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THE WALES ROD AND LINE (SALMON AND SEA TROUT) BYELAWS 2017

THE WALES NET FISHING (SALMON AND SEA TROUT) BYELAWS 2017

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APPENDIX TO THE REBUTTAL PROOF OF EVIDENCE

OF

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On behalf of
NATURAL RESOURCES WALES

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ENVIRONMENT AGENCY

AN INVESTIGATION INTO THE IMPACT OF FLOW REGULATION ON FISHERIES OF THE RIVER DEE

FINAL REPORT

AUGUST 1998

Aquatic Pollution &
Environmental Management

CONTENTS

EXECUTIVE SUMMARY

i Objectives

There is a need to assess the impact of the current regulation scheme on fish populations in the Dee to provide a baseline against which to consider any future changes to the flow regime within the catchment. The extensive regulation of the Dee has undoubtedly had a significant impact on the flow regime within the river. In particular, a number of actual and potential effects of the flow regulation system on the fish populations of the Dee have been identified and need to be fully evaluated.

In the light of proposed changes to the flow regulation scheme (to augment existing storage), there is an urgent need to assess the impact of the current regulation scheme on fish populations in the Dee before additional changes are implemented. The overall objective of this study is therefore to assess any adverse impacts of flow regulation on the fisheries of the Dee and assess the effectiveness of the current fisheries mitigation scheme.

The overall objectives of the project are:

a) To review the impact of flow regulation and abstraction on fisheries of the River Dee by identifying the physical, chemical and biological impacts on salmonid and coarse fisheries, including the upper tributaries, main river and estuary.

b) To make recommendations on the future management of flow regulations and abstraction to minimise adverse effects on fish stocks and fisheries.

c) To review the effectiveness of the current mitigation programme and make appropriate recommendations.

ii Water quality

- Generally, water quality throughout the river's freshwater length is regarded as being of a high standard.
- The estuary is of reasonable quality but the outer reaches deteriorate to Class B (fair) due to industrial and sewage pollution.
- Some of the upper catchment tributaries (Alwen sub-catchment) appear to be susceptible to acidification.
- Biological monitoring data indicates an improvement in water quality over recent years in some areas of the catchment.
- Studies attempting to examine the impact of regulated flows on the invertebrates community are inconclusive, invariably been of limited duration and failing to take into account other factors such as agricultural pollution, afforestation and changes in land management.

iii Flow Data

- Regulation impacts upon flows at the opposite ends of the spectrum, peak flows during floods are topped, and extreme low flows are prevented.

- Spring, summer and early autumn freshets are frequently significantly reduced in magnitude.

- Regulation appears to have made late spring, summer and early autumnal freshets less common.

- The nature of releases appears staged and unnatural, having been 'damped' when compared with the normal characteristic freshet flow patterns.

- Reducing the magnitude and the naturalness of these freshets flows could be significant either initiating or encouraging adult salmon upstream migration.

- Reducing extreme flows during spates may encourage siltation of spawning areas and precipitate habitat change.

[illegible] really ?

- Regulated releases increase minimum winter water temperatures and depress the summer maximum. [illegible] really ?

- Regulation benefits salmonids in the river by eliminating extreme summer low flows. However, augmented flows during the summer months do not benefit the coarse fish community.

- The residual flow to the estuary being maintained at an artificially high level by regulation is beneficial to estuarine water quality.

iv Fisheries Data

- Rod and net catches have declined in the Dee when compared with other Welsh control rivers during the 1960 to 1975 period coinciding with the operation of Celyn. A consistent decline has also been demonstrated when compared to English west-coast rivers draining into the Irish Sea, implicating regulation in the absence of other significant differences.

- The timing of the salmon run has changed but merely reflects the national trend.

- Location of catches within the Dee is likely to have changed, fish being drawn further into the system probably as a result of regulation encouraging more rapid upstream migration.

- Estuarine telemetry studies highlighted the importance of freshwater flows for fish movements. Most fish negotiate Chester Weir without interruption at flows of 13 m^3/s^{-1} and above.

At lower flows, e.g. the residual flow under typical summer conditions, delays may be experienced although most fish still negotiate the weir successfully.

- Freshwater telemetry has highlighted the importance of autumnal freshets in stimulating migration.
- The importance of maximising the "naturalness" of freshets to stimulate fish movement has also been stressed.
- Once salmon enter freshwater they move rapidly through the lower reaches, regardless of prevailing flows. Typical first phase migrations are of the order of 49 km into freshwater. Flows in excess of 20 m^3/s^{-1} reduce migration speed.
- Once fish reach the middle reaches of the river around Bangor-on-Dee migration rate decreases significantly. Migration speed now increases over the range 20 to 30 m^3/s^{-1}.
- Spawning is greatly reduced compared to historic levels, except in one or two notable off-line tributaries (Hirnant & Mynach), a decline which coincided with the commissioning of Llyn Celyn.
- Juvenile populations have been maintained at high levels in some off line tributaries, (e.g. Ceiriog) but larger tributary on-line sites have suffered significant declines, implicating regulation as the most likely cause of the deterioration.
- Changes in the temperature regime do not appear to have affected egg development and emergence of fry as has been demonstrated in other regulated systems.
- Juvenile populations in the Llyn Tegid tributaries have seen a precipitous decline in juvenile salmonids but this cannot be directly attributed to regulation having occurred some years after Celyn came on-line.
- Recent studies have implied that a lack of spawning adults (particularly spring fish) is responsible for poor salmonid populations in the Tegid tributaries.
- Other notable issues which may have impacted upon juvenile salmonids in the catchment include land use changes and eutrophication.
- Acidification would appear to have had a significant impact on juvenile salmonids in the Alwen sub-catchment, but despite low pH and high aluminium, water quality is not considered the limiting factor in the Tegid tributaries.
- Enhanced flows during augmentation from Brenig may be negatively impacting juvenile salmon and trout.

- Smolt age composition has undergone a marked change from predominantly 2 year old fish to a high proportion of 1 year old smolts, the latter having reduced survival. Hence the altered temperature regime is thought to be a contributory factor resulting in reduced smolt to adult survival rates.

- UDN in the late 1960's infected over 90% of the spring fish and possibly contributed to the accelerated demise of the early running multi sea-winter stock.

- Evidence from telemetry studies confirms that multi sea-winter fish spawn high up in the catchment and therefore this component of the stock may have been disproportionately affected by UDN affecting production in the upper tributaries.

- The mitigation arrangements for lost salmonid spawning grounds and juvenile areas, is inadequate and should be at least doubled to compensate for the impact of dam construction on the Dee stock.

- Cyprinid fish populations are affected severely by regulation, with temperature and flows having a negative impact on stocks.

- Grayling have prospered at the expense of other species in the Dee, the physical environmental changes precipitated by regulation favouring this species.

- Dace have become the dominant cyprinid species, appearing less affected by regulation than other coarse fish.

v Mitigation

Current Mitigation Programme

- No mitigation arrangements were found for Brenig to compensate for spawning grounds inundated following construction.

- No mitigation arrangements were discovered for loss of spawning on the Alwen following the construction of Alwen reservoir.

- Following alterations to Llyn Tegid sluices, mitigation effort was concentrated on enabling access for adults. This was considered successful for up to 15 years after construction, although recently other factors out-with the scope of mitigation have impacted on stocks.

- The original mitigation targets for Llyn Celyn to compensate for the lost 10 miles of spawning habitat have never been met (based on 100,000 yearling parr and 14,000 smolts - Liverpool Corporation). However, the agreed mitigation package only accounted for between 30 and 50 % of the lost salmon production.

- Tributaries in the Brenig sub-catchment were originally part of the mitigation package for Celyn, unfed fry (150,000 to 200,000) being seeded into nursery streams. Following construction of Brenig, no compensation for this loss to the mitigation arrangements was made.

- Most brood stock for the mitigation programme are obtained from the Alwen, not the Tryweryn as originally intended. The level of brood stock collection from the Alwen has had a marked impact on the residual spawning population.

- No mitigation arrangements were made for coarse fish.

vi Conclusions

Examination of the information contained in this report leads to the conclusion that there are a multiplicity of factors operating which impact upon the fish populations of the Dee. Notable issues which give cause for concern are:-

- Water quality in Llyn Tegid and the feeder tributaries.
- Land use changes to pasture, sheep overgrazing etc.
- Acidification in the Alwen sub-catchment.
- Sheep dip impacts on the invertebrate community.

However, in addition to these issues, and probably of greater significance to the Dee fish community overall, regulation is affecting fisheries by;

- Damping freshets and hence affecting upstream migration of salmonids.
- Reducing scouring flows, promoting siltation of salmonid spawning and juvenile rearing areas.
- Influencing the location of catches and hence the economic viability of the salmonid fishery in some locations.
- Altering the temperature regime, which impacts negatively upon the coarse fish populations and may be responsible for a shift in smolt age.
- Inducing habitat and temperature changes encouraging the expansion of the grayling population and the dominance of the coarse fish community by dace.

With the notable exception of the grayling population, the general conclusion of the study is that regulation has resulted in an overall reduction in fish populations, but specifically in the years immediately following the construction of Llyn Celyn.

vii Recommendations for future mitigation

Suggested Improvements to the Current Mitigation Programme

- Fry should be retained for longer in the hatchery, planting as 0+ parr in late summer.
- Smolt stocking should continue but experiments with smolt release ponds should be pursued.
- Brood stock collection should be focused on the Tryweryn, particularly following success with autumnal artificial freshet releases.
- Kelt reconditioning should be explored further.
- A detailed habitat survey should be undertaken to determine whether habitat improvements, particularly gravel cleaning, are necessary.
- A rolling buy-out programme for estuary nets offers a cost effective and environmentally sensitive means of protecting returning adult stock to significantly increase spawning escapement.
- For coarse fish an off-line spawning lake has been proposed but may be considered too capital intensive.
- Riverine, habitat improvements for coarse fish, particularly in the tributary streams, should be implemented on as wide a basis as is feasible.
- A variety of monitoring arrangements are proposed to assess the effectiveness of the suggested alterations to the current mitigation scheme.

viii Recommendations for future regulation the Dee

The following amendments to the current use of special release water available for environmental purposes as part of the River Dee regulation scheme, are suggested in order of priority.

1. Releases to maintain water quality in the estuary and to minimise the impact of pollution incidents, i.e. preservation of fish life is the first priority.
2. Releases to encourage incoming salmon to leave the tidal reach and enter freshwater and to prolong the initial migration phase of new entrants to the river thereby widening their distribution.
3. Releases from Llyn Tegid, and if possible from Llyn Brenig, during the autumn to encourage fish to move up to the spawning reaches and from Llyn Celyn to encourage fish to enter the Tryweryn trap.

4. Releases from Llyn Tegid to "flush" spawning gravels in the upper Dee should siltation prove to be a problem, on at least a 3 yearly cycle.

1. INTRODUCTION

1.1 Objectives

There is a need to assess the impact of the current regulation scheme on fish populations in the Dee to provide a baseline against which to consider any future changes to the flow regime within the catchment. The extensive regulation of the Dee has undoubtedly had a significant impact on the flow regime within the river. In particular, a number of actual and potential effects of the flow regulation system on the fish populations of the Dee have been identified and need to be fully evaluated.

In the light of proposed changes to the flow regulation scheme (to augment existing storage), there is an urgent need to assess the impact of the current regulation scheme on fish populations in the Dee before additional changes are implemented. The overall objective of this study is therefore to assess any adverse impacts of flow regulation on the fisheries of the Dee and assess the effectiveness of the current fisheries mitigation scheme.

The specific objectives of the project are:

a) To review the impact of flow regulation and abstraction on fisheries of the River Dee by identifying the physical, chemical and biological impacts on salmonid and coarse fisheries, including the upper tributaries, main river and estuary.

b) To identifying and provide terms of reference for any further studies required to quantify any impacts on fisheries.

c) To make recommendations on the future management of flow regulations and abstraction to minimise adverse effects on fish stocks and fisheries.

d) To review the effectiveness of the current mitigation programme, including the impact of broodstock collection.

e) To identify and cost options for mitigating damage to fish stocks which could include artificial rearing and restocking and habitat improvements and recommend a preferred option.

1.2 Background

The Welsh Dee is one of the most highly regulated river systems in the UK. Regulation serves a number of functions; it offers not only the prospect of storing water but also controlling floods, allows releases for environmental purposes and can be used to generate electricity via hydropower. Since its introduction, flow regulation on the Dee has developed into a multi-purpose multi-user system (Figure 1.1).

Water resources have been developed by reservoir construction in the headwaters to support abstraction of large volumes of water for potable and industrial uses in North East Wales, the North West and Merseyside.

In addition, flooding has been reduced, benefiting both local communities and agriculture. The Dee is now an internationally recognised example of advanced river basin management (Pearce & O'Hara, 1984), flows being controlled in a complex manner utilising stored water from three large water bodies. These comprise a natural lake, Llyn Tegid, and two man-made reservoirs, Llyn Celyn and Llyn Brenig. A fourth reservoir, Alwen, in a valley adjacent to Llyn Brenig, is also potentially available to the regulation system, although it is currently not part of the scheme.

1.2.1 History of Regulation on the Dee

The Dee has a long history of anthropogenic influence dating back to early human settlements (Pearce & O'Hara, 1984). Initially the river was mainly used by the local population as a source of drinking water and food, a transport route and a site for disposal of sewage and other wastes. The requirement for power generation resulted in the establishment of weirs and water wheels at various locations, and fish trapping facilities were established. However, more recently, means of regulating flows in the river for water supply and flood alleviation were required.

An excellent account of the history of the Dee Regulation System is given in Hodgson (1993). In fact, regulation began at the beginning of the 19th century, when Thomas Telford constructed a simple adjustable weir at the outlet of Llyn Tegid to store excess floods. The additional water could then be released in dryer periods to supplement low natural flows and guarantee a supply of water to the Shropshire Union Canal at Llangollen. In addition, the Chester Water Company have been abstracting water from the Dee for over 100 years.

However, the first major regulation to affect the lower reaches around Chester did not occur until the early 1950s. The Dee and Clwyd River Board increased control of Llyn Tegid sufficiently to reduce winter flooding and to allow 2.7 m^3 sec^{-1} of abstractions along the river in dry summer conditions. In addition, in 1956 they allowed further flood alleviation by extending regulation control to allow the top few metres of Llyn Tegid to control catchment flood waters. Not only did this control discharge from Llyn Tegid but, by diverting the river Tryweryn upstream of the newly constructed sluice gates, this catchment was also controlled.

Following ever increasing demands for more water a new reservoir, Llyn Celyn, was constructed in 1964 in the Tryweryn headwaters. This reservoir, used in conjunction with Llyn Tegid, was to be used to support an additional abstraction of 3.4 m^3 sec^{-1}. In addition, extra allocations were made for the first time to improve residual flows below abstraction points and to provide special releases for fishery and environmental purposes (Blezard & Lambert, 1979, in Hodgson 1993).

Despite the increase in water available from the above schemes, projected demands revealed further requirements for potable water to the year 2010. Hence another reservoir was built at the head of the Alwen catchment.

Llyn Brenig was completed in 1976 and came on-line in 1979, creating a further 60 million m^3 of stored water for domestic supply purposes.

Alwen reservoir, also within the Alwen catchment, was built in the 1920s as a direct supply reservoir (0.5 m^3 sec^{-1}) to Birkenhead. Currently it does not form any part of the regulation system, although its conjunctive use with Llyn Brenig is a future possibility.

Since 1979, summer flows entering the tidally affected lower Dee, near Farndon, have normally been maintained at a minimum of 11 m^3 sec^{-1} to allow for increased abstractions for public supply in the Chester area and allow a minimum flow of 4.2 m^3 sec^{-1} over Chester weir.

The following Table details the permitted abstractions:

Table 1.1 Licensed Abstractions on the River Dee

Abstractor	Net Licensed Abstraction		Abstraction Points
	ml/d^{-1}	m^3 sec^{-1}	
Welsh Water	27.2	0.31	1
North West Water	704.6	8.16	5
Dee Valley Water	41	0.47	3
British Waterways	28.3	0.33	(1)*
Total	801.1	9.27	9

* abstraction point shared with North West Water, the licence holders for the abstraction licence.

Note : Wrexham Water and Chester Waterworks are now known as
Dee Valley Water.

Table 1.2 Abstraction Location

ABSTRACTOR	SITE	NGR
Welsh Water	Poulton	SJ 4079 5912
North West Water	Heronbridge	SJ 4117 6430
	Huntington	SJ 4142 6337
	Deeside	SJ 4068 6580
	Fron (Pont Cysyllte)	SJ 2708 4195
	Llantysilio (Horseshoe Falls)	SJ 1960 4328
Dee Valley Water	Berwyn	SJ 1948 4333
	Bangor on Dee	SJ 3863 4636
	Dee	SJ 4177 6633
British Waterways	Llantysilio (Horseshoe Falls)	SJ 1960 4328

1.2.2 Management of the System

The statutory framework for the regulation of the Dee is specified in Section 9 of the Dee and Clwyd River Authority Act 1973. The responsibility to implement and manage the system is now vested in the Agency via its predecessor the National Rivers Authority and, before that, the Welsh Water Authority.

The detailed procedures for regulating the Dee are incorporated into;

'Dee General Directions' – National Rivers Authority (1989)(under Review)

The system allows for the prescription of a maintained flow, except during droughts more severe than the 'design drought' (1 in 100 years) while having regard to;

- Public water supply
- Mitigating flooding,
- Maintaining water supplies to the Shropshire Union Canal,
- Safeguarding fisheries and other environmental purposes.

In brief, Llyn Celyn is the mainstay of the system, combining the functions of flow regulation, flood alleviation and hydropower generation. Llyn Tegid, although it has limited storage potential, allows temporary storage of Celyn releases in the summer and flood alleviation in the winter. Llyn Brenig, a slow filling reservoir, enters the Dee via its tributary the river Alwen. It provides water in severe drought, although phased usage with Llyn Celyn maximises the refilling characteristics of both reservoirs in normal rainfall years.

The regulation releases maintain flows in the Dee to permit abstraction in the lower reaches, principally in the Chester area, and to maintain an acceptable flow into the estuary. As noted in Table 1, there are a total of 10 abstraction points on the river, water being utilised by Welsh Water, North West Water, Dee Valley Water and British Waterways.

In addition to the water supply, flood alleviation and electricity generation components of the flow regulation system in the Dee, a special release volume is retained. As of the 1st May each year the available storage for special release purposes is assessed in relation to the absolute value of system storage of that time. A maximum of 119 cumec days (10,281 Ml) is made available. This water is available for environmental and fisheries purposes, and any other purpose that the Agency deem appropriate.

With respect to fisheries the special release water is used to encourage upstream migration of salmonids and to dilute pollutants in the event of an emergency situation arising. This volume of water may increase as the summer progresses depending on the time of year and rainfall. The volume is calculated as the spare capacity after all licensed abstractions have been accounted for and the volume of stored water available is sufficient to satisfy these requirements in a one in a hundred year drought.

The average daily flow over Chester Weir has been around 39 $m^3 sec^{-1}$. Whilst winter flows can exceed 180 $m^3 sec^{-1}$, the prescribed residual flow at this time is 4.2 $m^3 sec^{-1}$. However, during drought conditions this summer residual flow can be reduced to natural dry weather flows of 2.8 $m^3 sec^{-1}$. The prescribed flow was defined as the minimum flow that would avoid mortalities of both salmonid and coarse fish in the tideway section below Chester Weir (Hodgson *et al.*, 1980).

The rational behind setting a residual flow of good quality water was that river quality could deteriorate at times of discharge from Chester Sewage Works, particularly during hot summers, low flow and small tidal sequences.

2. INFORMATION SOURCES

An immense amount of information is available on the River Dee, having been collected over many years from investigations prior to and after the various stages in the development of the scheme. Of particular note are the following sources of information, reports, raw data etc;

Agency archives and reports for :–

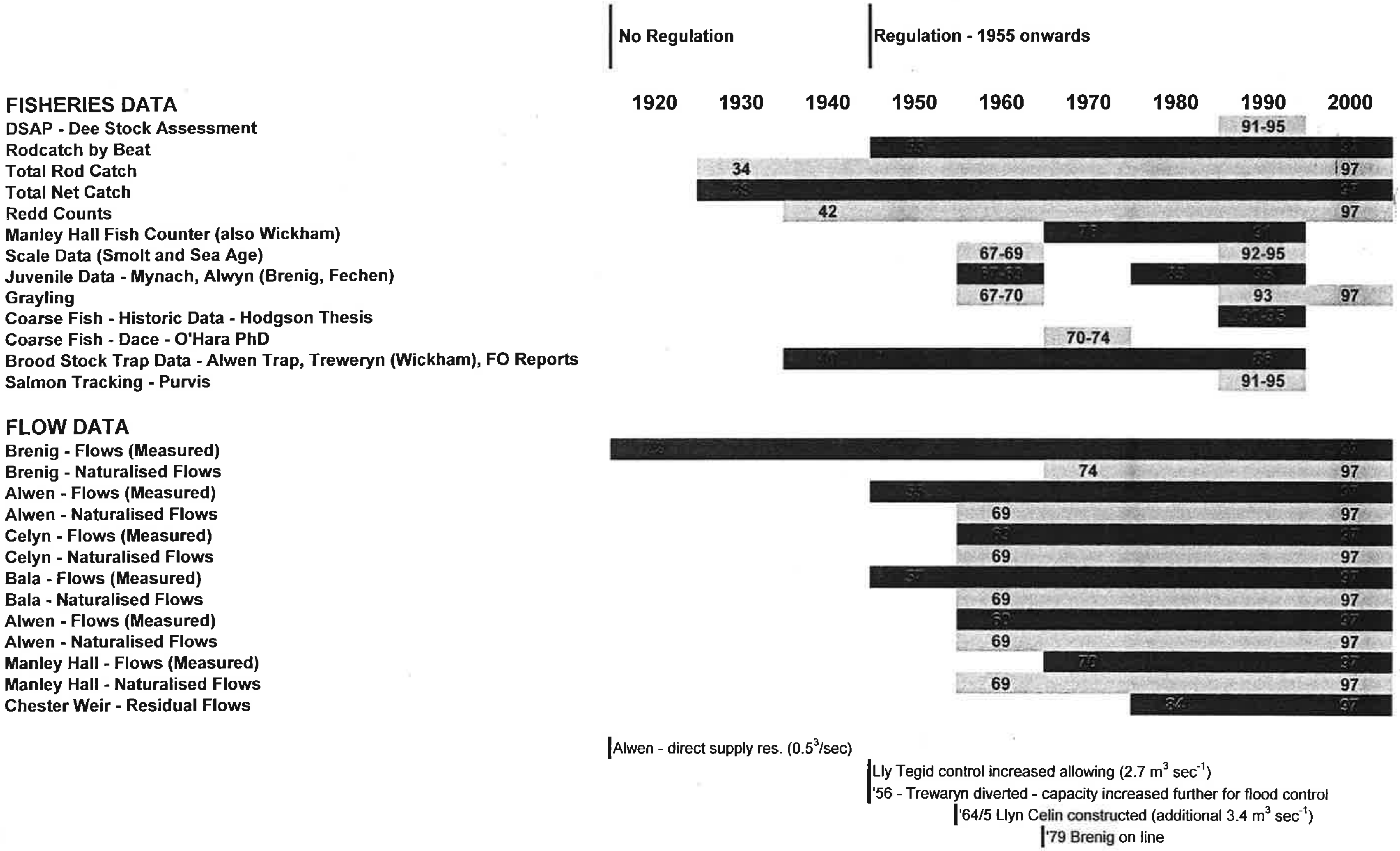
- Flow,
- Fisheries and
- Invertebrate data.

