for different rivers. *= $P < 0.05$, **= $P < 0.01$ and ***= $P < 0.001$

SALMON FRY per 100m ²		indicates significant difference			
RIVER	YEAR	YEAR			
		2002	2003	2004	2005
CALDEW	2002		0.672	0.083	0.262
	2003	0.672		0.371	0.586
	2004	0.083	0.371		0.75
	2005	0.262	0.586	0.75	
DACRE	2002		0.345	0.102	0.269
	2003	0.345		0.012	0.059
	2004	0.102	0.012		0.563
	2005	0.269	0.059	0.563	
IRTHING	2002		0.746	0.015	0.326
	2003	0.746		0.189	0.558
	2004	0.015	0.189		0.216
	2005	0.326	0.558	0.216	
LOWTHER	2002		0.957	0.311	0.106
	2003	0.957		0.505	0.227
	2004	0.311	0.505		0.109
	2005	0.106	0.227	0.109	
UPPER EDEN	2002		0.102	0.164	0.021

	2003	0.102		0.163	1
	2004	0.164	0.163		0.061
	2005	0.021	1	0.061	
LOWER EDEN					
	2002				
Only sampled in 2003 & 2005	2003				0.395
	2004				
	2005		0.395		
PETTERIL					
NO SALMON PRESENT					

Trout fry

Comparisons of average trout fry on six different rivers in the Eden catchment is given in Figure 7. The lower Eden is not included as trout fry are only found in the upper reaches of the becks. The Caldew and Upper Eden have the lowest numbers of trout fry per 100m² in 2005 compared to all other years studied. 2003 had the highest number of trout fry for all of the rivers compared to all other years.

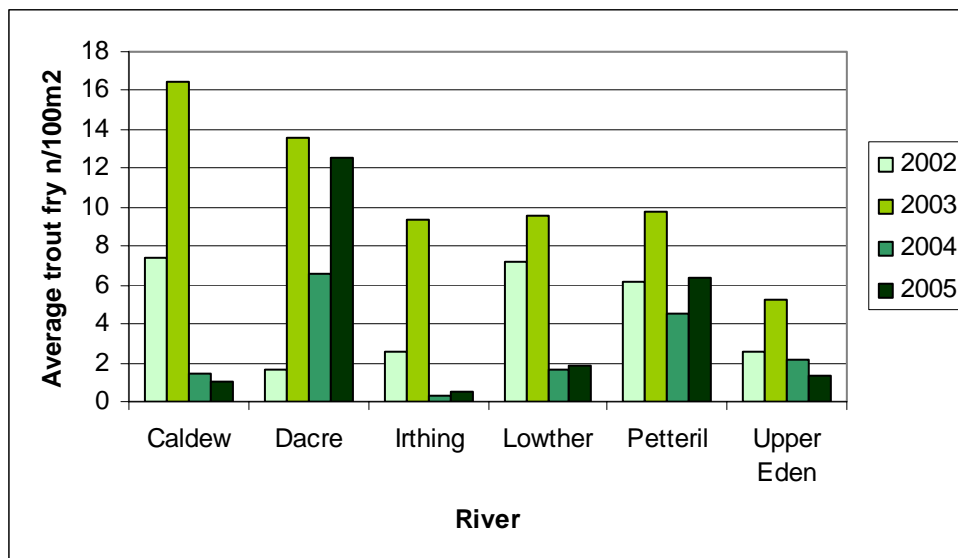


Figure 7: Average trout fry per 100m² - comparisons between rivers

The only rivers in which post flood (2005) trout fry numbers per 100m² differed significantly to any of the pre-flood years was on the Caldew and Lowther and then the average fry for 2005 was significantly lower than trout fry numbers in 2002 and 2003 (Table 9). 2004 was also significantly different for these two rivers compared to 2002 and 2003 on the Caldew and 2002 on the Lowther. The only other rivers which had a significant difference between years for trout fry numbers per 100m² was the Dacre (2003 significantly higher than 2002) and the Irthing (2003 significantly higher than 2004). For both the Upper Eden and Petteril there was no significant difference in the numbers of trout fry per 100m² between any of the sampled years.