- Research undertaken in Liverpool University under the direction of Dr J W Jones from 1966 to 1979 (Appendix I).

- The Management and Ecology of the Welsh Dee – an Annotated Bibliography – Pearce & O'Hara (1984).

Following an extensive review of information sources, data were identified that were thought to be of significance to this project and of value in analysing the status of the Dee fish populations at various points in time. Combining this information with data on flows and other possible deleterious influences would then allow an analysis of the potential impacts arising from the regulation scheme. Figure 2.1 represents the various data sets graphically, showing where valuable information was unearthed and over which time periods.

Figure 2.1 - Time periods covered by data sets



3. WATER QUALITY

The River Dee is some 160 km in length, originating in the Cambrian Mountains and flowing eastward, before heading due North between Wrexham and Chester. It enters the Irish Sea in Liverpool Bay via a long protracted estuary. The catchment is largely rural, supporting mixed beef and sheep farming on high ground and intensive dairy farming in the lowlands of the Cheshire Plain and North Shropshire. Commercial and industrial developments are mainly concentrated around the estuary as well as the urban centres of Wrexham, Ruabon and Chester.

High standards of water quality are maintained throughout the river's freshwater length. From Bala to just downstream of the Alyn confluence water quality is equivalent to Fisheries Ecosystem (FE) Class 1 (very good), and further downstream to Chester Weir FE2 (Good). The estuary is also of reasonable quality being Class A (good) for the majority of its length but falling to Class B (fair) in the outer estuary. The main reasons for deterioration in water quality are industrial and sewage pollution, mainly confined to the catchment area downstream of Wrexham. In addition, some of the upper catchment tributaries, particularly in the southwestern region are susceptible to acidification due to geological conditions.

3.1 Macroinvertebrates

3.1.1 Introduction

Macroinvertebrates are monitored by the Agency as part of the biological grading component of the General Quality Assessment (GQA), along with chemical sampling, to help provide a comprehensive picture of the health of rivers and canals. Each species thrives best under a narrow range of environmental conditions. The status of macroinvertebrate communities therefore reflects the extent to which rivers are affected by environmental stresses, the major one of which is pollution.

Macroinvertebrates are also sensitive indicators of flow-related habitat changes and different taxa will respond in different ways to environmental change. However, it is only recently that their use in setting flows has been seriously considered (Petts *et al.*, 1996, Petts *et al.*, in draft.). The effects of regulated flows on macroinvertebrate assemblages may be direct, through changes in hydraulics and consequently habitat availability, or indirect as a result of siltation and macrophyte growth. The degree of impact will be dependent on the significance of regulated flow regimes.

3.1.2 GQA of the River Dee

The results from recent biological monitoring in the Welsh Dee are described within the GQA 1995 Welsh Region, Northern Area Report (Report No: EAN/97/01). The GQA provides the biological results for the 1990 and 1995 surveys with any improvements or deteriorations (i.e. changes of >40%) highlighted. In addition, any issues outlined in the Catchment Management Plan (CMP) or Local Environment Agency Plan (LEAP) can be discussed in relation to the biological quality.

By examining the GQA data for the Dee two objectives can be met:

- To highlight the general water quality problems effecting macroinvertebrate communities in the catchment.

- To examine any gross changes in macroinvertebrate communities in GQA sites which are affected by regulated flows.

3.1.3 General Water Quality Issues in the Dee

A total of eighty-four GQA sites were sampled on the Dee in 1995. These are covered within Areas 4, 5 and 6 of the Environment Agency Wales. Data from the 1990 survey were available for 68 of the 84 sites (81%). This enables any gross changes in biological quality to be detected at those sites over the 5 year period.

Seven sites in the Dee catchment had BMWP scores for both spring and autumn seasons that were more than 40% higher than the 1990 scores, indicating a probable improvement in water quality. Thirty sites showed an increase of more than 40% for one season only (either Spring or Autumn). No sites had a score less than 40% of the 1990 score in one season, while two sites showed a 40% or more decrease in both seasons. The remaining sites (29 in total) were not significantly changed in terms of overall biological quality compared with 1990.

The main water quality problems in the catchment in relation to the CMP or LEAP for the Dee catchment are summarised as follows:

a) Organic Pollution

Organic pollution from Combined Storm Overflows (CSO's), tip leachates and various other inputs results in depressed dissolved oxygen and elevated ammonia in certain watercourses in the Dee catchment. Two of the more serious are at Finchetts Gutter, which is classified as 'poor' biological quality, and the Gwenfro, which had very low invertebrate diversity resulting in either 'poor' or 'very poor' biological quality in most areas except in the upper reaches.

b) Agricultural Pollution

Many watercourses in the Dee catchment drain large agricultural areas. Farm pollution from both point and diffuse sources results in biological diversity being reduced in both Worthenbury Brook and Cyflymen Brook, with large growths of sewage fungus and elevated ammonia being present in the latter.

As a result of the concerns associated with the use of synthetic pyrethroid based sheep dips, the Agency initiated a sheep dip monitoring programme for the 1997 dipping season. Approximately 15 km of the Ceirw are included in the monitored catchments of the survey (Sheep Dip Welsh Monitoring Programme, Summary Report, 1997).

A serious incident relating to sheep dip pollution occurred in April 1997 in the Afon Twrch in the upper Dee catchment. Macroinvertebrate communities were severely impacted on an 8 km stretch of the Twrch and the Dyfrdwy, after its confluence with the Twrch (Millband, 1997).

c) Heavy Metal Contamination

Zinc contamination from abandoned metal mines effects both the Afon Garth and the Clywedog. While zinc levels are high there appears to be moderate impacts to the fauna from contamination. However, biological quality is 'poor' in the upper reaches of the Clywedog, as a result of drainage from metalliferous waste tips at Minera.

d) Acidification

Severe problems of acidity have been observed in the upper Alwen at Pont Yr Alwen downstream of Alwen Reservoir. In comparison with 1990 data there had been a significant decrease in biological quality in both seasons. There is a high percentage cover of managed forest surrounding the Alwen Reservoir and the upper reaches of Afon Ceidiog, which may be contributing to the acidification of the sub-catchment.

3.1.4 The Impact of Regulated Flows in the Dee

a) GQA Data

Nine GQA sites in the Dee catchment can be identified as sites which have been subjected to regulated flows and routinely monitored for over 15 years.

These are as follows:

The Agency Site Ref.	**River**	**Site Description**	**NGR**
1. N196	Tryweryn	Pont Tryweryn	SH 930 362
2. N190	Brenig	Penter Llyn Cymmer	SH 974 528
3. N184	Alwen	Pont-Yr-Alwen	SJ 963 524
4. N182	Alwen	Glanalwen Fords	SJ 057 428
5. N159	Dee	Llanderfel	SH 982 366
6. N158	Dee	Corwen	SJ 082 437
7. N153	Dee	Bangor-on-Dee	SJ 388 454
8. N126	Dee	Farndon	SJ 411 545
9. N123	Dee	Chester	SJ 408 659

Table 3.1 shows the spring BMWP scores for these sites and Table 3.2 shows the biological classification of these scores based on the Welsh Classification Scheme.

Table 3.1 Spring BMWP for the Nine Sites on Dee Catchment 1980-1995

Site Ref.	River	Site Description	NGR	80	81	82	85	86	87	90	91	92	95
N196	Tryweryn	Pont Tryweryn	SH 930 362	146	132	127	131	110	111	131	-	146	134
N190	Brenig	Penter Llyn Cymmer	SH 974 528	108	122	107	111	124	124	147	118	117	143
N184	Alwen	Pont-Yr-Alwen	SJ 963 524	76	57	76	90	-	71	60	90	65	32
N182	Alwen	Glanalwen Fords	SJ 057 428	128	175	137	128	147	140	140	-	169	237
N159	Dee	Llanderfel	SH 982 366	150	135	164	170	137	164	162	-	161	169
N158	Dee	Corwen	SJ 082 437	101	-	-	103	-	161	165	-	183	164
N153	Dee	Bangor-on-Dee	SJ 388 454	78	145	131	121	115	94	87	-	164	220
N126	Dee	Farndon	SJ 411 545	37	-	44	-	-	101	98	120	102	50
N123	Dee	Chester	SJ 408 659	40	-	-	46	58	63	35	29	43	49

Table 3.2 Spring BMWP of Nine Sites based on Welsh Classification (below)

Site Ref.	River	Site Description	NGR	80	81	82	85	86	87	90	91	92	95
N196	Tryweryn	Pont Tryweryn	SH 930 362	2	2	2	2	2	2	2	-	2	2
N190	Brenig	Penter Llyn Cymmer	SH 974 528	2	2	2	2	2	2	2	2	2	2
N184	Alwen	Pont-Yr-Alwen	SJ 963 524	3	3	3	3	-	3	3	3	3	4
N182	Alwen	Glanalwen Fords	SJ 057 428	2	1	2	2	2	2	2	-	1	1
N159	Dee	Llanderfel	SH 982 366	1	2	1	1	2	1	1	-	1	1
N158	Dee	Corwen	SJ 082 437	2	-	-	2	-	1	1	-	1	-
N153	Dee	Bangor-on-Dee	SJ 388 454	3	2	2	2	2	3	3	-	1	1
N126	Dee	Farndon	SJ 411 545	4	-	4	-	-	2	3	2	2	3
N123	Dee	Chester	SJ 408 659	4	-	-	4	3	3	4	4	4	4

BMWP Score Range	**Class**	**Quality Description**
>150	1	very good
101 –150	2	good
51-100	3	moderate
26-50	4	poor
0-25	5	very poor

The results indicate that spring BMWP scores at Pont Tryweryn, downstream of Llyn Celyn, and at Pentrellyncymmer, downstream of Llyn Brenig, show little variation from 1980 to 1995. Both sites are described as 'good' in terms of biological quality.

BMWP scores at Pont-Yr-Alwen on the Alwen are low compared to other sites in the upper catchment, with biological quality described as 'moderate' to 'poor'. As discussed in the previous section this is most probably attributable to acidic flushes as a result of afforestation. Any impact of regulated flows from Llyn Alwen will be masked by this acidic effect. However, the acidification appears to be localised, with scores increasing at Llanfihangel Glyn Myfyr (SH 991 493), approximately 7 km downstream of Llyn Alwen. Furthermore, data from the site at Glanalwen Falls describe the Alwen as 'good' to 'very good.'

The Dee at Llanderfel, downstream of Llyn Tegid, is classified as mainly 'very good' from 1980 to 1995. In addition, BMWP scores at Corwen exceeding 100 indicate that biological quality is high downstream of the confluence with the Alwen.

The impacts of regulated flows in the middle and lower Dee catchment are difficult to monitor as more watercourses join the main river, bringing their own set of influencing factors. The site at Bangor-on-Dee shows a fluctuation in biological quality since 1980 with higher scores reported in 1992 and 1995 than previous years. BMWP scores are considerably lower at Farndon and Chester as more polluted watercourses drain into the Dee, reducing biological quality to mainly 'moderate' and 'poor'.

The GQA macroinvertebrate data provide no conclusive evidence of changes in biotic score that could be attributed to regulated flows. This is not surprising considering the number of other factors acting on distribution and effective sampling of macroinvertebrates. These include:

- Natural seasonal variation.
- Climatic variation.
- Pollution incidents and other water quality issues.
- Problems of the comparability of macroinvertebrate sampling and historic data.

In addition, computer analytical packages e.g. RIVPACS have not been used on GQA data to examine changes in macroinvertebrate assemblages at the group/family level. The use of RIVPACS assessment to examine the impact of low flows and the management of flow regimes has been recently investigated (The Agency, R&D Technical Report W72).

b) Other Studies

Various studies have been undertaken in the Dee catchment to examine the impact of regulated flows on the receiving water biota including macoinvertebrate communities. The main advantage of this type of approach is that specific sub-catchments can be examined in detail in order to focus on possible changes in macoinvertebrate assemblages at the family and species level.

Rahim (1974) examined the ecology of bottom fauna in 5 tributaries feeding into Llyn Tegid, namely the Llafar, Twrch, Dyfrdwy, Lliw and Glyn. He compared macoinvertebrate communities in these streams to assemblages downstream in the regulated Dee between Llyn Tegid and Corwen. He suggested that the regulated Dee favoured certain groups/families of macroinvertebrates including representatives of the Hirudinea, Oligochaeta, Lamellibranchia, Crustacea, Hydracarina, Megaloptera and Coleoptera. In comparison, the feeder streams tended to be dominated by plecopterans, ephemeropterans and dipterans. He concluded that differences were a result of less scouring in the regulated river, providing a more stable environment compared with the shifting beds and flooding of the unregulated streams.

Currently, the Agency is undertaking various studies examining the upper Dee catchment in vicinty of Llyn Tegid. The occurrence of blue-green algal blooms in the lake suggests that eutrophication is occurring in the catchment. This may well influence the macroinvertebrate communities in both the unregulated streams upstream of Llyn Tegid and the regulated Dee downstream. In addition, recent problems associated with pollution from sheep dipping have had serious impacts on macroinvertebrates in the Afron Twrch and the Dyfrdwy upstream of Llyn Tegid (Millband, 1997).

Macroinvertebrate communities in the Llyn Tegid tributaries have also been investigated by the Agency in relation to studies examining the reasons for low juvenile salmon production in the area. Cove (1997) showed that despite unfavourable water chemistry of an acidic nature (pH min 4.1), macroinvertebrate populations were both abundant and diverse. Furthermore, these communities appeared to make a significant contribution to the food chain of the fish present.

Studies by the Agency and other workers have also focussed on the Alwen and Brenig river systems. Almukhtar (1982) examined the impact of acidification on the upper Alwen indicating that macroinvertebrate communities were characterised by low diversity and the domination of chironomids, oligochaetes and plecopterans. He also suggested that increases in silt occurred during construction and several years after the Llyn Brenig was brought on-line. This resulted in a serious depletion of fauna 1 km downstream of the impoundment and less severe but notable effects 5 km downstream during construction. Numbers of ephemeropterans including *Ecdyonurus* sp. appeared reduced several years after impoundment. However, he noted towards the end of his study that a rapid recovery of benthic fauna was occurring in the Brenig as silt was increasingly washed downstream.

While specific studies have attempted to examine the impact of regulated flows on macroinvertebrate communities in the upper Dee, much of the evidence is conflicting and does not fully take into account the influence of other factors i.e. the impact of agricultural pollution, afforestation and changes in land management. In addition, projects tend to be over a period of one or two years so that long-term impacts tend not to be investigated.

c) Potential Impacts of Regulated Flows on Macroinvertebrate Communities

The potential impacts of regulated flows can be summarised in an attempt to scope future investigations, targeting specifically the effect of regulated flow regimes on macroinvertebrate communities. These are as follows:

- Increased river discharge resulting in the wash-out of habitat features, plants and macroinvertebrates.
- Retardation of macroinvertebrate growth as a result of the reduction in food availability (wash-out of detritus).
- Increased siltation resulting in a change in substrate and an associated change in biota.
- Reduction in mean water temperature resulting in the retardation of growth of aquatic macrophytes and the development of habitat.
- Reduction in mean water temperature resulting in the retardation of macroinvertebrate life-cycles dependant upon temperature triggers.
- Reduction in dissolved oxygen concentration resulting in localised reduction of oxygen-sensitive macroinvertebrates.
- Reduction in dissolved oxygen concentration resulting in localised metal oxide precipitation leading to smothering of the biota.

3.2 Summary

- Generally, water quality throughout the river's freshwater length is regarded as being of a high standard.
- The estuary is of reasonable quality but the outer reaches deteriorate to Class B (fair) due to industrial and sewage pollution.
- Some of the upper catchment tributaries (Alwen sub-catchment) appear to be susceptible to acidification.

- Biological monitoring data indicates an improvement in water quality over recent years in some areas of the catchment.

- Studies attempting to examine the impact of regulated flows on the invertebrate community are inconclusive, have invariably been of limited duration and failed to take into account other factors such as agricultural pollution, afforestation and changes in land management

4. FLOW DATA

4.1 Data

Flow data were obtained as mean daily flows for a number of locations throughout the Dee catchment. These included;

- Alwen Reservoir
- Brenig Reservoir
- Celyn Reservoir
- Bala
- Alwen Druid
- Manley Hall
- Chester Weir

For Bala, Alwen Druid, Manley Hall and Chester Weir, in addition to measured daily flows data were also presented as 'Naturalised' Flows, providing an indication of the likely hydrological scenario in the absence of regulation. For each flow gauging site naturalised flows were calculated (details in Appendix II together with hydrographs).

4.2 Comparison of Measured and Naturalised Flows

Comparing the measured and naturalised flows for wet and dry years allows the impact of regulation on the flow regime in different locations within the catchment to be assessed. The total discharge for each year going back to 1970 was based on the naturalised average daily flows. This revealed the wettest year to be 1974 and the driest to be 1975. For Chester Weir, due to the more limited timescale of the database, the relevant wettest year was 1994, with the driest being 1996.

Comparing naturalised and measured flows for these extreme years (Figures 4.1 to 4.7[1] in Appendix II), the pattern of winter retention and summer releases is evident. Whereas peak flows are 'clipped' in the winter, rendering measured flows lower than naturalised, the opposite occurs in summer when natural flows would often have been significantly lower than those which were being measured.

The overall effect is best illustrated by comparing the hydrographs for the Alwen Druid gauging station before and after operation of Brenig. As can be seen for the wet and dry years of 1974 and 1975 respectively, both measured and naturalised flows follow similar patterns[2]. Comparing these data with 1994 and 1995, when Brenig was on-line, the difference is quite marked.

The effects above are most pronounced in dry years, 1975 and 1996 being the examples used in the figures.

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[1] Note logarithmic scale.

[2] The slight divergence observed in the summer months is assumed to be due to the compensation flow from Alwen Reservoir artificially elevating summertime flows.

It is evident that the higher up in the catchment the greater the divergence between naturalised and measured flows during the summer months. Progressing downstream, the difference appears less, as illustrated by the reduced area between the naturalised (yellow) and measured (red) lines. At Chester Weir, however, abstraction has taken place, further reducing the difference in overall terms between the two flow data sets.

It is important to recognise that the difference between measured and naturalised flows is very significant at the opposite ends of the extreme flows. The peaks are topped, and the extreme low flows are prevented. More detailed examination of the various figures presented shows, however, that in both wet and dry years, spring, summer and early autumn freshets are frequently significantly reduced in magnitude. In addition, the nature of releases, particularly from Brenig, appears staged and unnatural, having been 'damped' in comparison with the normal characteristic flow patterns.

The impact of reducing the magnitude and the 'naturalness' of these freshet flows could be significant in either initiating or encouraging upstream migration of adult salmon. This may be even more important at Chester Weir where flows in excess of 13 cumecs are regarded as significant in encouraging fish past the weir[3]. Lesser flows result in a delay in crossing the weir which, in a proportion of fish, lends them more susceptible to exploitation from estuary nets (although this may be negated by recent net byelaw changes). In both wet and dry years a number of such freshets would be anticipated during the late spring, summer and early autumn from the naturalised flows, but with measured flows they appear a rare occurrence. However, usually during early spring, measured flows are sufficiently high such that there is unlikely to be any impediment to early running multi sea-winter fish.

Reducing the extreme flows during spates may impact upon fish habitat, allowing siltation in the absence of flushing flows, which scour gravels and remove fine particles. These flows not only maintain the integrity of spawning gravels but also prevent siltation of juvenile habitat, macrophyte colonisation and attendant fundamental habitat alterations. Evidence from elsewhere suggests that flushing flows need to of the order of 1.7 m^3s^{-1} per metre width of stream to effect movement of gravels and allow flushing out of silt (Fredrikson *et al.*, 1980). In the Dee below Bala, assuming a width of say 20 m, the flushing flow required would be in excess of 34 m^3/s^{-1}. In the upper reaches these flows would not appear to be being maintained for prolonged periods and are infrequent. Naturalised flows indicate a much greater (four fold) increase in the frequency of this type of freshet. Anecdotal evidence also suggests increased macrophyte colonisation in the main river and may be related to increased siltation.

Finally, spring freshets are also important in precipitating smolt migration. This may operate either indirectly by acting as a stimulus to migration or directly by aiding the displacement of smolts downstream. Removing the freshets may impact upon this migration.

However, the potential benefits of regulation should also be recognised. It is apparent from all the hydrographs, for both wet and dry years, that low summer flows are avoided.

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[3] Fish still negotiate the weir via the fish pass at the residual flow 4.2 cumecs, although typically delays of up to 36 hours may be experienced.

For salmonids, this is significant not only in maintaining wetted area and hence maximising both rearing space and food availability for juveniles, but also in guaranteeing a residual flow to the estuary, providing significantly more freshwater flow to the estuary than would be the case in many dry summers. However, such conditions are not advantageous to cyprinids.

4.3 Summary

- Regulation impacts upon flows at the opposite ends of the spectrum, peak flows during floods are topped, and extreme low flows are prevented.
- Spring, summer and early autumn freshets are frequently significantly reduced in magnitude.
- The nature of releases appears staged and unnatural, having been 'damped' when compared with the normal characteristic freshet flow patterns.
- Reducing the magnitude and the naturalness of these freshets flows could be significant either initiating or encouraging adult salmon upstream migration.
- Regulation appears to have made late spring, summer and early autumnal freshets less common.
- Reducing extreme flows during spates may encourage siltation of spawning areas and precipitating habitat change.
- Regulation benefits salmonids in the river by eliminating extreme summer low flows. However, artificially high flows during the summer months do not benefit the coarse fish community.
- The residual flow to the estuary being maintained at an artificially high level by regulation is beneficial to estuarine water quality.

5. FISHERIES DATA

5.1 Salmon &Trout

The Dee is predominantly a salmon fishery, historically valued for its nationally important run of multi-sea winter spring salmon. Hence a significant amount of historic data are available for this species. In contrast, the Dee has never been a recognised sea trout fishery, and consequently equivalent data sets are poor. Hence this section will concentrate mainly on salmon, with reference to trout and migratory trout where relevant.

5.1.1 Rod & Net Catches - Overall Trends

Examination of salmon rod and net data (Figure 5.1) confirms the downward trend in catches. Data were extracted from the Dee Fishery Reports, which contained returns dating as far back as 1928. Although the accuracy of such historic data sets can be called into question, particularly with respect to under reporting in the early years, changing methods and lack of data on effort, they can provide a useful indicator of general performance of fisheries over time.

Trend analysis, polynomial and linear regression, confirm the downward trends for both nets and rods. Utilising the more reliable recent data from post 1951 (see Table 5.1), the trend towards decreasing catches in the 70's (annual average of 786 salmon) and 80's (annual average of 516 salmon) is well illustrated when compared to the figures for the 50's (1069 salmon) and the 60's (1143 salmon).

Table 5.1 Monthly Composition of Dee Salmon Rod Catch 1951-90

Month	DECADE							
	1951-1960		1961-1970		1971-1980		1981-1990	
	Mean	%	Mean	%	Mean	%	Mean	%
Mar	324.5	30.5	196.0	17.1	116.1	14.8	32.7	6.3
Apr	280.0	26.3	243.0	21.2	112.3	14.3	49.1	9.5
May	181.1	17.0	223.9	19.6	99.5	12.7	56.3	10.9
Jun	96.8	9.1	85.6	7.5	109.1	13.9	49.2	9.5
Jul	46.9	4.4	95.1	8.3	61.9	7.9	51.1	9.9
Aug	40.8	3.8	95.1	8.3	91.1	11.6	82.2	15.9
Sep	49.4	4.6	108.8	9.5	97.8	12.4	123.7	24.0
Oct	44.5	4.2	96.3	8.4	98.3	12.5	72.1	14.0
ALL	1063.9	100.0	1143.8	100.0	786.1	100.0	516.4	100.0

The line of best fit for rods can be greatly improved by only using data from post 1965, immediately after Celyn came on line (Figure 5.2). However, it is interesting to note that no discernible decrease in rod catches is seen after Brenig came on line in 1979 (Figure 5.3). Similarly, if the high net catch of 1981 is discounted, net catches also appear relatively stable, exhibiting no downwards trend post Brenig.

By comparing the rod and net catches in other river systems it may be possible to determine whether these trends are apparent within the Irish Sea stock as a whole or if they are indicative of a problem inherent to the Dee. The impact of common issues such as UDN, high seas fisheries and climate change can therefore be eliminated to highlight specific differences between these catchments such as the degree of regulation, which may influence fish stocks over and above national trends.

Taking data from the period 1951 to 1995, trend analysis for salmon rod and net catches was undertaken by combining data for a number of Welsh rivers including,

Wye, Usk, Twyi, Taf, Cleddau,Teifi, Rheidol, Dyfi, Mawddach, Dwyryd,
Glaslyn, Dwyfawr, Seiont, Ogwen, Conwy, Clwyd.

Annual catches (rods and nets separately) were combined for each river and converted to logs, thus providing a control data set for comparison. Logged annual catches from the Dee were then subtracted from the logged combined Welsh rivers annual average, providing an indication of any deviations from the trends in other rivers of the region (the control group). The results for rods and nets are shown in Figures 5.4 to 5.7.

Comparing the Dee rods with the combined Welsh control rivers there has been considerable variation in the relationship over the time period examined (1951 to 1995). In the early 1950s the variation was marked, in some years the Dee performing significantly better that the other Welsh rivers as illustrated by the large negative difference (over – 1.0) between the Dee and the combined Welsh rivers control (Figure 5.4).

However, from about 1960 onwards (for the next 15 years), the difference between the Dee and the other rivers became progressively less significant (see Figure 5.5). The tendency for the logged average catches to approach unity is illustrated by the trend line ($r^2 = 0.486$, $p<0.05$). In other words, rod catches were converging, the Dee catch being a smaller proportion of the Welsh rivers control group rod salmon catch. For the first five of the 15 years period (1960 to 1965), the Dee represented an annual average of 19.1% of the Welsh control group rod catch. By the end of the period 1970 to 1975, this proportion had decreased to 9.7%.

A similar tendency is seen with net catches when comparing the average catch for the Welsh control rivers with that from the Dee (Figures 5.6 and 5.7). The initial variation is not as great as that seen for rods, but the 1960 to 1975 period also shows a parallel and significant deteriorating trend ($r^2 = 0.468$, $p<0.05$).

In the early 1960s the Dee net catches were more substantial (approaching -1.3) than those in other Welsh rivers but as time progressed they converged towards the average Welsh river net catch (< -1.0) by the end of the 15 years.

Over the first five years of the 15 year period (1960 to 1965) the Dee net catch was 75% of the control group but by the final five year period (1970 to 1975) the average percentage had decreased to 40%.

During this period some factor not influencing other Welsh rivers would therefore appear to be operating in the Dee. The impact of construction and commissioning of Llyn Celyn is the most likely cause of this comparative deterioration.

It is, however, important to note that during the period post 1975, both rod and net catches have displayed the opposite trend, particularly since 1983. Catches have diverged significantly from the Welsh river control group averages, indicating a comparative improvement relative to these other rivers. However, it should be borne in mind that this analysis is relative and should not be confused with the overall position illustrated in Figures 5.1 to 5.3.

It is also interesting to compare catch data from the Dee with rivers in North West England which drain into the Irish Sea (Ribble, Lune and Eden). Basic trend analysis using the same technique as that above for Welsh rivers is presented in Figures 5.8 and 5.9. In contrast to the Dee, none of these rivers displays any trend towards decreasing rod catches, in fact in all three the trend appears to be towards moderate increases, although there is some evidence that this trend is reversing.

Over the period 1965 to 1995, a marked deterioration in the Dee rod catches compared to the North West rivers is evident, the consistent decline only reversing in the 1990s. A comparable decline is also seen in net catches over the period 1965 to 1984, although a trend towards improving catches relative to the North West rivers is evident from 1985 to 1995.

Therefore, this basic trend analysis indicates that factors are operating within the Dee catchment which have impacted negatively on Salmon in the river during the period when a major change to the hydraulic regime occurred (1960 to 1975). During this period the Dee salmon catch has deteriorated as a proportion of the Welsh rivers control group catch. Subsequently this situation has been redressed, although not so much by a substantial improvement in the Dee but rather as a consequence of a greater deterioration in other Welsh rivers.

It is also evident that catches in some Welsh rivers appear to be displaying different trends to those in North West England, although they are supposedly part of the same group of stocks. Differences in catch data collection policy and declaration techniques may be responsible for these apparent differences but it should be recognised that the system in Wales is arguably more efficient and reliable. Hence the comparisons with Welsh rivers alone still appear significant.

Although the data are not sufficiently robust to identify regulation as the cause of this decline in the years following construction and commissioning of Celyn, indications are that the artificial flow regime may be one of the factors.

5.1.2 Timing of the Run & Stock Composition

In common with many rivers throughout the country the Dee has seen a significant shift in the composition and timing of salmon migrations, moving away from a significant spring run, multi-sea winter salmon fishery, to one dominated by late summer and autumn running 1-sea winter fish. Table 5.1 illustrates the change. Typically, pre 1960, March and April were the dominant months, on average accounting for over 50% of the annual rod catch. During the 60's this reduced to less than 40%, in the 70's to less than 30%, and more recently in the 80's to less than 17%.

Data from Manley Hall fish counter (Table 5.2) are only available over the period 1976 to 1991, and therefore provide no confirmatory evidence of the situation in the 60's, with the salmon run dominated by multi-sea winter fish. However, by 1976, in the succeeding years for which a reasonable data set exists (11 out of a possible 16), the peak run was in August or later on over 80% of occasions.

More recent data from the fish trap at Chester Weir and mark recapture experiments (Table 5.3) confirm this continuing trend for 1991 through to 1997. In all years the peak run was in September[4], varying between 32 and 42% of the total. The second most important month in terms of numbers of salmon was August in all but one of the five years (1995 –July), where the run varied between 21 and 31% of the total. Therefore, in most recent years between 53 and 66% of the total salmon run has been in the late summer/early autumn period of August and September.

Data for adult stock age composition are presented in Table 5.4 for the period 1992 to 1995. As can be seen, 1 sea winter fish dominate the stock, representing over 75% of the returning adult stock over recent years. 2 sea winter fish represent approximately 22%, whilst 3 sea winter fish account for less than 1%.

It is evident that a significant change was already underway prior to any of the major reservoirs on the Dee coming on line. This suggests that the alteration in the timing of the run and stock composition are more probably related to the national trend seen in many west coast rivers rather than any localised impact of regulation.

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[4] In most years September data is combined with in-season October data (i.e. the last 6 weeks of the angling season).

Table 5.2 Upstream fish counts; Manley Hall, 1976-91.

Month	1977	1978	1979	1981	1983	1984	1985	1987	1988	1989	1990
Jan	23	10	9	1		2	0			5	52
Feb	20	14	1	1		9	31	17		10	26
Mar	136	208	13	6	96	53	58	86		11	125
Apr	318	125	53	146	68	89	97	350	101	54	174
May	481	452	224	608	111	106	179	473	294	124	248
Jun	927	490	91	743		421	1071	1407	878	712	480
Jul	554	935		663	530	437	1001		1284	809	701
Aug	571	1187	367	628	688	327	1477	911	1295	240	163
Sep	1202	654	643	1284	950	843	948	857	1076	385	517
Oct	506	179	456	212	276	449	514	290	778	712	1071
Nov	139	161	153	111	172	180	234		372	326	314
Dec	68	33	46	14	51	44	109		165	100	81
TOTAL	4945	4448	2056	4417	2942	2960	5719	4391	6243	3488	3952

Table 5.3 Estimated Salmon Run at Chester Weir - Mark Recapture and Trap Estimates Combined)

Year	Mark Recapture & Trap Estimates Combined												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1991	-	-	-	-	-	435**	395	1360	1512	650	-	-	4352*
1992	-	-	165**	275	281	130	973	987	1481	129	194	28	4643
1993	-	-	48**	46	234	281	1774	2594	3633	292	640	215	9757
1994	-	-	11**	75	243	294	641	1285	1804	765	164	3	5285
1995	-	-	-	201**	172	208	782	443	2813	440	583	61	5703
1996	-	-	-	-	-	510**	331	443	3311	208	85	43	4931
1997	-	-	-	-	-	480**	768	1601	2082	217	248	100	5496

* Incomplete data set for close season.

** Combined estimate from January to month stated.

Table 5.4 Year Class Composition of Salmon Run at Chester Weir 1992 - 97

	YEAR CLASS									
SEA AGE	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**ALL**
1SW	-	24	2053	5983	4909	2151	7127	3352	1867	27466
2SW	17	875	1453	1229	469	635	2411	192	0	7281
3SW	71	55	33	3	35	48	31	0	0	276
ALL	88	954	3539	7215	5413	2834	9569	3544	1867	35023
PS	-	-	-	-	-	-	-	-	-	792

5.1.3 Changes in Location of Catches

In addition to the general trends discussed above with respect to the size, timing and composition of the salmon run, it was also considered prudent to investigate whether the location of catches between the beats had changed over time. In other words, are fish being deterred from entering the river, running later and hence being available to rods late in the season?

Table 5.5 show rod catches as 5 year averages for eight beats. The lower reaches, Sutton Green to Erbistock, Erbistock to Pontcysyllte, and Pontcysyllte to Glyndyfrdwy, display a trend towards decreasing rod returns as a percentage of the total catch over the first to the third of the three five year periods. This is most marked in the Erbistock to Pontcysyllte reach, where the 1981-85 average was half of that in the early 1960s as a percentage.

Table 5.5 Rod catches per beat as 5 year averages over three selected periods.

Beat	5 Year Average		
	1961-1965 (Average Total = 1,219)	1971-1975 (Average Total =916)	1981-1985 (Average Total = 494)
1. Sutton Green- Erbistock	247 *20%*	246 *27%*	76 *15%*
2. Erbistock- Pontcysyllte	174 *14%*	106 *12%*	33 *7%*
3. Pontcysyllte- Glyndyfrdwy	385 (1) *32%*	146 *16%*	115 (4) *23%*
4. Glyndyfrdwy- Alwen Junction	373 (3) *31%*	276 *30%*	182 *37%*
5. River Alwen - River Ceirw	- -	39 *4%*	6 *1%*
6. Alwen Junction - Llandderfel	103 *9%*	78 (3) *9%*	31 (4) *6%*
7. Llandderfel – Bala	38 (3) *3%*	77 (2) *8%*	16 (4) *3%*
8. River Tryweryn	- -	2 (3) *<1%*	10 (1) *2%*

NB: Figures in Italics are a percentage of the average annual catch for that period (hence figures do not add up to 100%). Those in parenthesis are the number of data points for each average figure where this was less than 5.

In contrast, the next reach up the Dee, Glyndyfrdwy to the Alwen Junction, has increased from 31 to 37% of the average annual catch.

All the upstream reaches, including the Alwen, comprise a comparatively small component of the total catch, varying between 11 and 21%.

For the most recent period for which this data set is available (1981-85), the upper reaches accounted for 12% of the catch on average.

The nature of the data does not lend itself to robust conclusions. However, there are indications that in the lower reaches of the Dee, below Glyndyfrdwy, anglers returns have decreased, the most productive stretch proportionately being that immediately below the Alwen. This observation could of course be linked to a shift in angling effort. Alternatively it may be a response to regulation, bearing in mind that the three time periods have been chosen to coincide with the period following the potential impacts of Celyn and Brenig coming on-line.

Lees (1972) suggested that a likely consequence of augmenting flows by regulation releases was that salmon would move through the lower and middle reaches of the river more quickly, and that catches by angling in the more upstream areas would benefit at the expense of the lower beats.

5.1.4 Migration & Flows

The relationship between salmon migration and flows in the Dee has been the subject of considerable investigation. One of the principal sources of data is the fish counter and flow monitoring station at Manley Hall, near Erbistock. As mentioned earlier, data are only available for the fish counter over the period 1976 to 1991 but, due to counter failure, reasonable data sets exist only for some of these years.

Figures 5.10 – 5.16 show salmon numbers for each month during the years for which reasonable data were available, together with the mean daily flows during that year. During the summer months, when flows are low and the effect of regulation most pronounced (e.g. 1984, 1989, 1990), salmon maintain upstream migration, although the larger runs appear to coincide with the wetter months as summer draws to a close and autumn progresses (e.g. 1981, 1990). In addition, freshets above the regulated flows appear to stimulate migration during the summer months (e.g. June 1977, June 1985). However, salmon appear to continue to migrate upstream during dry summer months, albeit in smaller numbers, even when flow is dominated by regulation releases.

The second valuable source of data is that from the telemetry studies undertaken in the early 1990s (Purvis *et al.*, 1994). Although data on the freshwater migration phase were collected, these data are not yet fully available, although a summary of the preliminary findings is presented in Appendix II. The most detailed information in report format thus far is therefore confined to the estuarine area of the Dee.

Data were collected during 1992 and 1993. Unfortunately, during these years the summer weather was typically cool and wet which, when combined with the regulated flows, resulted in correspondingly mild estuarine conditions.
Hence, poor water quality in the estuary, low oxygen and high temperatures were not commonly experienced during the study, apart from limited periods at certain locations within the tidal cycle.

Nevertheless, the study highlighted the significance of freshwater flows in influencing upstream migratory behaviour. Even in the lower estuary, for a significant proportion of fish, active upstream migration occurred throughout the tidal cycle, suggesting that fish were responding to riverine flows. This behavioural response was more pronounced in the middle estuary, resulting in more rapid migration.

One of the most significant findings for the current project was that net migration rate through the middle estuary was significantly reduced during periods of lower freshwater flow and higher temperatures. Substantial alterations to rate of passage occurred at flows of the order of 8 to 12 cumecs and at temperatures between 15 and 17 °C. Tide height and state were also of great importance and provided strong evidence that salmon were actively migrating towards freshwater during passage through these reaches.

It was also significant to note that Chester Weir was not considered to be a significant impediment to fish movement, the fish ladder being regarded as the major factor promoting rapid fish movement across the weir. Over 90% of radio tagged salmon utilised the fish ladder. If fish were held up at the weir, they tended to stay in the vicinity, typically in the pools within the pass itself. In addition to the efficiency of the ladder, the fact that Chester Weir itself was inundated on 25 % of tides further added to the ability of fish to successfully negotiate this potential obstruction.

However, delays in passage time were still observed, but typically were less than 36 hours for 75% of salmon. The position of the weir at the effective head of tide on the Dee was itself considered a significant influence on fish behaviour, where flows in excess of 30 cumecs significantly reduced delays below the weir.

Whereas delays were reduced at this level of flow, most fish actively migrated across the weir when flows were above 13 cumecs, or with higher tides. The state of tide or level of light intensity (at low flows) also influenced the ability of fish to overcome delays at Chester Weir.

It is important to note, however, that for the proportion of fish that are displaced back to the estuary (estimated as 30% of weir arrivals), exploitation by the nets is inevitably increased for this component of the population[5]. Estimates are that 10 % of the in-season population failed to cross Chester Weir as a result of net capture, following displacement from the weir. Hence the significance of maintaining sufficient freshwater flows to encourage upstream migration and passage over Chester Weir is highlighted.

As mentioned above, a summary is provided of the initial findings from the freshwater telemetry studies on the Dee in Appendix III, but it should be stated that these findings are very much preliminary and at an early stage of analysis.

Typical first phase migrations of salmon are of the order of 49 km into freshwater. Once salmon enter freshwater they move rapidly through the lower

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[5] Net byelaw changes should reduce net exploitation.

reaches of the Dee, regardless of prevailing flows, although flows in excess of 20 m^3/s^{-1} reduce migration speed. Conversely, however, when fish reach the middle reaches of the river around Bangor-on-Dee, migration rate decreases significantly but is stimulated at flows in excess of 20 m^3/s^{-1}.

No clear diurnal pattern of migration through the lower river was detected. However, although from Bangor-on-Dee upwards migration was still random with respect to time of day at flows greater than 20 cumecs, at lower flows migration took place primarily between the hours of 21.00 and 03.00.

The majority of salmon showed a three-stage or stepped pattern of migration, with one or more prolonged cessations of upstream migration, defined as periods of quiescence lasting more than 15 days (median 32 days, maximum recorded 134 days). However, even while still actively migrating, salmon do exhibit short delays, typically of 3 to 15 days, but these are distinguished from quiescent delays which were observed in all river reaches. Most quiescent delays were common in the middle river, with the modal reach being downstream of Erbistock Weir.

Although salmon were able to pass Erbistock Weir at regulation flows of 11 cumecs, delays here were more prolonged at low flows, and the probability of passage increased as the flow increased from 20 to 30 cumecs.

Salmon typically recommence migration in response to freshets, but not all freshets are effective in promoting migration. However, higher flows (>25 cumecs) and freshets are likely to prolong movement of fish which are still actively migrating or undergoing short delays, but are much less likely to encourage quiescent fish to recommence migration. By comparison, larger freshets are needed to encourage quiescent fish to recommence migration.

No threshold peak freshet flow/starting flow quotient (Q_{ps}) for re-commencement of migration was apparent, but freshets with a Q_{ps} of 4 to 5 were twice as likely to promote migration as freshets with a quotient of 1 to 2.

From September onwards quiescent fish were much more likely to respond to freshets by re-commencing migration than earlier in the year. However, these secondary migrations following periods of quiescence were usually at a slower speed than initial migrations.

The only salmon likely to be present in the upper river (i.e. above Glyndyfrdwy) prior to the autumn are early entrant fish which came into the river before July. Early entrants typically spawn in the upper part of the catchment, whereas the majority of summer and autumn entrants spawn in the middle and lower reaches. Salmon are vulnerable to capture by angling during their initial migration phase in freshwater and again during their secondary migration in the autumn, but are generally uncatchable while quiescent. Early entrant fish with a more prolonged initial migration phase are exploited more heavily than summer and autumn entrants.

The study found that freshets during times of low flow are important in encouraging fish still in their initial migration phase to resume or continue their upstream migration. Salmon responded to smaller increases in flow during low flow periods, indicating that relative changes in flow seemed to be of significance.

However, quiescent fish were less likely to be stimulated to move by smaller freshets, except in autumn. A 20 cumec freshet in late September 1991 stimulated migration in 13 fish, while a similar freshet in August only moved 2 fish. Thus responses of quiescent salmon to summer freshets were mixed, and flows which would produce significant upstream migration in early autumn were of limited success in August. The variation in migration flow threshold values, depending on previous experience, physiological condition and time of year therefore complicates consideration of appropriate minimum advisable flows.

Upstream movements in autumn, often associated with movement into the spawning reach or tributary, were almost exclusively associated with increases in flow. Small freshets in late September and early October were particularly important in 1991, whereas similar magnitude freshets in August had been ignored.

Failure of artificial releases to stimulate upstream movement of quiescent fish may have been related to the type of discharge. These consisted of a level supplement over and above the regulation release over many days. Stepped releases to follow a normal freshet pattern may therefore be more successful.

Catchability by angling was highest during the pre-quiescence phase, and fish making step-wise progression up river were more vulnerable to capture. More frequent freshets which prolong this phase and stimulate more fish to follow this pattern would be the most likely mechanism to increase the rod catch. Early entrant fish tended to have an extended initial migratory phase with a brief holding period (3 - 14 days) in the middle river and were particularly vulnerable to capture during this migration (i.e. the catchable period for these fish was effectively extended).

Catchability of salmon rapidly decreased once quiescence began, and only increased again during increased activity in the autumn. By way of illustration, all rod recaptures at Erbistock were within 11 days of arrival.

Spawning of early entrant multi-sea-winter salmon in the upper Dee was regarded as important, as local sub-catchment or tributary phenomena could have a disproportionate effect on this component of the stock.
Partial spatial segregation of spawning amongst different stock components suggests a degree of reproductive isolation.

Survival of kelts to return as previous spawners was poor, with 17% of the initial freshwater entrants leaving the river as kelts, but only 2% of the adult run into freshwater being previous spawners. There was also significant post-spawning mortality in the river indicating that kelt reconditioning may therefore be worthwhile on the Dee.

While the study was not able to define a minimum advisable flow, it highlighted many other important areas. The importance of autumnal freshets in stimulating migration (and availablity to rods) was emphasised as was the significance of imposing a higher degree of "naturalness" to mimic the flow pattern of natural events. As was found in other studies on the Tywi (Evans *et al.,* 1994), early running spring fish tended to spawn higher in the catchment. With respect to the Dee this may result in this component of the stock suffering from additional environmental stress, such as poor water quality in some of the upper tributaries, putting further pressure on juvenile survival.

5.1.5 Spawning

In a review of the salmonid fish of the Dee and Clwyd, Lees (1972) refers to the Alwen tributaries as providing some of the best spawning and rearing grounds in the Dee catchment. The Ceirw, was particularly notable with excellent spawning areas but was only accessible up to around Bont-y-Glyn. Upstream of this point a further 13 miles of good quality potential spawning and nursery habitat was present. A tributary of the Ceirw, the Merddwr, was also noted as a good spawning area for salmon.

The re-routing of the Tryweryn at Bala in 1956 destroyed salmon spawning gravel both in the Dee itself below the lake outfall and in the lower Tryweryn below Bala Bridge. Conversely, Brenig Dam did not flood spawning areas but inundated an area used by the Rivers Authority as a stocked nursery.

The Hirnant was regarded as excellent spawning and rearing habitat but only in the first mile, the higher reaches being accessible only during exceptionally high flows due to the falls at Garth Goch. Further down the Dee, the Morwynion was also considered a good spawning area, but again only the first mile was accessible[6]. Upstream contained a further 7 miles of good nursery. Moving further downstream, the Eglwyseg was considered to have good quality spawning and nursery areas but suffered from poor access, as did the Ceiriog upstream of Chirk.

Examination of redd count data for the whole river shows a marked decline in spawning activity over recent years (see Figure 5.17).

Although caution must always be used when evaluating redd count data due to variations in effort and reporting together with the effect of parameters such as flow and turbidity, such data can be valuable in assessing long term trends in distribution rather than abundance.

The overall decrease in redd cutting appears to be most noticeable 5 years after Celyn came on line (1965), with subsequent total redd counts being below 1000 in the majority of years for which data are available. Although post 1979, (after Brenig) redd counts appeared to be very low, less than 500, spawning activity on

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[6] In the early 1990's salmon fry have been reported above Bryneglwys.

average remained more or less at the levels seen during the seventies, varying between 500 and 1000 redds most years.