Table 9 Mann-Whitney U test comparisons for trout fry between years for different rivers. *=P<0.05, **=P<0.01 and ***=P<0.001

TROUT FRY per 100m2		indicates significant difference			
RIVER	YEAR				
		2002	2003	2004	2005
CALDEW	2002		0.727	0.014	0.004
	2003	0.727		0.022	0.003
	2004	0.014	0.022		0.574
	2005	0.004	0.003	0.574	
DACRE	2002		0.014	0.17	0.13
	2003	0.014		0.109	0.526
	2004	0.17	0.109		0.522
	2005	0.13	0.526	0.522	
IRTHING	2002		0.163	0.081	0.834
	2003	0.163		0.014	0.201
	2004	0.081	0.014		0.095
	2005	0.834	0.201	0.095	
LOWTHER	2002		0.548	0.085	0.024
	2003	0.548		0.042	0.006
	2004	0.085	0.042		0.418
	2005	0.024	0.006	0.418	
UPPER EDEN	2002		0.555	0.741	0.551
	2003	0.555		0.611	0.365
	2004	0.741	0.611		0.192
	2005	0.551	0.365	0.192	
PETTERIL	2002		0.346	0.327	0.05
	2003	0.346		0.903	0.268
	2004	0.327	0.903		0.255
	2005	0.05	0.268	0.255	
LOWER EDEN	NO TROUT PRESENT				

4.2.3 Parr numbers

Using the Environment Agency quantitative data it is possible to examine the change in salmonid parr numbers over the last four years and descriptive statistics for each of the years 2002-2005 are given in Table 10. 2005 had the lowest mean number of both salmon and trout parr. A Kruskal-Wallis was performed on the data and showed there was no significant difference between years for either salmon or trout parr numbers ($p = 0.799$ and $p = 0.460$ respectively).

Table 10 Descriptive statistics for parr in the Eden catchment.

	Year	Number	Mean n 100m	Median	Variance	Standard Deviation
		of sites	\bar{x}		s^2	s
N						
Salmon Parr	2002	17	4.50	3.50	30.67	5.53
	2003	17	5.06	2.27	32.80	7.73
	2004	17	4.77	2.00	29.33	5.42
	2005	17	4.10	0.44	46.41	6.81
Trout Parr	2002	25	9.96	6.43	92.91	9.64
	2003	25	7.5	4.26	84.19	9.18
	2004	25	6.91	3.43	90.99	9.54
	2005	25	5.86	4.17	40.95	6.4

4.4 Overall Results

The results of this study were unexpected in that the large scale flooding on the Eden catchment in January 2005 appeared not to have a significant effect on salmon fry numbers. Average salmon fry numbers per 100m² did not decrease in the Eden post January 2005 flood, on a river or catchment basis. In fact, 2005 salmon fry numbers were higher than 2002 and 2004 numbers indicating the flood has not had a negative impact. 2003 had the greatest number of salmon fry on a catchment scale and on an individual river level except on the River Lowther which had greater salmon fry numbers in 2005. Flows on the Lowther are regulated by the Haweswater abstraction system, so the high rainfall levels in January 2005 may have had less of an impact on this river.

2005 had the lowest mean and median numbers of trout fry on a catchment scale. Trout bury their eggs at a shallower depth than salmon and so are more susceptible to floods washing out the redds and destroying the eggs. However, comparing the fry numbers in rivers which we had flow data for, against flood return values gave no significant correlation between reductions in fry numbers and size of flood return.

The River Petteril had the highest flood return value (100 years) however; this beck has historic poor numbers of salmonids (due to motorway runoff) so it is very difficult to see any flood related changes in fish numbers.

There are several reasons why there could be no observed effect on salmon fry numbers due to flooding. Table 11 compares the fish that have gone past the Corby Counter (Environment Agency fish counter which records migrating salmonids returning to the river to spawn) against the number of fry found in the following year. This shows 2005 had the greatest number of adults (40% more than the next highest year) which had come up to spawn and should therefore have yielded a high number of fry.

Table 11 Fry found compared to fish past Corby counter year before

	2002	2003	2004	2005
Mean salmon fry n/100m2	23.91	46.15	14.20	32.22
Mean trout fry n/100m2	18.03	46.13	12.67	10.66
Fish at Corby year before	7274	8643	6747	12230

Comparing fish past the Corby counter with the numbers of fry found the following year shows 2005 is an extreme outlier and that the average number of salmon fry per 100m² in 2005 would be expected to be much greater (Figure 8).