Looking at the above tributaries in more detail, it is apparent that they virtually all show a decrease in spawning activity whether or not they are directly subject to regulated flows. Data for the main river Dee are poor (Figure 5.18) but 1980s counts are up to two orders of magnitude below those few data points recorded prior to any regulation of the river. The river Alwen, subject to regulation from Brenig post 1979, shows a marked reduction in redd count during the 1970s (Figure 5.19) and has never returned to the numbers recorded in the sixties and previously. It is, however, important to note that low counts were recorded in the early part of the decade before reservoir construction took place. Data for the Tryweryn show a similar pattern but are phased earlier, a marked decline in redd count coinciding with the construction of Celyn (Figure 5.20). The number of redds recorded has remained around or below 50 ever since reflecting both lost spawning gravel due to the areas flooded behind the dam and that lost due to the diversion of the river above the sluices at Bala. A similar decline in spawning activity is evident on the Bala tributaries (Figure 5.26).

With respect to the tributaries not directly affected by regulation, such as the Ceirw and the Merddwr of the Alwen sub-catchment and the Ceiriog, most display a decrease in redd count post 1960's (Figs 5.21 to 5.23). The Alwen tributaries (particularly the Ceirw) appeared to have a very marked decrease. This may reflect differences in water quality between these areas, the Alwen sub-catchment, at least in part being subject to acidification problems which could be impacting upon the salmonid populations in these rivers.

It is, however, interesting to note that several of the tributaries not directly affected by regulation showed an initial increase in redd count in the years immediately after Celyn came on line. This observation is particularly marked in the Hirnant and Mynach (Figures 5.24 & 5.25). It is plausible that these streams were utilised by fish that would otherwise have spawned in the upper Dee itself or in the upper Tryweryn. Both the Hirnant and the Mynach continue to be important spawning tributaries on the Dee and in recent years have displayed redd counts which are not dissimilar to those preceding regulation.

The overall trend from the redd count data is however towards a decline in spawning activity post regulation, although there is some evidence of a decrease in spawning activity by 1960 prior to the construction of Celyn in some areas (e.g. Tryweryn and Ceiriog).

Nevertheless it would appear that a reduction in the redd count has been most significant on the rivers directly affected by regulation and would appear to be caused primarily as a consequence of the construction of Celyn. Although one or two second order tributaries have not seen such a deterioration, most would appear to display a decline in redd counts since the sixties, although often not as marked as in the primary rivers. In addition, acidification in the Alwen sub-catchment may exacerbate the overall reduction in redd count in this area.

5.1.6 Juvenile Populations

A significant amount of survey effort has been expended over the years to estimate juvenile salmon and trout population densities at various points throughout the Dee catchment. Early studies, dating back to the sixties were undertaken by Liverpool University in response to specific issues raised by the development of the regulation scheme (Appendix I). Subsequently, more systematic, albeit periodic, investigations have been instigated by the Welsh Water Authority, the NRA and now the Agency.

In particular, the Dee Stock Assessment Programme (DSAP) was initiated in 1989, providing a rigorous investigative framework within which juvenile population monitoring was undertaken. Unfortunately however, survey sites and techniques were not co-ordinated or calibrated making comparison between long term data sets difficult. Hence much of the historic and indeed more recent information has to be viewed in isolation, and is thus rendered redundant in the context of this report as it does not lend itself to temporal or spatial comparisons.

Nevertheless, detailed and painstaking evaluation and matching of survey sites has provided a number of studies which allow comparisons between historic data and more recent NRA/Agency data. The following rivers therefore lend themselves to an evaluation of the long-term effects of the regulation scheme on juvenile salmonids.

a) Afon Mynach

With the completion of the Llyn Celyn Reservoir and the closure of the upper Tryweryn to adult salmon in 1961, as mentioned earlier, there was a subsequent increase in the numbers of adult salmon spawning in the Mynach. Juvenile salmonid populations in this tributary of the Tryweryn were studied by Laird (1976). Her investigations dealt mainly with the growth and movement of juvenile salmon and trout, but some information on population densities was obtained which can be compared with more recent data from the Regional Juvenile Salmonid Monitoring Programme (Davidson – pers. comm.). Four of Laird's sites were within the length covered by the RJSMP, and results from these sites are summarised in Table 5.6 below. Comparable data from the RJSMP's quantitative surveys are given in Table 5.7.

Table 5. 6 **Juvenile Salmon and Trout Population Densities - Afon Mynach - 1972/73 (From Laird, 1976)**

		Numbers per 100 m sq.					
		Salmon		Trout		Class*	
Site and Date		0+	>0+	0+	1+	>1+	
Site 1 GR SH 906 397	July '72	-	7.42		< 22.68 >		
	Aug '73	34.2	24.69	-	20.21	11.85	B
Site 3 SH 908414	June '72	-	7.63	-	< 27.38 >		
	July '73	-	18.5		25.67	7.69	
	Sept '73	50.69	12.39	13.64	16.23	4.19	B
Site N SH 910415	July '73	-	6.88	-	21.25	1.88	
	Aug '73	268.75	8.75	26.25	11.88	2.50	A
	Oct '73	70.42	8.44	14.10	7.66	6.13	B
Site 4 SH 911423	July '72	-	17.32		< 29.48 >		
	Sept '72	-	11.91	19.38	< 18.58 >		
	July '73	-	4.68	-	22.33	4.86	
	Sept '73	59.83	5.89	11.97	14.18	3.63	B

*** Class derived from Classification Matrix for juvenile salmon given in Dee Stock Assessment Programme Report for 1992 (NRA, 1994).**

Table 5. 7 **Juvenile Salmon and Trout Population Densities - Afon Mynach Recent Data from Regional Juvenile Salmonid Monitoring programme.**

		Numbers per 100 m sq					
		Salmon		Trout			Class*
Site and Date		0+	>0+	0+	1+	>1+	
Site 40 GR SH 909415	1987	128.0	14.0	9.0	< 24.0 >		A
	1988	53.0	5.0	5.0	< 4.0 >		B
	1989	65.5	8.2	19.0	< 7.8 >		B
	1990	59.8	17.3	8.2	5.8	0.4	A
	1991	62.5	7.5	4.9	5.6	-	B
	1992	98.10	16.2	38.0	6.4	1.4	A
	1993	51.8	7.8	16.5	2.1	1.6	B
	1994	109.2	1.7	15.5	13.5	1.6	B
Site 42 SH 912418	1994	37.7	12.0	0.6	12.6	1.9	B
Site 43 SH 908427	1994	28.3	9.0	5.6	6.8	0.5	B
Site 44 SH 906392	1987	72.0	11.0	6.0	< 10.0 >		B
	1988	42.0	3.0	6.0	< 3.0 >		C
	1994	20.8	4.1	7.2	4.6	1.3	D

*** Class derived from RJSMP Classification Matrix.**

Comparison of these two data sets suggests that in the Mynach there has been no significant change in the abundance of juvenile salmon with time. These results are consistent with that which would be expected given the maintenance of reasonable redd counts on this tributary. Both Laird's data and that from the RJSMP surveys typically gave class scores of B and occasionally A, using the RJSMP classification matrix. The only significant decline would appear to be at RJSMP Site 44, which was approximately 0.5 km downstream of Laird's Site 1, where the class had declined from B to D by 1994. The RJSMP programme also includes semi-quantitative surveys of the Mynach sites. These figures are not presented here, as they are not directly comparable with the 1972/73 figures. However, when converted to class scores, using the classification matrix for semi-quantitative surveys, the typical score is class B, with the occasional A. Site 44 is again atypical, and over the period 1986 to 1993 the class fluctuated between B and D.

Comparisons of the abundance of trout in the two time periods indicates that there has been a reduction in their numbers since 1972/73.
No obvious reasons for this are apparent, given the maintenance of the salmon population.

b) Bala Lake Tributaries.

Woolland (1972) obtained a limited amount of data on population densities of juvenile salmon and trout in the Little Dee (Dyfrdwy), Afon Glyn and the Afon Lliw during 1969/70. His estimates were based on recaptures of tagged fish of greater than 0+ age, using the methods of Schnabel (1938) and Schumacher and Eschmeyer (1943). Individual sampling sites were not identified, although site locations shown on maps in the Liverpool University report on River Regulation and the Dee Catchment (Liverpool University, 1972) indicate that they were probably in the lower reaches of these streams.

Woolland's data are given in Table 5.8 below, and more recent data for comparison from RJSMP surveys are given in Table 5.9.

Table 5.8 **Juvenile Salmon and Trout Densities for Llyn Tegid Tributaries - 1969/70 (From Woolland, 1972).**

Tributary	Numbers per 100 m sq Salmon >0+	 Trout >0+
Afon Glyn	38.2 - 41.2	20.2 - 43.0
Little Dee	-	23.0
Afon Lliw	14.4 - 37.3	-

Table 5.9 **Juvenile Salmon and Trout Population Densities - Llyn Tegid Tributaries. Recent Data from RJSMP.**

Quantitative Surveys.

Site and Date		Numbers per 100 m sq Salmon 0+	 >0+	 0+	 Trout 1+	 >1+	Class
Little. Dee 1.	1985	1.0	1.0	2.0	< 1.0 >		
DGR SH 878311							
Little Dee 2.	1985	3.0	1.0	2.0	0	0	D
GR SH 874 302							
Little Dee 3	1985	0	7.0	7.0	< 4.0 >		D
SH 857286	1986	5.0	4.0	7.0	< 8.0 >		
"	1987	6.0	6.0	16.0	<10.0 >		C
"	1992	5.0	8.0	9.5	1.6	0	C
"	1993	10.3	1.2	8.4	1.2	0	D
"	1994	5.4	0	12.1	3.6	0.6	D
Lliw 4	1985	1.0	1.0	2.0	< 1.0 >		D
SH 867308	1993	0	0	2.9	2.4	0.5	
Lliw 5	1985	1.0	1.0	2.0	< 6.0 >		D
SH 855308							
Lliw 6	1985	0	0	2.0	< 4.0 >		E
SH 828324	1993	5.0	2.2	2.1	0	0	D

Table 5.10 Juvenile Salmon and Trout Population Densities - Llyn Tegid Tributaries. Recent Data from RJSMP.

Semi-quantitative surveys.

		Salmon		Trout			Class
		0+	1+	0+	1+	>1+	
Little Dee 1	1989	13.6	1.2	1.2	0	0	C
Little Dee 2	1989	6.1	0.6	2.1	0	0	D
Little Dee 3	1989	9.5	4.6	4.6	< 3.7 >		C
“	1990	2.9	5.3	2.9	2.4	0.6	C
“	1991	41.9	15.3	14.3	2.8	0.6	A
Lliw 4	1989	12.0	1.9	1.9	0	0	C
Lliw 5	1989	0.8	3.9	1.9	< 1.9 >		C
Lliw 6	1989	0	2.2	4.5	< 8.0 >		D

Although the data obtained by Woolland in 1969/70 were very limited and are not strictly comparable with the more recent data, there is evidence of a marked decline in the abundance of juvenile salmonids in the Little Dee and Afon Lliw. The recent figures for the Lliw in particular give cause for concern. Salmon have been virtually absent from these streams in recent surveys, whereas Woolland's figures suggest a parr density in the good-to-excellent range. The Afon Glyn figures were even better, but there is no recent data for this tributary.

It is therefore apparent that juvenile salmonid populations were significant and of good quality in these tributary streams more than 15 years after alterations to the sluices in Llyn Tegid and the diversion of the Tryweryn. In addition, Wooland's data describe healthy salmon populations a full five years after Celyn came on line. Any direct influence of regulation on these headwater juvenile populations is therefore far from apparent, the deterioration in salmonid populations having taken place some time after these major hydrological changes took place.

A recent report on the Bala tributaries (Cove *et al,* 1997 – currently in draft format), has investigated the problems in more detail. Water quality is considered to be borderline for sustaining salmonids, low pH and high aluminium concentrations giving cause for concern. However, despite this observation, the main limitation on juvenile salmonid populations was considered to be poor recruitment as a result of insufficient spawning adults.

Given the earlier comments with regard to the decline in spring running fish and their tendency to spawn higher in the catchment, the conclusions seem logical, particularly given evidence from invertebrate data and fry stocking experiments.

c) Rivers Brenig and Alwen.

Studies on the fish populations and ecology of the River Brenig, its tributary the Fechan and the main River Alwen were the subject of several Liverpool University Ph.D. and BSc Honours Degree projects, both before and after the construction of the Brenig Reservoir. In particular, Cane (1974) and Grundy (1979) obtained quantitative information on salmonid populations, which can be compared with more recent data from the RJSMP. Three of Cane's sampling sites were relatively close to RJSMP sites and one of Grundy's. Cane used a mixture of depletion estimates and mark-recapture estimates of population size, and Grundy used depletion estimates.

Table 5.11 Juvenile Salmon and Trout Population Estimates - R.Alwen Catchment - 1972 and 1978/79 data. (From Cane, 1974 and Grundy, 1979).

		Numbers per 100 m sq						
Site and Date		Salmon			Trout			**Class**
		0+	1+	>1+	0+	1+	>1+	
Brenig, Cane Site B2	1972	-	11.2	2.4	-	14.2	16.5	
GR SH 975540	1978/9		<--0.30-->		-	<--34.0-->		
Brenig, Grundy S.4	1978/9	-	<--8.0 --->		-	<--17.0-->		
GR SH 974527								
Alwen, Cane Site A2	1972	25.2	33.8	2.1	3.6	8.8	2.7	A
GR SH 987503								
Alwen, Cane Site A3	1972	49.6	26.9	0.8	12.8	6.8	4.0	A
GR SJ 029463								

Table 5.12 **Juvenile Salmon and Trout Population Estimate - River Alwen Catchment - Recent Data from RJSMP.**

(a) Quantitative surveys

Site and Date		**Salmon** 0+	**Salmon** 1+	**Salmon** >1+	**Trout** 0+	**Trout** 1+	**Trout** >1+	**Class**
		Numbers per 100 m sq						
Brenig, Site 10c GR SH 973527	1993	2.3	2.3	0	14.0	1.3	0	D
Alwen, Site 10 GR SH 988508	1985	26.0	<--6.0-->		10.0	<--3.0-->		B
Alwen, Site 8 GR SJ 029464	1985	5.0	<--1.0-->		3.0	<--1.0-->		D

Table 5. 13
(b) Semi-quantitative surveys

Site and Date		**Salmon** 0+	**Salmon** 1+	**Salmon** >1+	**Trout** 0+	**Trout** 1+	**Trout** >1+	**Class**
		Numbers per 100 m sq						
Alwen, Site 10	1991	4.0	1.2	0	0.2	0.7	0	D
Alwen, Site 8	1991	13.0	1.1	0	2.2	0.1	0	C

N.B. RJSMP Site 10c on the Brenig is at the same location as Grundy's Site 4 and approximately 1300 m downstream of Cane's Site B2/Grundy's Site 1;
RJSMP Site 10 on the Alwen is 500 m upstream of Cane's Site A2; RJSMP Site 8 on the Alwen is 100 m upstream of Cane's Site A3.

Cane's sites both fell within Class A of the RJSMP Classification Matrix, whereas in the more recent surveys, sites in the same localities scored as low as D. There would therefore appear to have been a significant decline in the juvenile salmon populations of the Alwen below the Brenig confluence since 1972. Confirmation that population densities were higher in the early 1970's was given by Swinney (1973) in a research report published in the Annual Report of the Dee and Clwyd Fishery Officer. Swinney provides figures for densities of salmon and trout in September 1973 at Pentrellyncymmer and Betws Gwerfil Goch:-

Table 5.14 Densities of salmon and trout in September 1973 at Pentrellyncymmer and Betws Gwerfil Goch.

	Densities in fish per 100 square metres		
	Pentrellyncymmer		Betws G.G.
	0+	>0+	>0+
Salmon	95	11	77
Trout	21	8	7

In conclusion, it is apparent that juvenile salmonid populations have declined significantly in both the Bala and the Alwen sub-catchments. Whilst it would appear probable that the construction and operation of Brenig has had a direct impact on salmonid populations of the Alwen[7], the same cannot necessarily be said of regulation from Bala Lake. Conversely, there is evidence that streams not directly affected by regulation, e.g. the Ceiriog, have sustained high juvenile populations.

5.1.7 The Temperature Regime of the Upper River Dee and its Possible Impacts on Survival of Salmon Fry

In studies on the effects of hypolimnial releases from Llyn Brianne reservoir on the River Tywi salmonid population, Wyke (1997) showed that the elevated temperatures of the release water during the late winter and early spring could accelerate early development of salmon alevins. Artificially elevated growth rates resulting in more rapid development meant that they reached the swim-up stage before the water temperature reached the critical level of 7 °C at which salmon fry commence feeding. The consequence of this was likely to be greater than normal mortality of fry in the period immediately following emergence from the gravel due to a period of enforced starvation.

To examine whether or not this was likely to be happening in the Dee, as a consequence of releases from Llyn Celyn, temperature records taken at the Bala sluices were examined for the winter and early spring periods of 1988/89 and 1989/90. Using the methodology described by Wyke (1997), the anticipated hatching and swim-up dates for salmon fry were estimated for these spring periods and compared with the dates at which the water temperature reached 7°C. A peak spawning season date of 7th December was assumed for Dee salmon (Cragg-Hine, pers. com.).

In 1989, the estimated hatching date was 19th February, and swim-up was still nowhere near taking place when the water temperature reached 7°C on 30th March. In 1990, which was a generally cooler winter but with a warmer early spring, the estimated hatching date was 10th March, but the water temperature reached 7°C by 15th March.

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[7] The Pont Barcer brood stock trap and to an extent acidification in the Alwen catchment may also have had a degree of influence on juvenile salmonids in the Alwen sub-catchment.

Thus in both these years it is most unlikely that there was any increased mortality of salmon fry in the principal spawning areas of the upper Dee because of inability to feed in the immediate post swim-up period.

Temperature records taken from the River Tryweryn at Llyn Celyn were also examined for the same time periods, and hatching dates estimated. In general, the temperatures here were typically about a degree colder than at the Bala sluices. In 1989 the estimated hatching date was 1st March, and in 1990 the 21st of March. Unfortunately the temperature records available did not extend far enough into the spring to determine the attainment of an average water temperature of 7 °C. However, by the beginning of April water temperature was typically 6 to 6.5 °C, and it is extremely unlikely that swim-up of salmon fry would have taken place at this time.

On balance, it seems unlikely that discharge of stored water from Llyn Celyn is having much impact on hatching and swim-up times for salmon ova and alevins. The release from Llyn Celyn is from stepped discharge points within the upper layer, rather than from the hypolimnion, and the temperature is therefore more likely to follow changes in air temperature. In addition, the impact of the release will be reduced by mixing with Llyn Tegid water.

5.1.8 Juvenile Age Composition

The change in adult stock composition from a multi sea-winter dominated fishery, to a one sea-winter fishery has already been discussed. However, examination of data contained within past PhD studies has indicated a change in smolt age in juvenile salmon and trout populations.

a) Salmon

Some of the earlier studies by Liverpool University collected data on smolt ages; these are given in Table 5.15 below.

Table 5.15 Salmon Smolt Ages 1938-1939 from Jones (1949), (quoted in Lees, 1972).

Year	**Percentage in each smolt age class.**		
	1 year	**2 year**	**3 year**
1938	7.0	89.8	3.2
1939	3.5	89.5	7.0
From adult scales	4.5	93.3	2.2

Although the location where the smolts were collected is not given, clearly most smolts (approximately 90%) were two years old.

Data presented by Lees (1972) of scale samples collected from the Dee Estuary commercial net catches (adults), 1967-1969 inclusive, are presented in Table 5.16.

Table 5.16 Salmon Smolt Ages Derived from Adults 1967-1969 from Lees, (1972).

Smolt Age	Percentage of each smolt age group in each sea age group.								
	1+SW	2.SW	2+SW	3.SW	3+SW	4.SW	4+SW	P.S.	Overall
1	3.7	2.9	4.4	3.1	6.1	8.3	-	-	3.9
2	89.0	88.4	90.6	95.6	90.9	91.7	100	100	90.6
3	7.2	8.7	4.9	1.4	3.0	3.0	-	-	5.4

Again the overwhelming proportion of smolts (90%) were two-year-olds. Examination of scale samples taken directly from smolts in 1969 were also undertaken by Lees shown in Table 5.17 below).

Table 5.17 Salmon Smolt Ages 1969 from Lees, (1972).

Sampling Location	Percentages in each age group		
	1 year	2 year	3 year
Headwater samples:			
Tryweryn and Mynach	0	78.3	21.7
Alwen and tributaries	0.5	69.4	30.0
Hirnant	0	67.1	32.9
Huntington Intake	4.20	87.41	8.39
Dee Estuary	7.10	85.79	7.10

Interestingly, whereas samples taken towards the estuarine end of the river contained a similar proportion of two year old smolts, those from the headwater streams contained a significant proportion of three year old smolts (21 to 32%). Data from Woolland (1972) in Table 5.18 confirms the earlier observation, where two year olds dominated the population.

Table 5.18 Salmon Smolt Ages 1969-1970 from Woolland (1972)
Samples collected from Llyn Tegid, near river mouths.

Year	Percentages in each age group		
	1 year	2 year	3 year
1969	1.5	94.7	3.8
1970	1.1	93.2	5.4

Similar results were found by Laird working in the early 1970s who examined smolts entrained at Huntington Intake.

Table 5.19 **Salmon Smolt Ages 1971-1972 from Laird (1976).**

Year	Percentages in each age group 1 year	 2 year	 3 year
1971	2.47	89.72	7.82
1972	4.35	85.21	10.43

However, when examining more recent data from the National Rivers Authority and the Agency (1992, 1993, 1994, 1995) a significant change appears to have taken place. Table 5.20 below shows data from scales of adult salmon taken in River Dee Trap at Chester (Dee Stock Assessment Programme), 1992 - 1997 data combined.

Table 5.20 **Salmon Smolt Ages 1992-1997 from Agency (1997).**

Smolt age	Percentage of each smolt age group in each sea age group 1SW	 2SW	 3SW	 Overall
1	37.61	40.75	27.27	37.92
2	61.06	58.31	71.43	60.86
3	1.33	0.94	1.30	1.22

The recent data show that the salmon population now has a significant proportion of one year old smolts (40%). Correspondingly, three year old smolts have become very rare, whilst two year old smolts, although still the most common at 58%, no longer comprise the overwhelming majority of the smolt group.

When the recent data from the DSAP are compared with the earlier data obtained by workers from Liverpool University it is evident that there has been a substantial shift in the age composition of River Dee salmon smolts during the intervening time. Both in the 1938/39 period and the 1967 - 1972 period, the vast majority of smolts were 2 years old, and typically made up 85-90 % of the stock. One year smolts were the smallest part of the stock, and in most years were less abundant than 3 year smolts. Lees (1972) recorded a particularly high proportion of 3 year smolts in the samples he collected in the headwaters. Similar results were obtained, whether based on examination of scales from smolts or from returning adults.

In contrast, the recent data from the DSAP has shown that during the 1992 - 95 period the percentage of 2 year smolts in returning adults has fallen to below 60% and the proportion of 1 year smolts has risen to 40%. Conversely, three year smolts contributed a much smaller proportion than in the earlier period.

b) Sea Trout

Much less historical information is available on sea trout smolts, and only Lees (1972) examined samples of significant size. His findings, based on samples of adult sea trout collected by electric fishing from River Dee tributaries during the autumns of 1967, 1968 and 1969, are given below. Whitling (0 sea winter) made up 56% of his samples.

Table 5.21 Sea Trout Smolt Ages 1967-1969 Derived from Adults in Lees (1972).

Year	**Percentage smolts in each age group**			
	1 year	**2 year**	**3 year**	**4 year**
1967 - 69 combined	0	67.2	30.7	2.1

Lees (1972) also collected a limited amount of data on sea trout smolts from the lower river in 1969.

Table 5.22 Sea Trout Smolt Ages 1969 from Lees (1972).

Location	**Percentage smolts in each age group**			
	1 year	**2 year**	**3 year**	**4 year**
Huntington Intake	0	50.0	50.0	0
Dee Estuary	0	55.0	45.0	0

Recent information is available from the Dee Stock Assessment Programme (NRA, 1994, 1995, 1996; EA, 1997). The overall percentage of whitling was 47.6% in these samples, but this percentage was biased downwards by low sampling efficiency for these small fish in 1992 and 1993.

Table 5.23 **Sea Trout Smolt Ages 1969 from NRA & Agency (1997).**

Year	Percentage smolts in each age group			
	1 year	2 year	3 year	4 year
1992-95 combined	1.23	87.84	10.83	0.10

As in the case of salmon, there appears to have been a shift towards a younger smolt age in sea trout since the late 1960's, with the proportion of 2 year smolts rising and that of 3 year smolts falling by significant amounts. A few 1 year sea trout smolts were recorded in recent studies, whereas Lees did not report any. As explained above, the proportion of whitling was lower in the earlier DSAP catches owing to sampling difficulties, but in later samples the proportion of whitling was about the same as in Lees' samples.

The reasons for this shift in age composition of smolts are far from clear. Younger smolts are typical of more southerly latitudes, and hence might be expected, if for example, climate change resulted in a significant elevation in temperatures. In fact, the opposite has taken place.

In earlier studies on the coarse fisheries of the River Dee, Hodgson (1993) demonstrated that, since significant regulation of the Dee commenced in 1965 there had been a reduction in summer water temperature in the lower Dee. In particular he noted a reduction in the number of degree days exceeding 12^{0}C (see section 5.2 on coarse fish). The warming of Dee water in its passage down the river from Bala was shown by Hodgson to occur principally in the steeper gradient reaches between Bala and Manley Hall. Since regulation, the flow through this reach has been enhanced, hence time of travel has been reduced during dry weather periods, thus reducing the opportunity for warming to occur. An initial reaction is that this should have caused a reduction in the growth rate of juvenile salmon in the main river, and hence should have tended to increase smolt age, rather than reduce it.

However, from the temperature records published by Hodgson, it is apparent that in the summer months water temperatures in the Dee are frequently above the optimum growth temperature for juvenile salmon of 16.5^{0}C, and this would have occurred more frequently in pre-regulation days. The temperature reduction may be beneficial in that high summer temperatures are avoided which may depress salmon growth rates, the optimum temperature range for growth of the species being encountered throughout longer periods of the year. It is therefore possible that regulation has actually acted to move summer temperatures back towards this optimum temperature in the main river, thus enhancing growth and possibly encouraging the production of one year smolts.

The latter argument does not obviously apply to those tributaries that are not subject to regulation (e.g. Hirnant).

An understanding of the relative contribution of such 'off-line' tributaries to the overall smolt production figure (as a percentage) may help to throw light on this issue. That is, if the contribution of such tributaries was high (say 50%), then the observed shift in smolt age would be unlikely to be due to regulation but some other factor. Currently, such data are not available.

The significance of this observation should not, however, be overlooked. It is known that in both hatchery reared smolts and in wild fish, younger smolts have poorer survival rates than older smolts. Crozier & Kennedy (in Mills, 1993) showed that return rates for 1^+ hatchery smolts varied from 0.1% to 2.3%, averaging 1%. Return rates for 2^+ ranged from 0.6% to 8.2%, averaging 2.3%. They demonstrated that 2^+ smolts have consistently better survival than 1^+ smolts, probably as a result of their larger size at release. Confirmation of better survival of larger smolts from other studies has shown that the same applies to wild as well as hatchery reared smolts. Hence, a significant impact on the adult stock may be anticipated as this change works its way through over the years.

5.1.9 Disease – The Role of UDN

Ulcerative Dermal Necrosis (UDN) after having originated in Ireland in autumn 1964 spread across the Irish Sea, finally infecting Dee salmon stocks in 1967. By April of that year, the disease was established throughout the whole length of the river, infecting an estimated 90% of the spring fish stock. In April alone over 300 dead fish were removed from the river, with many others having perished unseen. However, the figure rapidly tailed off to around 30 by the third week in May, and had dwindled to 2 or 3 a week by the beginning of August. The total number of dead fish removed from the river in 1967 was 1437. By comparison this had reduced to 431 by 1968.

The impact of the disease when compared to the overall stock is probably not that significant over several years. However, the impact on spring fish, the largest single component affected, may well have been much more serious, possibly initiating the long term trend away from multi sea-winter dominated catches seen today.

5.2 Coarse Fish

In addition to its renowned salmon fishing, the Dee also contains a diverse coarse fish community. Of particular interest is the development of a quality grayling fishery in the upper reaches, whilst the lower reaches have historically supported an important recreational fishery for a range of coarse fish species.

5.2.1 Cyprinid Fish

Examination of the Annual Reports of the Dee and Clwyd River Board reveal that as far back as 1931 the Dee was regarded as having a good quality coarse fishery.

Indeed, the lower reaches were considered suitable for species such as carp, 40,000 being stocked into the river in 1931 following drawdown of a lake at Mollington Hall. Fish to 6 lb. were taken at Farndon. By 1940, dace were emerging as the dominant species, with reports of extremely high populations of other small fish, notably minnows. Excellent angling was again reported in 1945 with bream and roach in good evidence.

O'Hara *et al* (1977) gave a more recent detailed account of the distribution of coarse fish in the River Dee in the early 1970's. In the Lower Dee downstream of Bangor-on-Dee the most abundant species recorded was the dace, with roach the next most abundant. Perch, were also classed as relatively important, but were known to have declined in abundance, possibly as a result of an outbreak of "perch disease" in 1972. Smaller numbers of bream, gudgeon, rudd, ruffe and pike were also recorded. Referring to an earlier report by the Fisheries Superintendent in 1954, O'Hara *et al* (1977) suggested that in earlier years, roach may have been the dominant species in the lower Dee.

Pearce (1983a) mentioned allegations made by anglers in 1972 and 1977 that the quality of the coarse fishery in the River Dee was declining, citing in particular smaller catches, and marked declines in the abundance of roach and perch, with dace dominating the catches. While a detailed examination of the evidence from angling catch records and from fishery surveys did not unequivocally support claims about an overall deterioration in fish catches, Pearce did confirm the increasing dominance of dace and decreasing abundance's of roach and perch, which from the anglers' point of view was detrimental. Attempts to remedy this by restocking have been unsuccessful (Pearce, 1983b) and the domination by dace and the reduced abundance of roach and perch has persisted to the present day (B.P Hodgson, pers. comm.).

The recent PhD study on coarse fish in the Dee by Hodgson (1993) attributes the decline in roach abundance to increasing regulation of the river. Enhanced summer flows created by releases of stored water from upstream to support river abstractions in the Chester area, have resulted in lower water temperatures in summer, and thus a shorter growing season for roach than was formerly the case. Whilst comparing long term surface water temperature data sets between the Dee at Manley Hall and Lake Windermere[8], Hodgson demonstrated, that after 1965, when Celyn came on line, there was increased divergence between temperatures in the two systems. Comparing 10 year periods before and after regulation, there was an average of 86 degree days per year reduction in the period post 1964, representing 17% of the original mean total. 21% of this temperature loss occurred during June, the period when roach fry are newly hatched. In comparison, the water temperature in Windermere displayed a net gain of 5 degree days per year during the same period.

The diets of juvenile roach and dace in the Lower Dee have been studied by Weatherly (1985).

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[8] Degree days above 12 °C.

The main foods of 0-group roach were filamentous algae, detritus, diatoms, Chironomid larvae and pupae, and Oligochaeta, although Copepod nauplii and rotifers were the staple diet up to the end of the fourth week. Dace fry fed exclusively on rotifers for the first week with copepods appearing in the stomachs in the fourth week. Subsequently, the main foods of 0-group dace were filamentous algae, detritus, Chironomid larvae and pupae, Oligochaeta and aerial insects. Weatherley (1985) concluded that the diets of roach and dace, although of high diversity in the Dee, were of poor quality, being generally detritus based and expressed the opinion that on the basis of diet alone, there were indications that the juvenile fish in the Dee were being limited by food supply.

More recent studies by Hodgson (1993) have confirmed these findings. During the late spring and early summer the diet of roach fry was predominantly made up of planktonic algae, Cladocera, Copepods and detritus. Later in the summer and early autumn, filamentous algae were important in the diet, together with Chironomids, but a lot of detritus was eaten throughout. The major difference between the diets of roach and dace fry according to Hodgson was the heavy dependence of dace on terrestrial and emergent insects. Growth of roach in their first year is very slow in the Dee, and this is attributed to a combination of the shorter growing season resulting from the lower temperature and the poor quality food supply. Typically the fish are significantly less than 40 mm in length by October, and Hodgson (1995) comments that in most seasons growth rates of roach in the Dee in their first summer are poorer than in other waters in Britain.

This poor first summer growth is likely to be having an adverse impact on the over-winter survival of roach in the Lower Dee. Information from Midlands Region of the Agency is that roach need to achieve a length of 50 mm by the end of their first year if they are to have much chance of surviving over winter. (R. North - pers. comm.) Loss of aquatic macrophytes in the Lower Dee as a consequence of heavy recreational boat traffic is also thought to be adversely affecting survival of roach fry by eliminating shelter for the fish and substrates for food organisms.

Dace are apparently not affected by river regulation to the same extent as roach. They hatch earlier in the year and thus have a longer growing season. They also have a more broadly-based diet and grow large enough by the end of their first summer to have a higher over-winter survival. This presumably explains their increasing dominance in the fishery.

From the anglers' point of view, this increase in abundance of dace and the loss of roach has an adverse impact on the quality of the fishery. The diversity (and probably also size) of fish caught is reduced, and from December onwards, when the dace begin to move up-river to their spawning grounds above Farndon, the fishing in the lower river becomes very poor.

5.2.2 Cyprinid Fish in the Tidal River Dee

O'Hara (1976) studied the distribution, abundance and growth of coarse fish in the tidal river and upper estuary during the period October 1972 to July 1974. Most of the effort was concentrated on dace which was the most common species, and was present on at least some occasions throughout the whole length sampled by seine netting, from Chester down to Queensferry. Other species recorded were roach, bream, rudd, gudgeon, perch, tench, ruffe and pike. Generally these were not found below O'Hara's sampling station 7, which was on the last bend before Saltney Ferry footbridge (approximately 5 km below Chester Weir) although there was hearsay evidence that in the past roach and perch had been more abundant further downstream. The overall population density of coarse fish in the tidal reach was very low, and the highest figure recorded by O'Hara was 0.3 fish per m sq.

Dace were captured in water of salinity up to but not above 11.2 parts per thousand. O'Hara demonstrated that dace avoided intolerable salinity conditions by emigrating upstream to "safe" areas, and he regarded salinity as being the major factor determining distribution of dace within the tidal reach. Dace were absent from the canalised reach at times of spring tides and high salinities, although it was accepted that high water velocities may have been a contributory factor. Tank experiments on salinity tolerance carried out by O'Hara showed that the incipient lethal level for dace was in the salinity range 10.3 to 13.7 parts per thousand. At 17.2 parts per thousand, all fish lost equilibrium within 215 minutes, and were dead within 345 minutes. Dace successfully completed swimming endurance tests in salinities up to 13.7 parts per thousand, but not at higher salinities. O'Hara concluded that dace were opportunists, and were able to exploit areas offering only a temporary habitat during favourable conditions as a consequence of their high mobility, dispersive ability and omnivorous diet.

Studies on the growth rates of fish in the tidal reach showed that dace were growing at about an average rate when compared with those from other rivers, but slower than dace at Llangollen on the Dee. The growth rates of roach and bream were relatively poor when compared with other rivers, but were not significantly different from growth rates in the Dee above Chester Weir.

O'Hara commented that the data collected during 1974 were obtained during a period of prolonged low freshwater discharge, and hence during a period of adverse salinity conditions for freshwater fish. Dissolved oxygen levels in the Hawarden Bridge - Queensferry Bridge area also dropped significantly during times of neap tides, low freshwater discharge and high temperatures, although water conditions were acceptable for most of the time. The distribution of coarse fish as observed during 1974 and reported by O'Hara would be a useful baseline against which to consider any possible changes in minimum residual flows.

5.2.3 Grayling

The Dee has gained a reputation as one of the countries finest grayling fisheries, a comparatively recent development. However, the fisheries Officer Annual Reports note that grayling were becoming more numerous and more widely distributed within the system as long ago as 1945.
Although grayling are themselves greatly valued as a significant asset and should be protected accordingly (Cove, 1997), concern has been expressed over their expansion within the Dee system, and whether this success would be to the detriment of other species, notably salmon and trout. Several studies from Liverpool University attempted to investigate this issue and provide useful background information.

Woolland (1972) in his studies on salmonid fishes in Llyn Tegid and the Dee, collected details of the distribution of grayling within the system together with information on their diet. He confirmed that the Dee from Bala Lake down to Glyndyfrdwy conforms to Huet's 'Grayling Zone'. Downstream of this point, as far as Erbistock, the river reverts to 'trout zone'. He reported that Grayling were known to be encroaching into this area, and increasing numbers have been reported since the commencement of regulation in 1956. The spread appears to have been as follows: -

1957 - Llangollen
1960 - Newbridge
1963 - Bangor-on-Dee.
1964 - Chester (a few).

He confirms that grayling had also entered some of the tributaries, e.g. the Tryweryn, Alwen and Ceiriog, quoting Iremonger (1971).

Woolland gives figures for age compositions at different sites throughout the catchment commenting that survival rates were lowest at Bala and increased downstream to a maximum at Corwen. He also demonstrated that survival was lowest where density was highest. Population estimates were made using the multiple census method of Schnabel (1938) as modified by Chapman (1952) and Schumacher and Eschmeyer (1943). The best (i.e. most reliable) estimate of population size was for the section just below Bala sluices - 0.024 grayling per m^2. Biomass of fish older than 1 year was estimated at 2.586 g/m^2. Estimates based on rod catch were obtained for other sites further downstream and varied from 0.143 fish per m^2 (biomass 15.421 g/m^2) to 0.057 fish per m^2 (biomass 5.760 g/m^2).

There were similar numbers of trout at Bala and Corwen but salmon parr were most abundant at Corwen and grayling at Bala. Salmon parr were dominant numerically at Corwen, with trout and grayling being present in about equal numbers.

The population density of grayling in the shoreline area Llyn Tegid was estimated at 0.244 to 0.358 fish per m sq (biomass 4.731 - 7.853 g/m sq.).

after the initial period). Wooland attributes the increase to enhanced survival of the early stages following raised summer lake levels.

With respect to growth rates of grayling Wooland stated that Corwen grayling grew faster than the Upper Dee fish, and faster than Llyn Tegid grayling for the first two years of life, then subsequently at the same rate. Llyn Tegid grayling grew faster than Upper Dee grayling, except in their first year.

Table 5.24 Grayling growth in the Dee catchment

	Lengths in cm. at each age					
	1	**2**	**3**	**4**	**5**	**6**
Upper Dee	12.0	21.3	27.0	31.6	33.4	-
Corwen area	12.5	23.8	30.3	34.4	-	-
Llyn Tegid	12.0	22.5	29.8	35.8	37.9	39.9

Woolland also gives detailed information on the diets of grayling in the Dee and Llyn Tegid, and quotes percentage occurrence, volume and number of categories of food items. Changes in diet with size of fish and season of year are included. He also investigated the relationship between diet and food availability by comparing diet with the benthic fauna. Main foods of grayling in the Dee were Trichoptera larvae and aerial insects, plus some Ephemeroptera and Plecoptera nymphs, Dipteran larvae and Crustacea. In Llyn Tegid the main foods were Crustacea, Ephemeroptera nymphs and Dipteran larvae, with some aerial insects and Trichoptera larvae. Grayling appeared to be predominately bottom feeders, with mid-water and surface food added when available.

Diets of salmon and trout in the Dee were also investigated, and Woolland concluded that the diets of grayling, salmon parr and trout overlapped, and suggested that there could be inter-specific competition for food. He also found evidence of intra-specific competition in grayling and salmon parr (at Corwen)[9].

Spawning occurred in May, probably in the lower reaches of Llyn Tegid tributaries and in the main River Dee. Spawning sites were typically over fine gravel (4cm depth) in fast-flowing, shallow water (approx. 10cm deep).

Woolland regarded their different spawning requirements to be a critical issue governing the increasing dominance of grayling. Grayling eggs under normal conditions would be expected to be more susceptible to floods and droughts than those of salmon and trout as they are laid in finer gravel at shallower depth.
By removing these environmental extremes, Woolland concludes that the Bala regulation scheme is likely to have been beneficial to the breeding success of grayling in the Dee and Llyn Tegid, and to have contributed to the increased stock observed since regulation began.

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[9] For comparison, main foods of salmon parr were Trichoptera larvae, Ephemeroptera nymphs, Dipteran larvae and aerial insects. Trout ate more aerial insects and Trichoptera larvae than salmon, but fewer Ephemeroptera nymphs and Dipteran larvae.

In another detailed study concerned mainly with salmon and sea trout, Lees (1972) also provides some useful information on grayling in the Dee catchment. His work suggests that grayling were spreading down the Dee, ousting the trout as their territory expanded. They were being reported from downstream of the River Alyn confluence, and below Chester Weir. Lees speculated that this could be a result of river regulation, which may have increased survival to hatching of shallowly-buried grayling eggs.

Siddiqui (1969) in a study of brown trout, grayling and rudd of natural regulated waters and regulated reservoirs in North Wales sampled Llyn Tegid by seine net from December 1965 to May 1967. Age, growth and diet of trout and grayling were studied. Grayling scales were passed on to Woolland who subsequently reported growth rates for Llyn Tegid grayling in his thesis (Woolland, 1972). Siddiqui caught more grayling in autumn/winter than in spring/summer. He suggested two possible explanations for this; either the lowered lake level in winter allowed seining of previously un-nettable sub-littoral areas, or grayling may have been moving into the lake from the river in the autumn, with regrading the Dee as part of the Bala scheme having made this easier.

Siddiqui also undertook a comparative study of the diet of grayling and trout. He concluded that there was competition between grayling and trout for ‘temporary’ fauna, e.g. gwyniad eggs, Chironomid larvae and pupae, other Diptera, and Ephemeroptera nymphs. The latter were more important in the diet of grayling than in that of trout. Siddiqui suggested that there may also be competition for bottom and mid-water fauna, such as Asellus, leeches and zooplankton. Asellus made up 15% of the annual diet of grayling, but only about 0.5% of that of trout.

The more recent study of Hodgson (1993) also provides useful comment on the grayling population confirming the extended range downstream to the Overton/Bangor-on-Dee area, possibly as a consequence of regulation. He suggests that the grayling population had also increased further upstream, and between Bala and Erbistock was considered one of the finest grayling fisheries in the country (Hodgson, B.P. and Scutter, D.M., (1983)).

Despite the historical evidence for an increase in the population and territory of the grayling, anglers have expressed concern over the past few years of decreasing catches (Cove, 1997). Examination of purposely collected angler’s catch data, both from studies by an individual (data from a Mr P Dutton) and an Agency questionnaire based angler’s census, concluded that evidence of a decline was equivocal. Having used angler’s census data to establish the baseline position in catch-effort terms, further long term studies have been recommended.

5.3 Summary

- Rod and net catches have declined in the Dee when compared with other Welsh control rivers during the 1960 to 1975 period coinciding with the operation of Celyn. A consistent decline has also been demonstrated when compared to English west-coast rivers draining into the Irish Sea, implicating regulation in the absence of other significant differences.

- The timing of the salmon run has changed but merely reflects the national trend.

- Location of catches within the Dee is likely to have changed, fish being drawn further into the system probably as a result of regulation encouraging more rapid upstream migration.

- Estuarine telemetry studies highlighted the importance of freshwater flows for fish movements. Most fish negotiate Chester Weir without interruption at flows of 13 m^3/s^{-1} and above. At lower flows, e.g. the residual flow under typical summer conditions, delays may be experienced although most fish still negotiate the weir successfully.

- Freshwater telemetry has highlighted the importance of autumnal freshets in stimulating migration.

- The importance of maximising the "naturalness" of freshets to stimulate fish movement has also been stressed.

- Once salmon enter freshwater they move rapidly through the lower reaches, regardless of prevailing flows. Typical first phase migrations are of the order of 49 km into freshwater. Flows in excess of 20 m^3/s^{-1} reduce migration speed.

- Once fish reach the middle reaches of the river around Bangor-on-Dee migration rate decreases significantly. Migration speed now increases over the range 20 to 30 m^3s^{-1}.

- Spawning is greatly reduced compared to historic levels, except in one or two notable off-line tributaries (Hirnant & Mynach), a decline which coincided with the commissioning of Llyn Celyn.

- Juvenile populations have been maintained at high levels in some off line tributaries, (e.g. Ceiriog) but larger tributary on-line sites have suffered significant declines, implicating regulation as the most likely cause of the deterioration.

- Changes in the temperature regime do not appear to have affected egg development and emergence of fry as has been demonstrated in other regulated systems.

- The Llyn Tegid tributaries have seen a precipitous decline in juvenile salmonids but this cannot be directly attributed to regulation, the decline having occurred some years after Celyn came on-line.

- Recent studies have implied that a lack of spawning adults (particularly spring fish) is responsible for poor salmonid populations in the Tegid tributaries.

- Other notable issues which may have impacted upon juvenile salmonids in the catchment include land use changes and eutrophication.

- Acidification would appear to have had a significant impact on juvenile salmonids in the Alwen sub-catchment, but despite low pH and high aluminium, water quality is not considered the limiting factor in the Tegid tributaries.

- Enhanced flows during augmentation from Brenig may be negatively impacting juvenile salmon and trout.

- Smolt age composition has undergone a marked change from predominantly 2 year old fish to a high proportion of 1 year old smolts. The altered temperature regime is thought to be a contributory factor resulting in reduced smolt to adult survival rates.

- UDN in the late 1960's infected over 90% of the spring fish and possibly contributed to the accelerated demise of the early running multi sea-winter stock.

- Evidence from telemetry studies confirms that multi sea-winter fish spawn high up in the catchment and therefore this component of the stock may have been disproportionately affected by UDN affecting production in the upper tributaries.

- Cyprinid fish populations affected severely by regulation, with temperature and flows having a negative impact on stocks.

- Grayling have prospered at the expense of other species in the Dee, the physical environmental changes precipitated by regulation favouring this species.

- Dace have become the dominant cyprinid species, appearing less affected by regulation than other coarse fish.