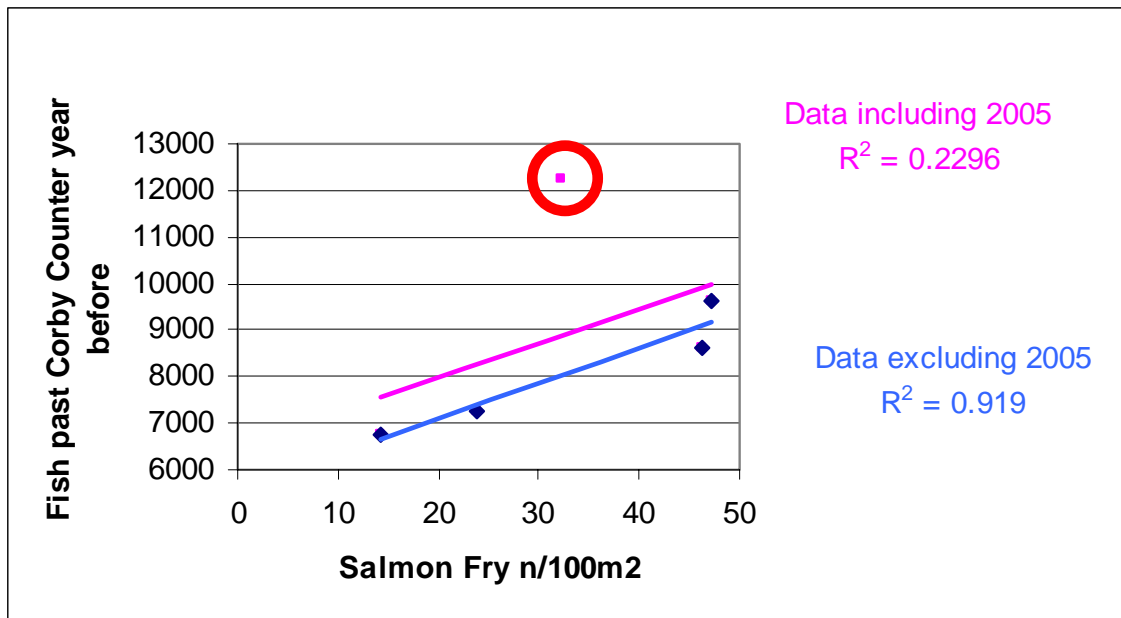


Figure 8: Average salmon fry per 100m² compared to fish past Corby fish counter year before.

The data in Table 12 shows the EA catch data and egg deposition rates - these values indicate whether the following year should have high fry numbers compared to previous years i.e. 2004 has the highest egg deposition rate and the highest number of salmon caught (by rod and in Caldew trap) so number of salmon fry should be high in 2005. This data shows that spawning adults/number of eggs would not be the limiting factor in 2005 and that any change in salmon fry numbers in 2005 compared to other years could be attributable to flood effects. The Caldew trap data, egg deposition rates (for 2004) and Corby Counter data indicate that 2005 should have had a healthy stock of fry and implies salmon fry numbers should actually have been a lot higher than were recorded and that the flood did indeed have an impact

The adult trout passing through the Caldew trap in 2004 was lower than 2002 or 2003 which would mean a lower number of spawning adults and hence may explain why the overall trout fry numbers in 2005 are lower than previous years.

Table 12 Environment Agency data for egg deposition rates for salmon and number of fish through Caldew Trap

	Salmon fry egg deposition rate (for year previous)	Caldew trap Salmon numbers	Total Salmon rod catch	Caldew trap Trout numbers
2001	13.03 (treat with caution due to foot and mouth)		1122	
2002	14.82	1319	963	117

2003	12.02	813	808	140
2004	32.43	1699	2622	98

The data from 2002-2004 show that there is a natural fluctuation in fry numbers over the catchment and as can be seen from the Caldew trap data this is most likely due to varying numbers of adults returning to spawn and also based on recruitment success.

Although there was no significant difference between years for number of salmon or trout parr, 2005 had the lowest average values of parr numbers compared to other years. Parr could have been displaced downstream by the floods or washed out of the river – anecdotal evidence reports salmon and trout found strewn on fields after the flood. The reduced numbers of salmonid parr in 2005 however, is more likely to be due to low salmonid fry numbers in 2004.

5 What Did and Did Not Work

The number of years over which the data has been gathered is a short time-scale against which to assess natural variance against environmental impacts.

Further analysis using data post-2005 may provide a broader picture.

Limited by having far few sites to assess the impact of the flood on salmon and trout parr. This was because most of ERT's electrofishing sites were 5 minute fry surveys.

Limited as there is no camera on the corby counter so we are not sure of the split of species – that is, how many are salmon and how many are trout.

Limited as flood returns could only be calculated for seven tributaries.

6 How Was Success Measured

Success was measured by having sufficient data to undertake a statistically rigorous analysis and against which to draw a robust conclusion.

7 How Was Help Acquired

APEM undertook the statistical analysis and report writing in partnership with ERT.

English Nature (now Natural England) funded the report writing.

ERT's pool of trained volunteers is invaluable in the collection of the electrofishing data. They are mostly local angling association members.

Land managers and angling clubs gave permission to access their land.

The Atlantic Salmon Trust provided funding towards the electrofishing survey.

The Environment Agency allowed us to use their electrofishing data giving greater catchment coverage of survey sites and also provided the data on flows.

8 What Could Have Been Done Better

Further assessment of data could be undertaken to look at the impacts of low flows on salmonid survival in the Eden.

It would have been preferable to have had more previous information on fish densities in the catchment prior to 2002, but it does show the importance of collecting a long-term dataset for its intrinsic value.