Figure 5.1 Dee Rod & Net Catches

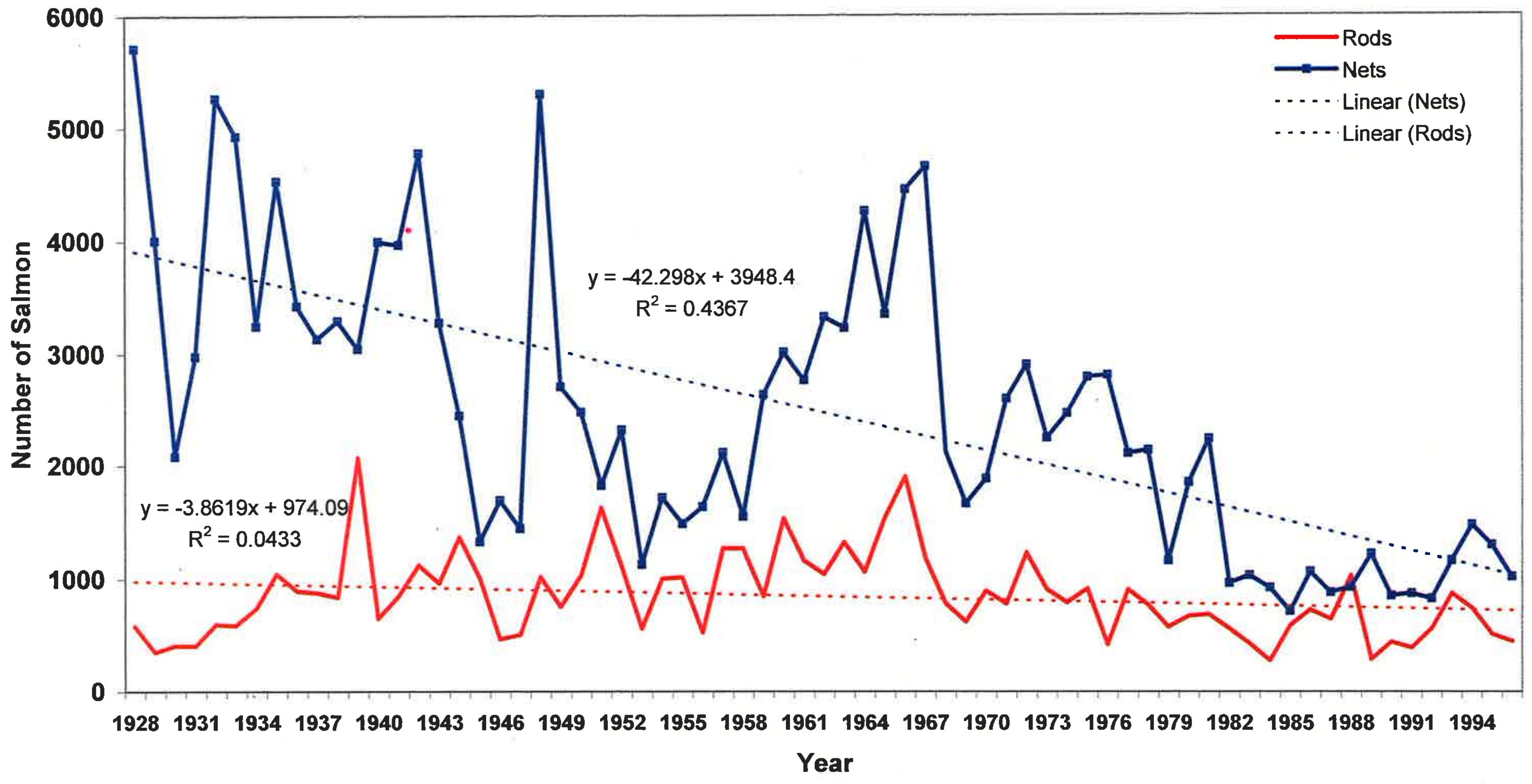


Figure 5.2 Rod & Nets Catches Post 1965 - After Celyn

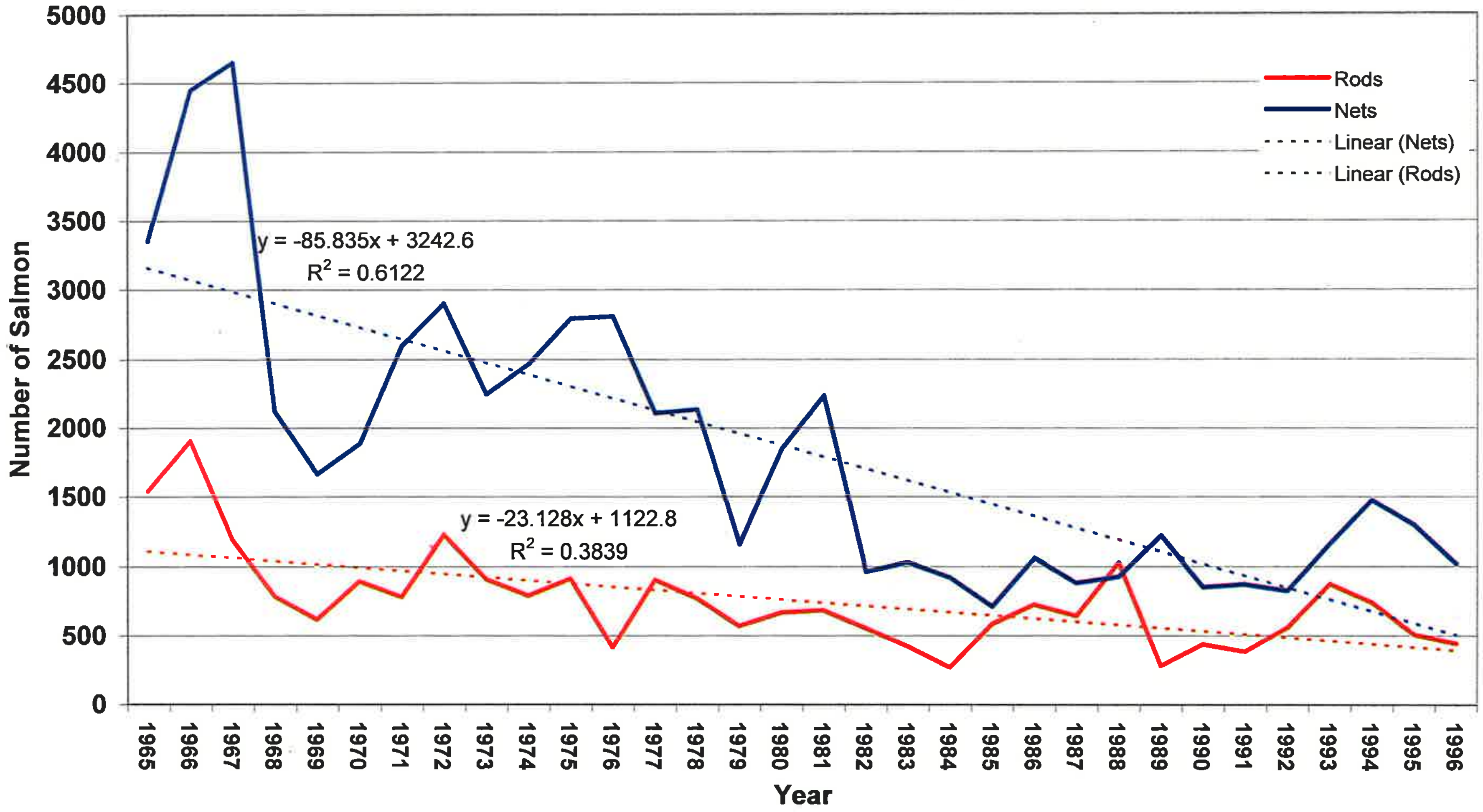


Figure 5.3 Rod & Net Catches Post 1979 - After Brenig

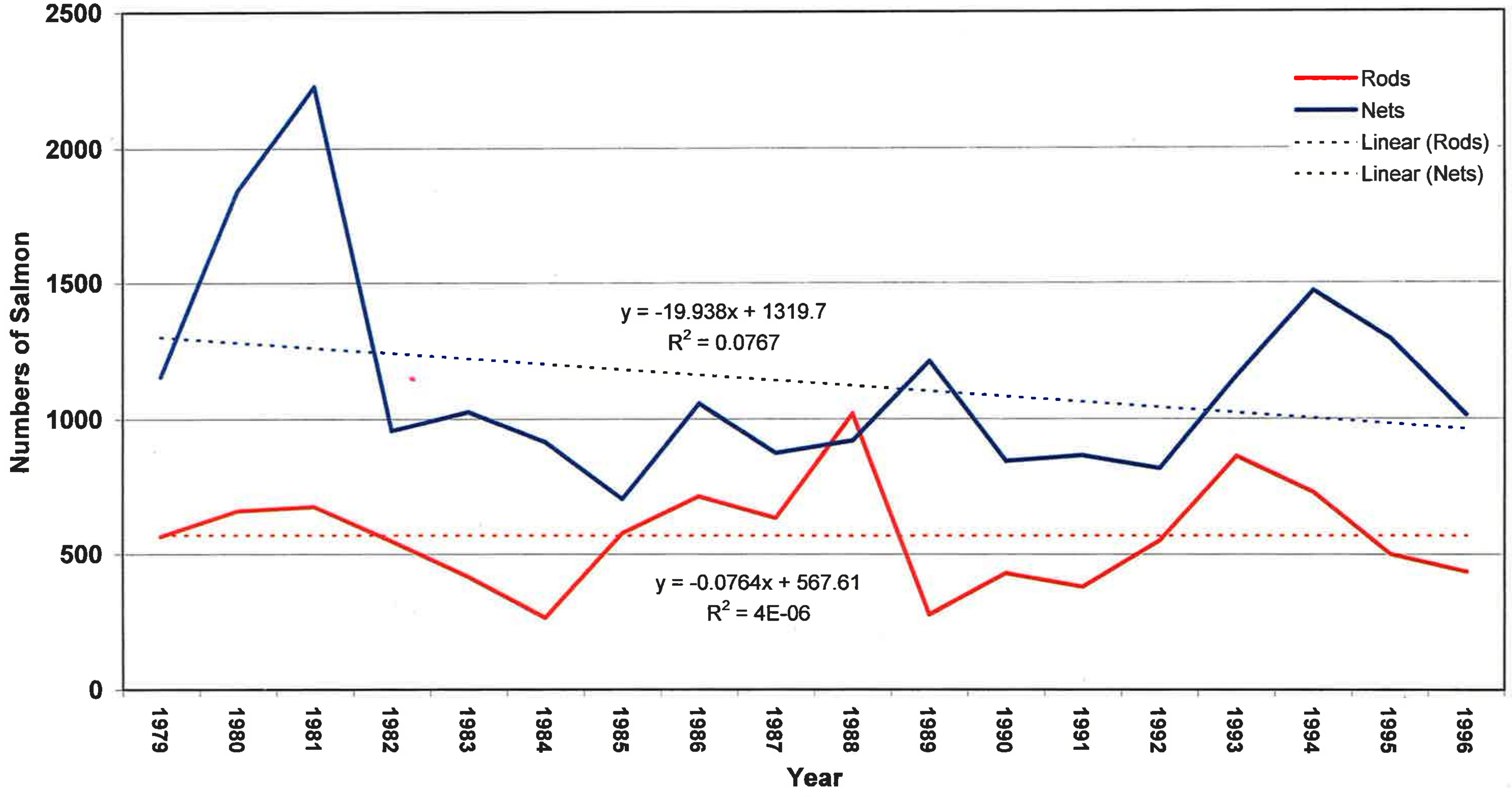


Figure 5.4 River Dee vs Combined Rod Catch of Welsh Control Group Rivers

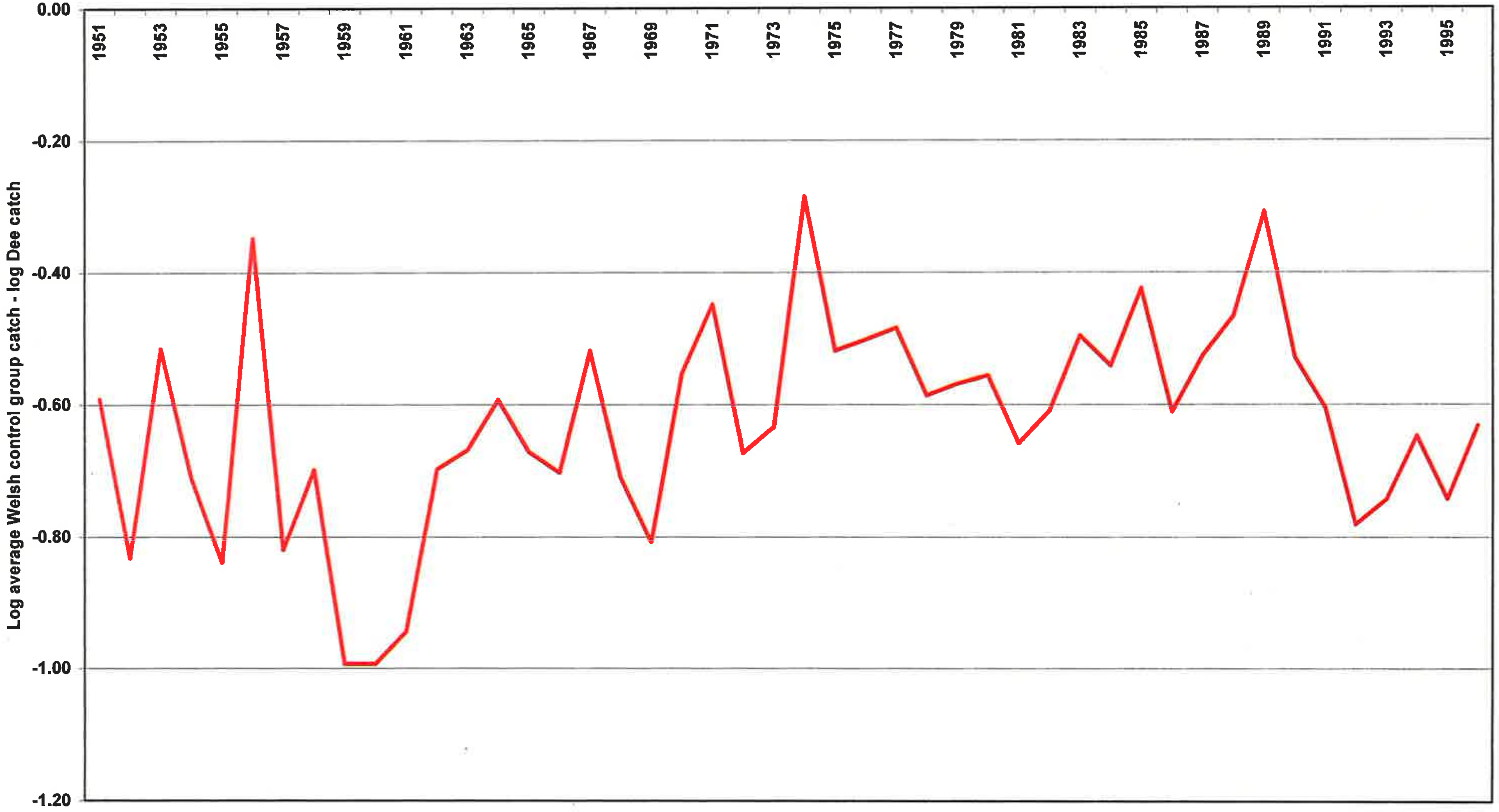


Figure 5.5 River Dee vs Combined Rod Catch of Welsh Control Group Rivers (1960 to 1975)

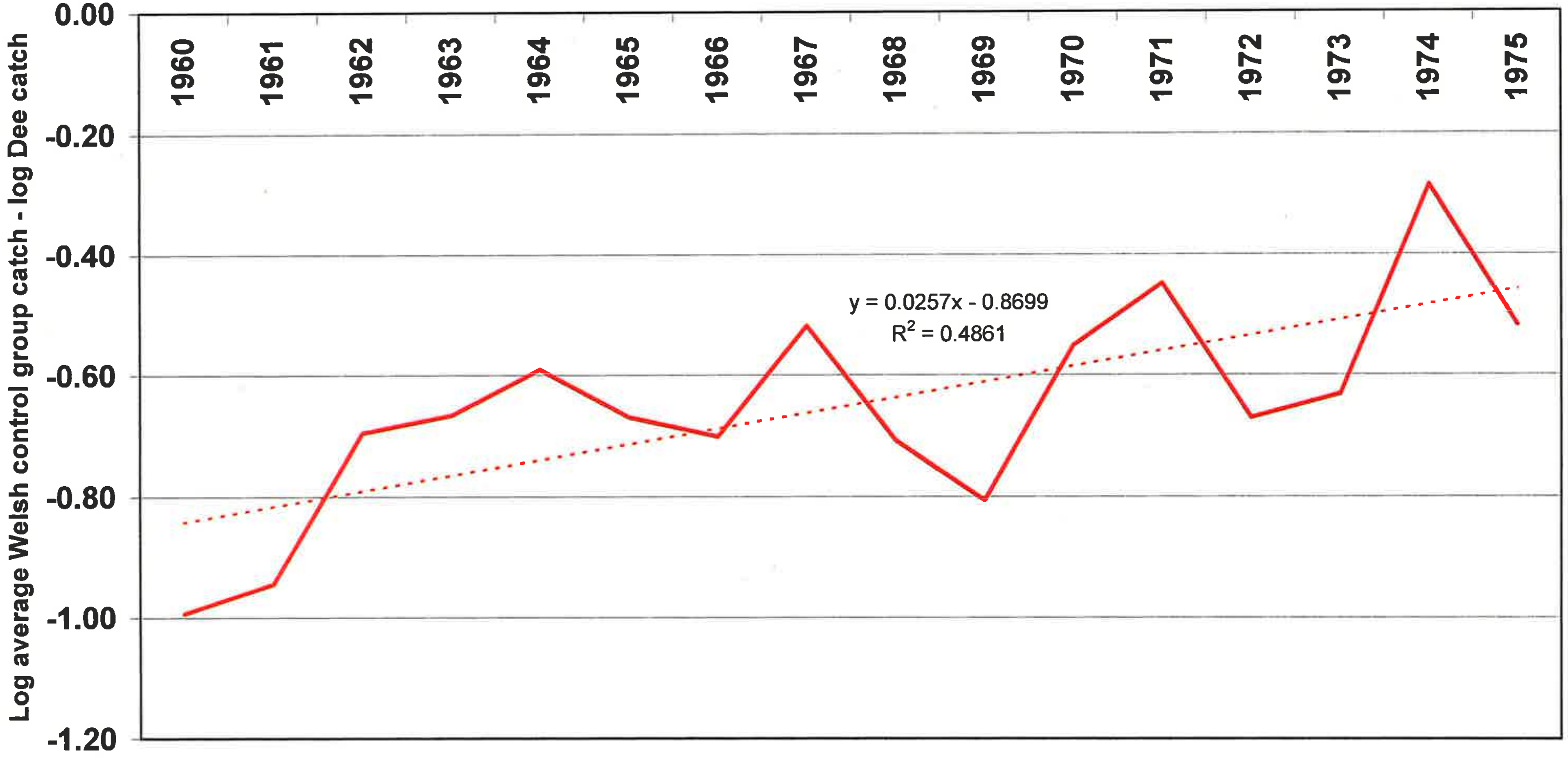


Figure 5.6 River Dee vs Combined Net Catch of Welsh Control Group Rivers

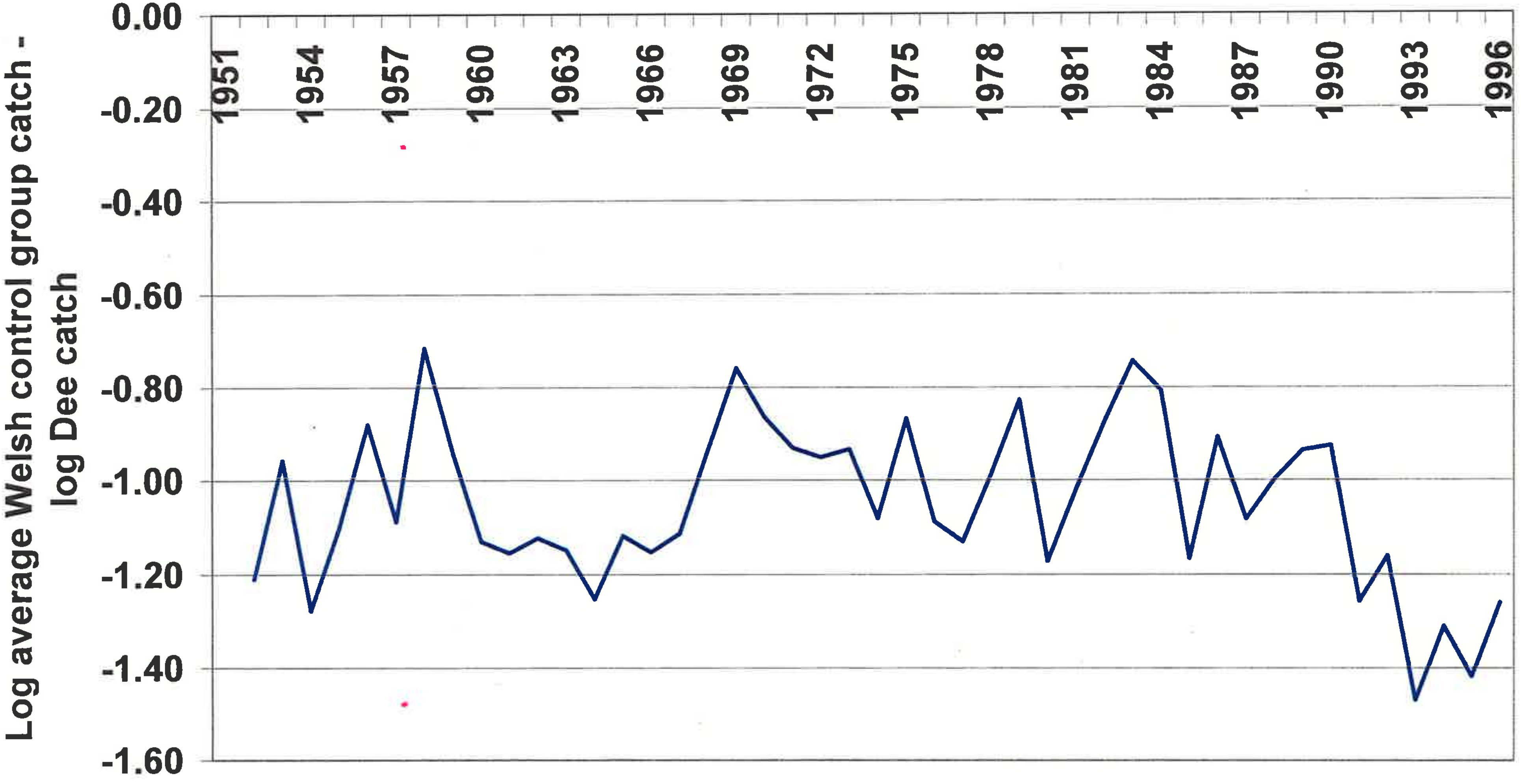


Figure 5.7 River Dee vs Combined Net Catch of Welsh Control Group Rivers (1960 to 1975)

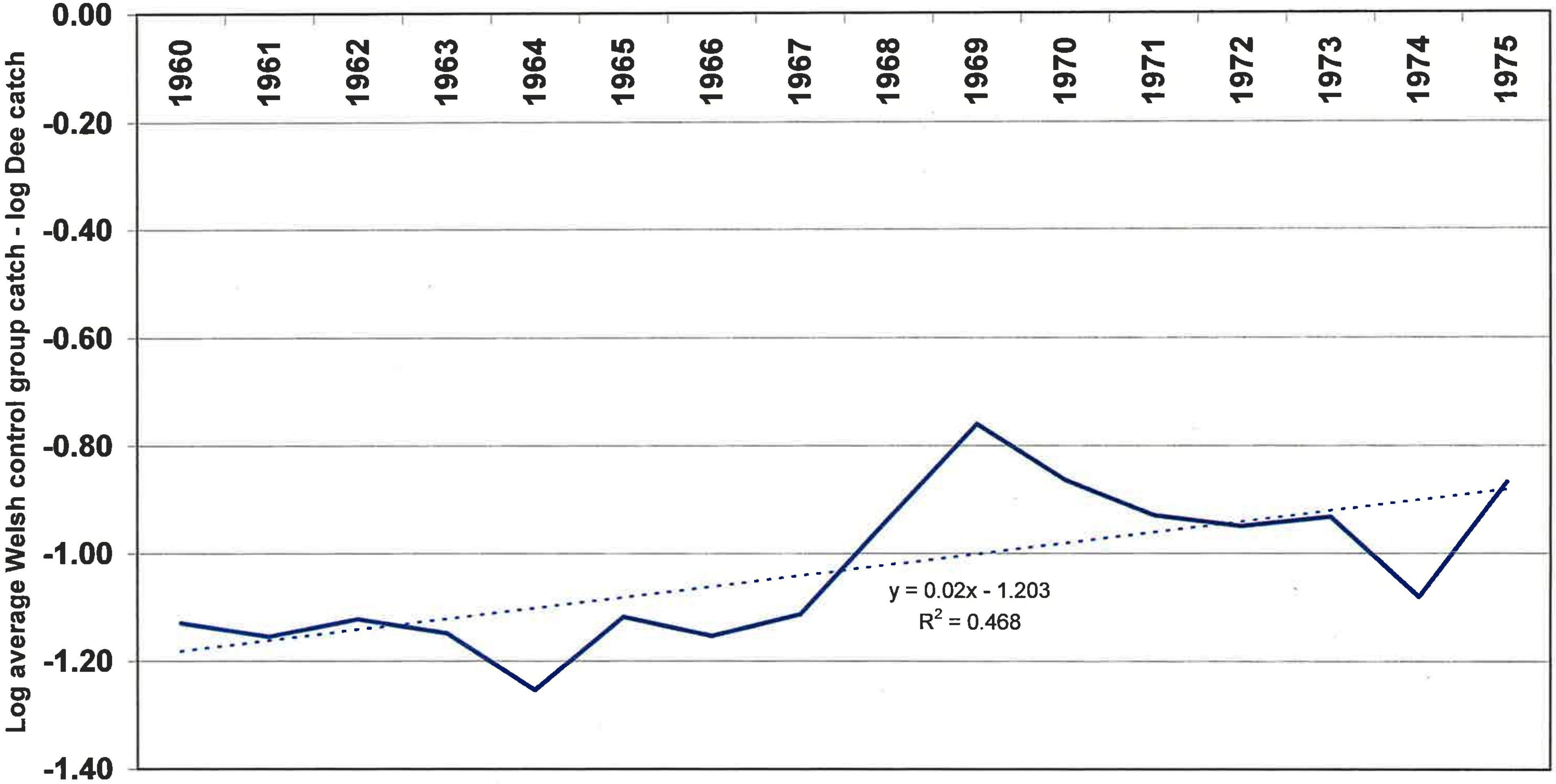


Figure 5.8 River Dee vs Combined Rod Catch of North West Control Group Rivers

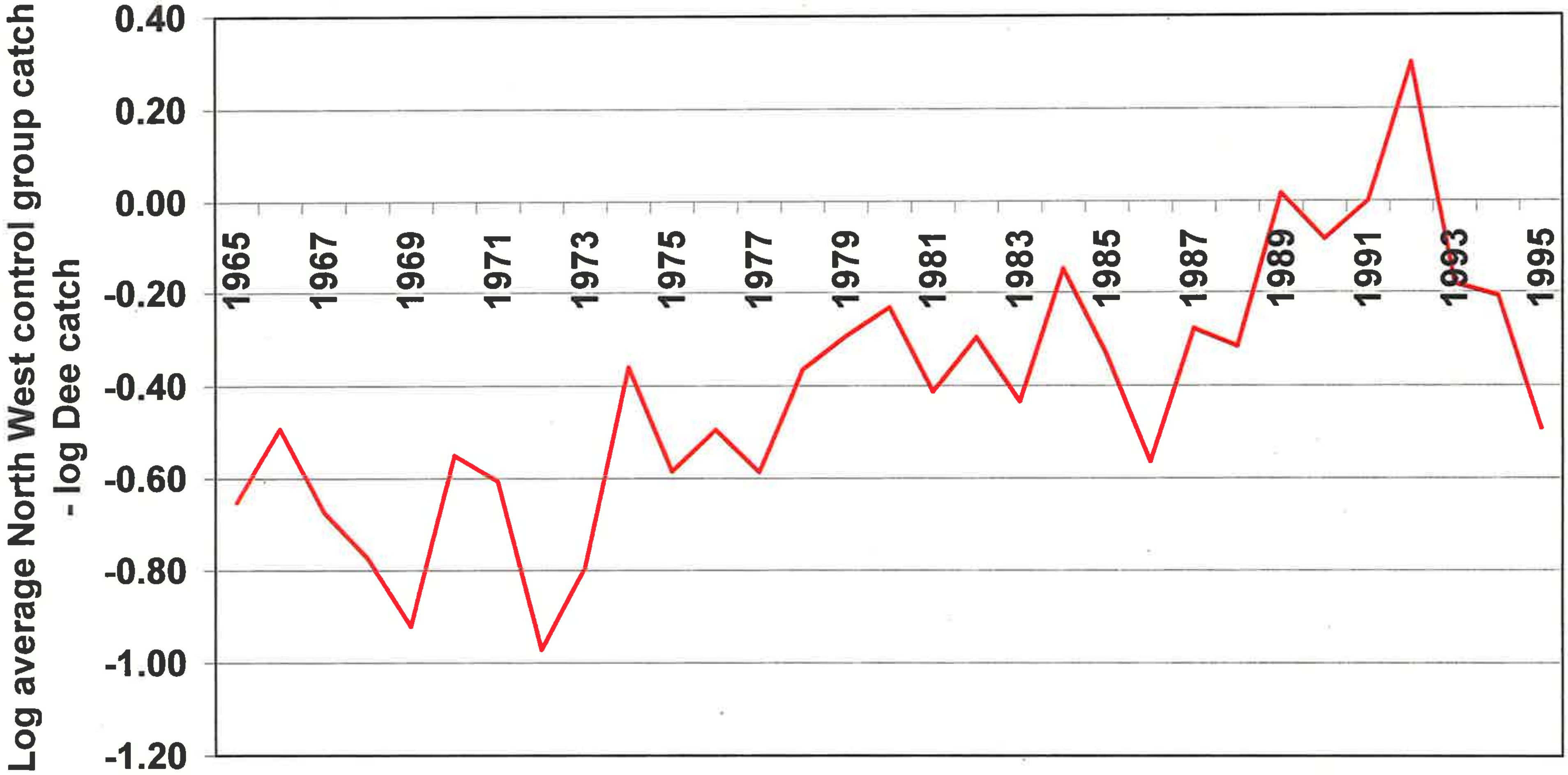
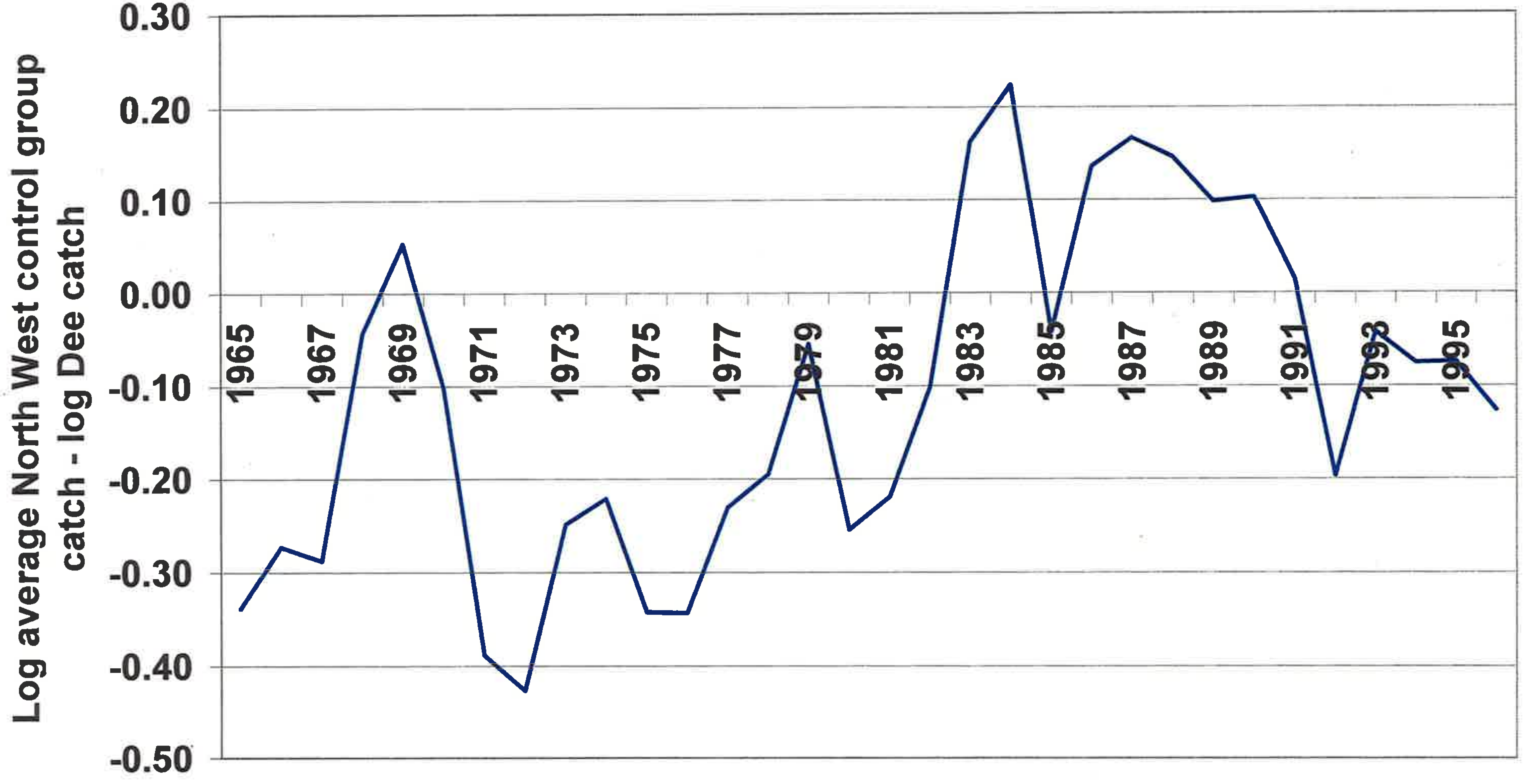


Figure 5.9 River Dee vs Combined Net Catch of North West Control Group Rivers



Measured flows and upstream Salmon counts for Manley Hall

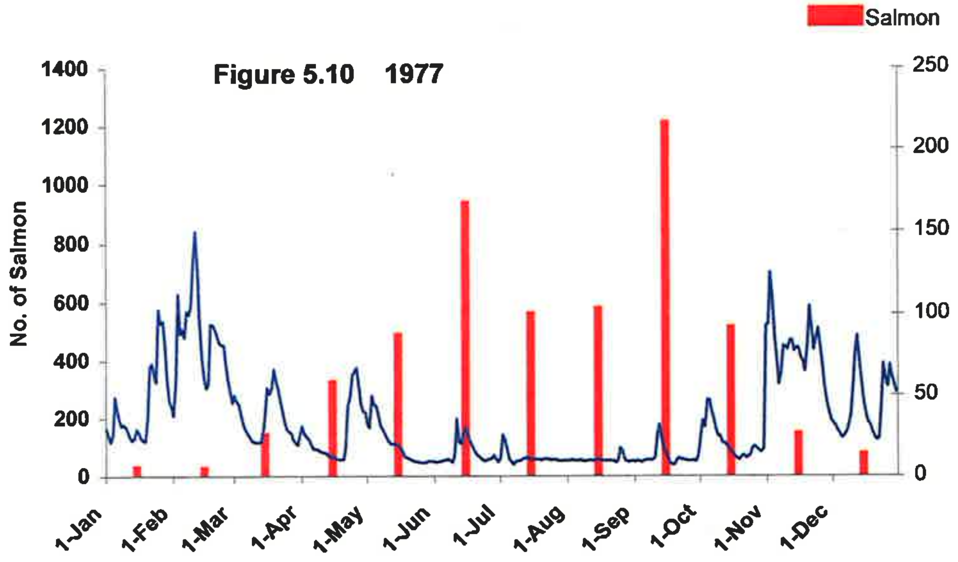


Figure 5.10 1977

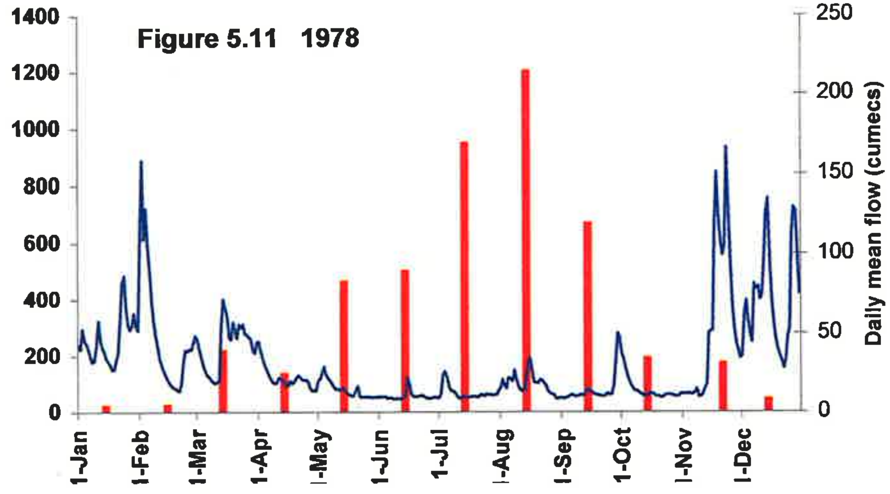
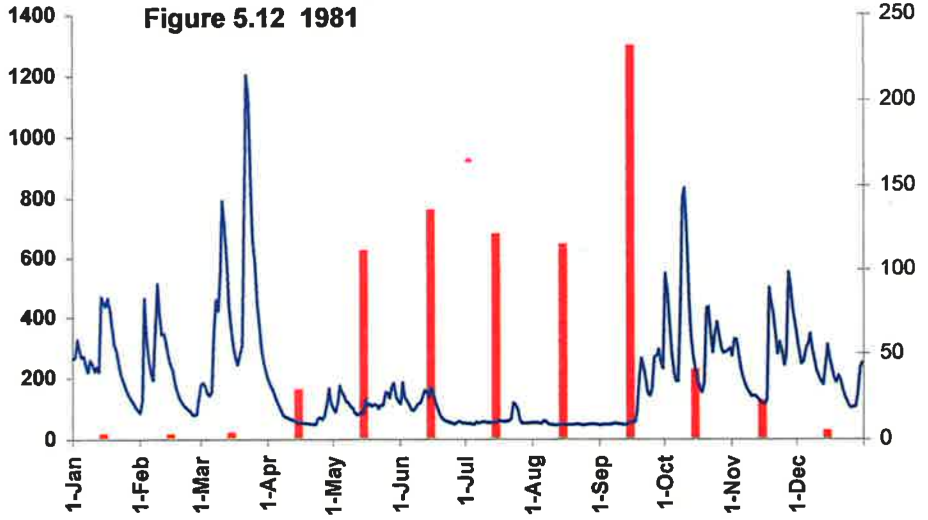


Figure 5.11 1978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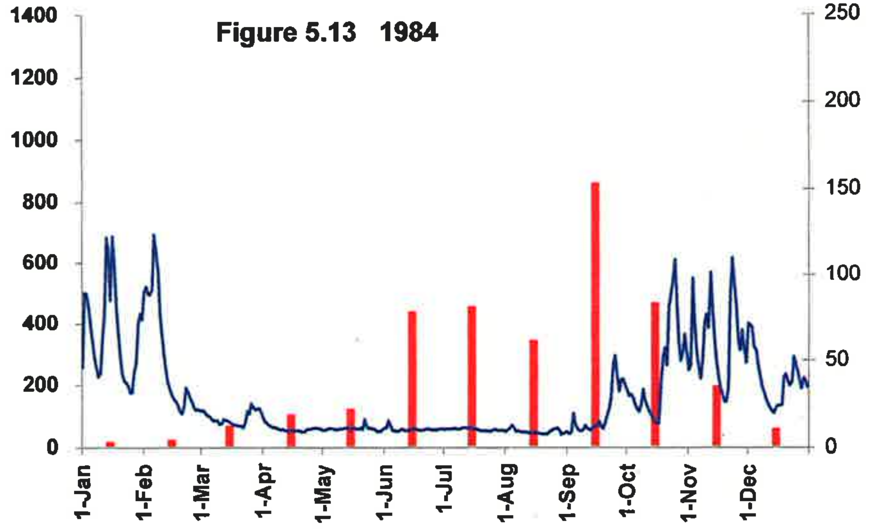
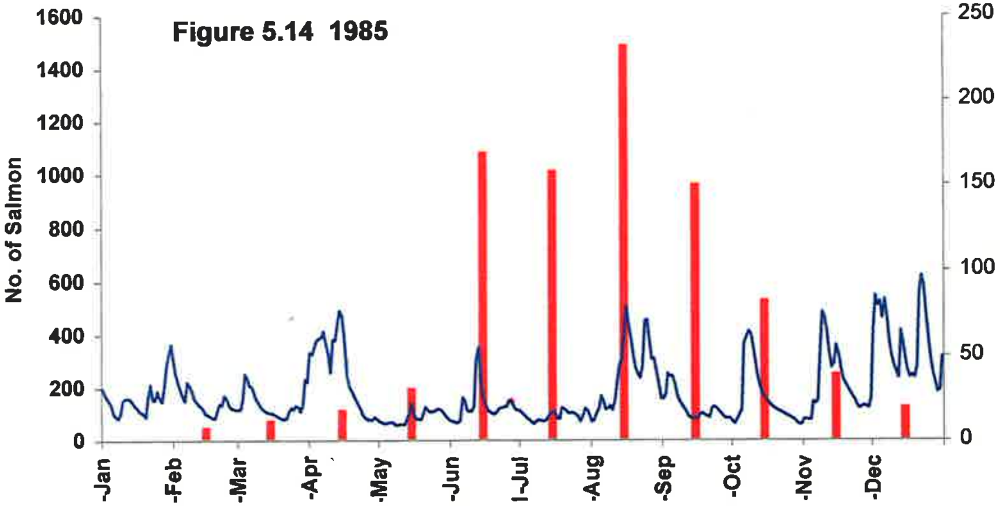


Figure 5.13 1984

Measured flows and upstream salmon counts for Manley Hall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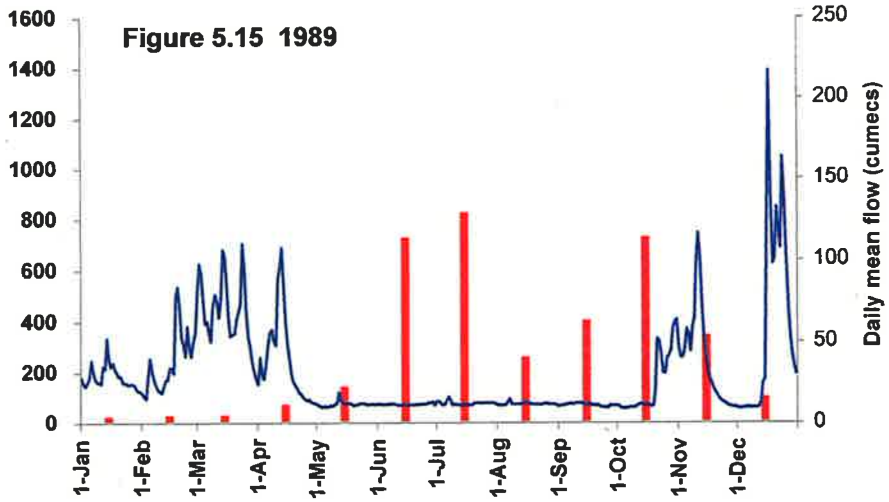
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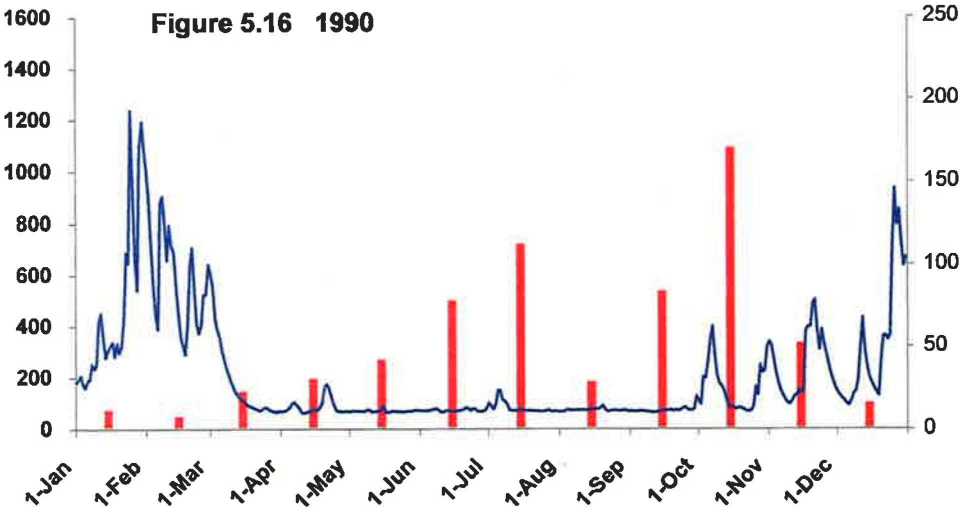


Figure 5.16 1990

Figure 5.17 Redd Counts - Tryweryn

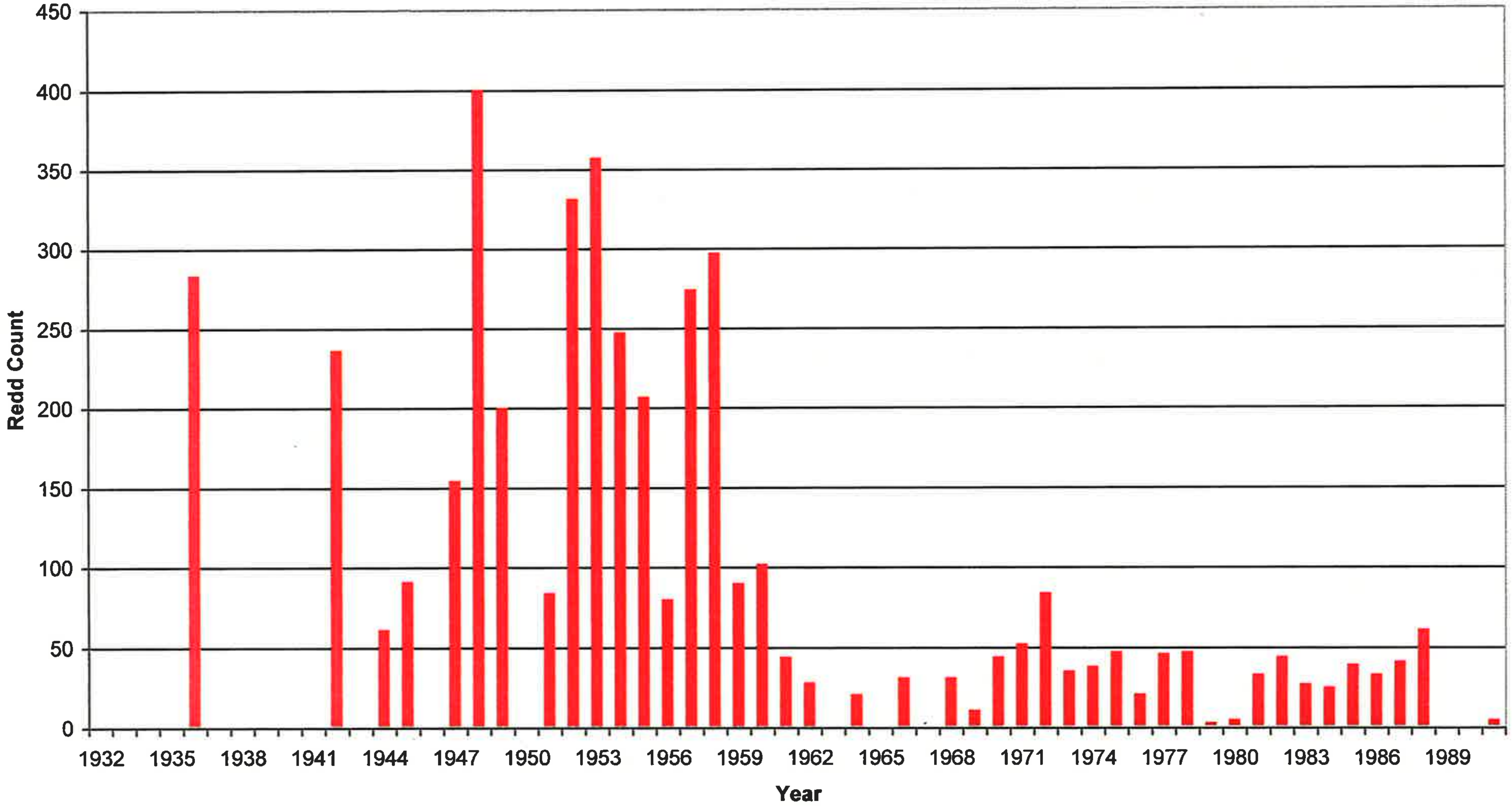


Figure 5.18 Redd Counts - Dee

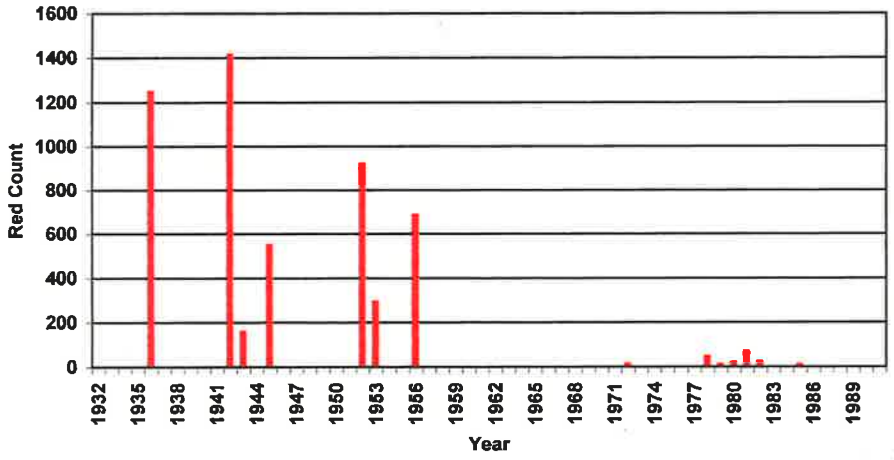


Figure 5.19 Redd Counts - Alwen

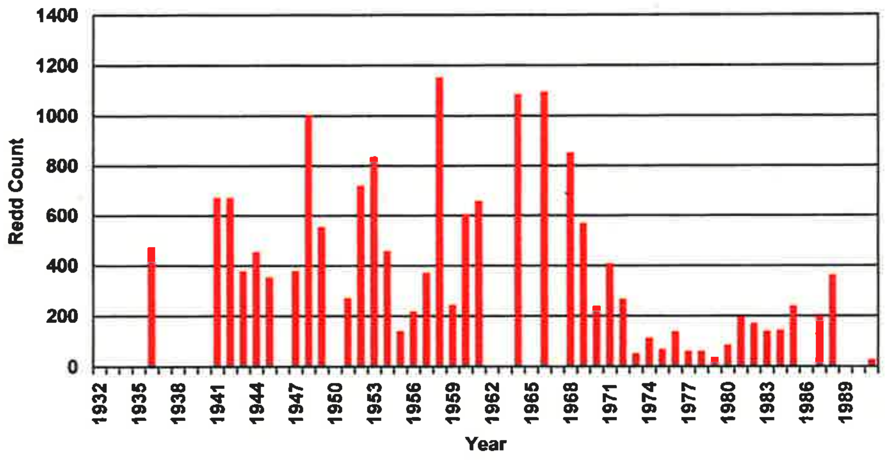


Figure 5.20 Redd Counts - Tryweryn

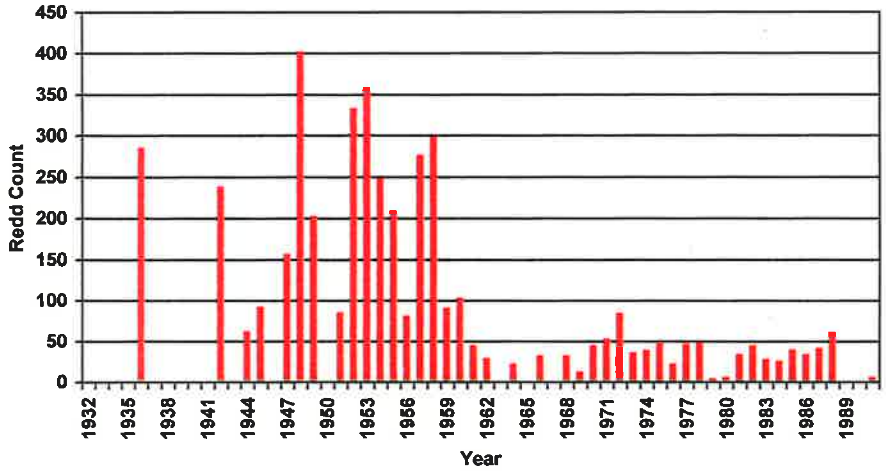


Figure 5.21 Redd Counts - Ceirw

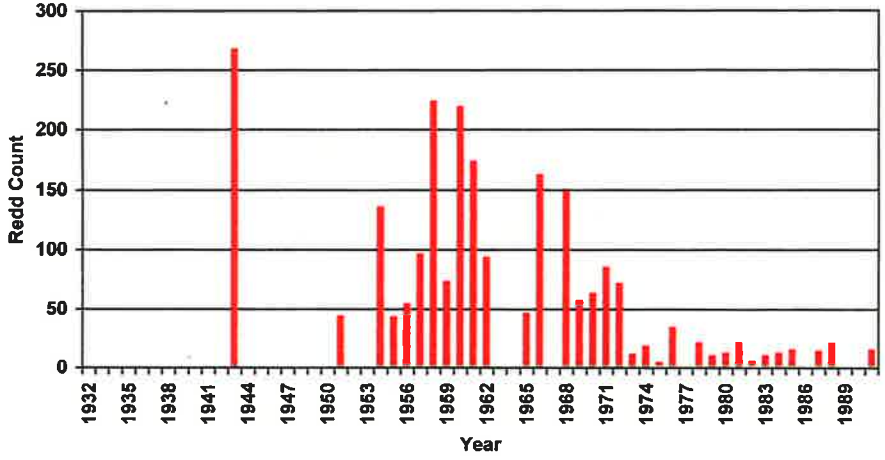


Figure 5.22 Redd Counts - Merddwr

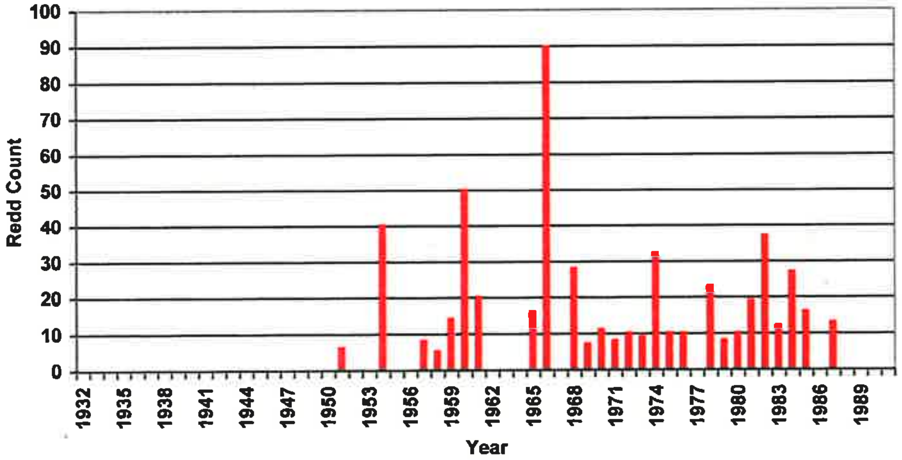


Figure 5.23 Redd Counts - Ceiriog

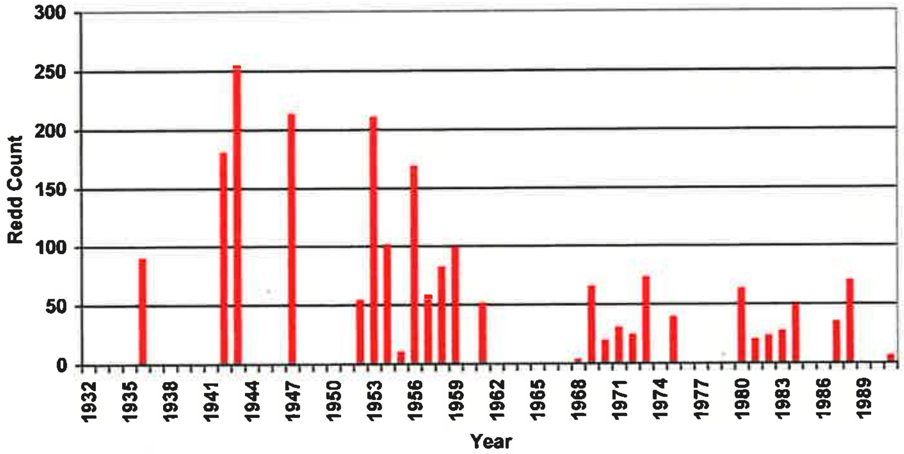


Figure 5.24 Redd Counts - Hirnant

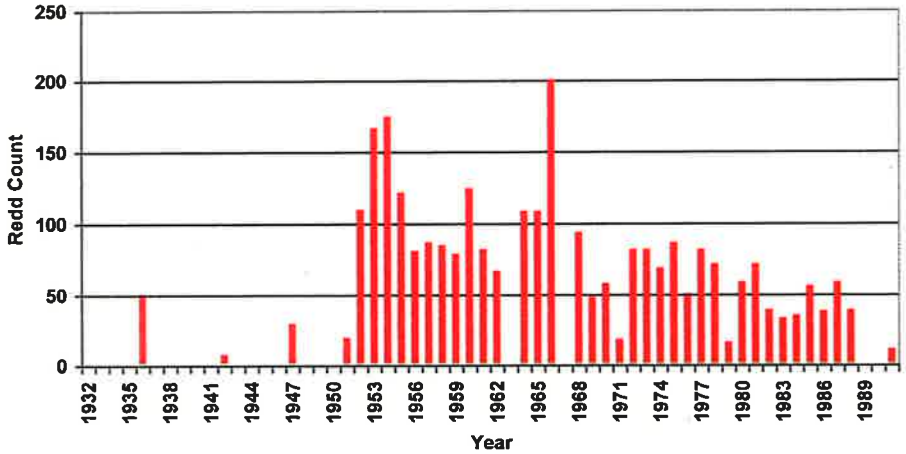


Figure 5.25 Redd Counts - Mynach

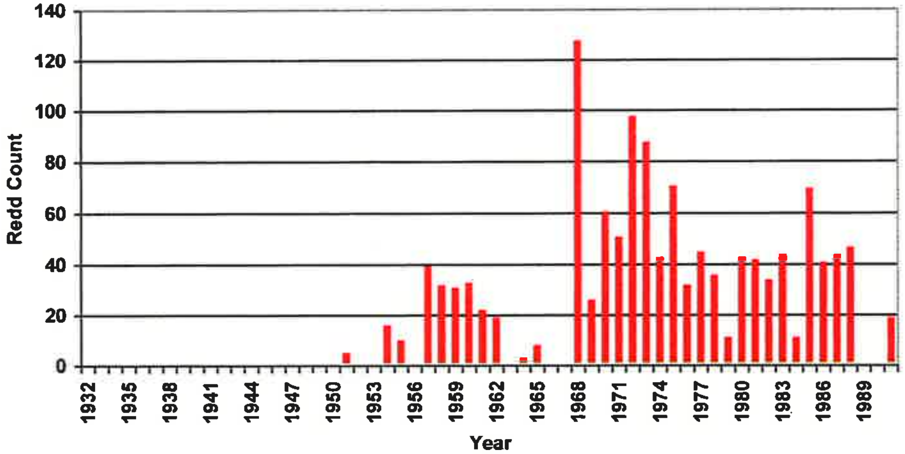
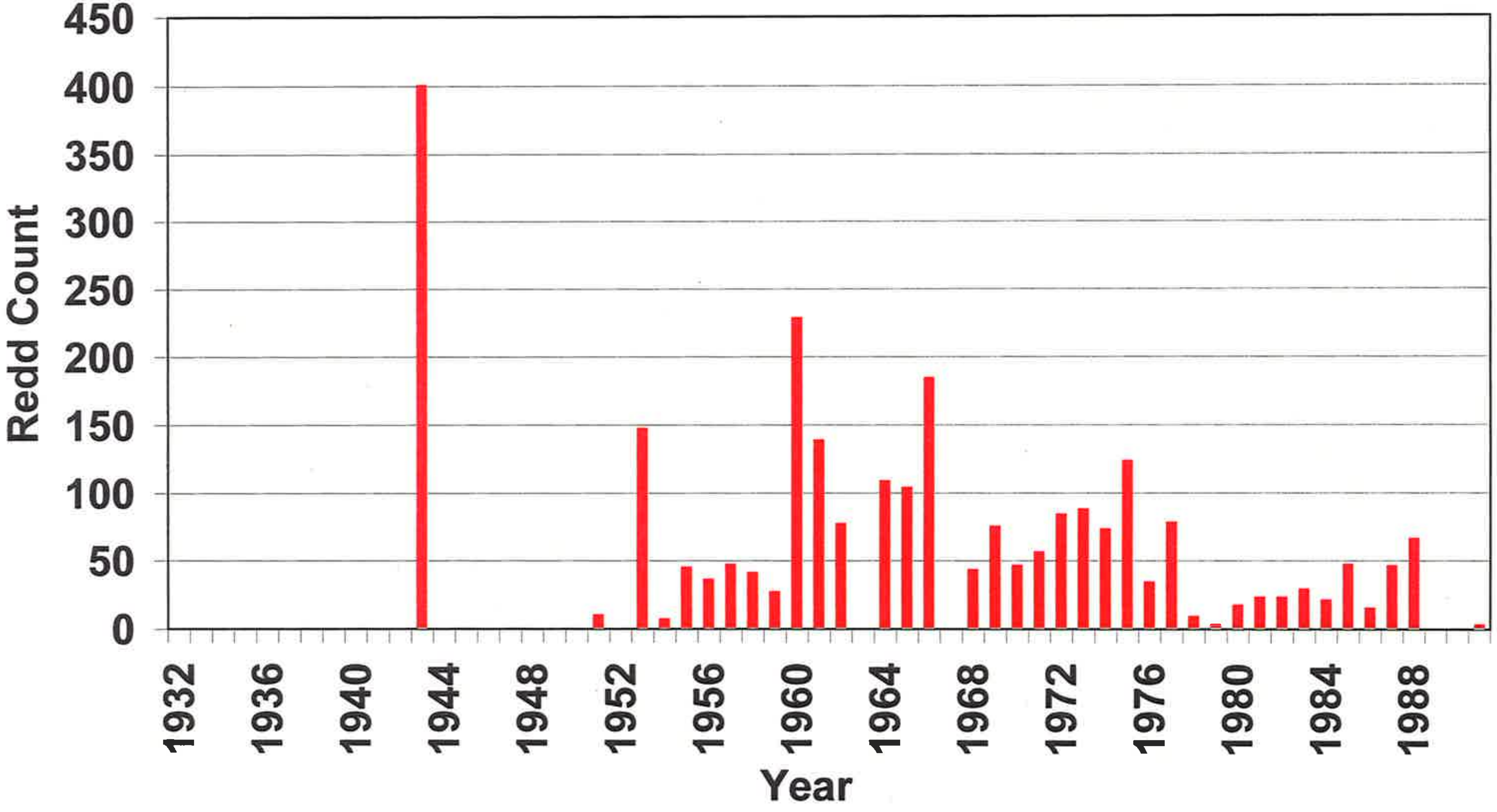


Figure 5.26 Redd Counts - Bala tributeries total



6. CURRENT MITIGATION

Examination of historic records provided details on the mitigation arrangements for spawning and nursery areas lost as a consequence of the construction of Llyn Celyn Reservoir and references were made to mitigation arrangements for Llyn Tegid. However, no details of mitigation arrangements were found for Llyn Brenig to compensate for the spawning grounds inundated following construction. Similarly no mitigation arrangements were discovered for the loss of spawning area on the Alwen following construction of Alwen Reservoir (1912).

6.1 Llyn Tegid Mitigation Arrangements

Following alterations to the Llyn Tegid sluice and the diversion of the Tryweryn with the attendant loss in spawning area in this tributary, mitigation proposals were primarily aimed at enabling access for adults. In an account of the Bala Lake regulation scheme, Wright (1955) commented that "facilities for salmon and other migratory fish to reach the spawning grounds in the upper Tryweryn and the tributaries to Bala Lake have been incorporated in the sluice barrage and the several weirs".

6.1.1 Potential Effectiveness of Llyn Tegid Mitigation Arrangements

From the limited data set provided by Woolland (1972) it would appear that this approach was reasonably successful, salmon parr densities in the Bala lake tributaries (Little Dee & Afon Lliw) being at that time, (some 15 years after construction) in the 'good to excellent' range. However, by the early 1990s salmon were virtually absent from these streams. Other extraneous factors, outwith the scope of the mitigation proposals for Llyn Tegid therefore appear to have been operating.

6.2. Llyn Celyn Mitigation Arrangements.

In contrast to the arrangements for Tegid, when the construction of the Llyn Celyn Reservoir was proposed it was agreed between the Dee and Clwyd River Board and Liverpool Corporation that the dam should not be made negotiable by salmon. The loss of the natural spawning ground upstream of the dam was to be made good in other ways (Iremonger, 1971). The length of spawning grounds to be lost totalled some 10 miles, 4 miles within the reservoir and 6 miles of upstream tributaries, which over the period 1955 to 1959 had held on average 196 redds per year. The proposal was to provide a fish trap immediately below the dam capable of accommodating up to 500 salmon and to increase the hatching and rearing capacity of the River Board's existing hatchery at Maerdy (Iremonger, 1971).

Later minutes of the Fisheries and Pollution Committee recorded that the hatchery was modernised and equipped to deal with 2 million eggs, and that 20 asbestos concrete Swedish tanks and a circular smolt pond were being built, and that the work was completed during early 1962. Altogether, provision was made for the rearing of 100,000 underyearling parr (7 - 8 months old) and 14,000 pre-smolts and smolts of one year to one year six months old (Iremonger, 1971).

In practice, fewer fish than this appear to have been produced. According to Iremonger (1971), between 500,000 and 1,000,000 salmon eggs were being hatched each year, and of the resultant fry some 60,000 were retained in the hatchery and reared to the under-yearling stage and 10,000 to the pre-smolt and smolt stage. The remaining unfed fry were released into the Tryweryn, the Authority's salmon nursery streams in the River Brenig catchment, and other small tributaries of the Dee inaccessible to mature salmon. The excess under-yearling parr not used for rearing to the smolt/pre-smolt stage were released in the autumn into tributaries of the upper Dee. Smolts were released near the tidal limit of the Dee in May and pre-smolts near the tidal limits of the Dee and Clwyd in the autumn.

Most of the ova reared at Maerdy, however, were derived from salmon trapped in the River Alwen at Pont Barcer, rather than from the Tryweryn trap, which has caught progressively fewer salmon since it was first operated in 1961 (See Table 6.1).

6.2.1 Potential Effectiveness of the Llyn Celyn Mitigation Arrangements.

a) Likely Loss of Smolts as a Consequence of Llyn Celyn Construction

Two possible approaches can be used to estimate the loss of smolt production in the Tryweryn, based either on (i) the area of rearing ground lost, or (ii) the reduction in natural egg deposition, based on previous known numbers of spawners.

(i) Iremonger (1971) estimated that some 10 miles (16 kilometres) of nursery stream had been lost behind the dam. Assuming a mean width of 8 metres, the total area lost would be of the order of 128,000 sq m. Yield of smolts from an upland area such as the upper reaches of the Tryweryn would not be high, and a figure of 4 per 100 sq m would be a reasonable expectation (Symons, 1979). On this basis, the likely annual production would have been of the order of 5,120 smolts.

(ii) The average number of salmon redds counted in the affected parts of the Tryweryn over the five years prior to the commencement of work on the dam was 196. However, experimental studies on an adjacent catchment, referred to by Iremonger, indicated that the ratio of redds counted to known numbers of spawning pairs of salmon was in the ratio 2 to 1, i.e. one female fish was responsible for 2 redds.
If this ratio is assumed to be correct, the average number of spawning females per year would have been about 98. Assuming an average weight

for spawning females at that time of 4.5 kg and an average fecundity of 1600 eggs per kg body weight, total egg deposition should have been of the order of 705,600. Egg to smolt survivals are typically in the range 1.0 - 1.5%, thus smolt production estimated by this approach would be of the order of 7,000 to 10,000 smolts per year.

(**Note:** A limited study of salmon smolts in Llyn Tegid was carried out in 1969 and 1970 by Woolland (1972). Based on recaptures of tagged smolts, he estimated that the total numbers in the lake were 5660 in 1969 and 7144 in 1970. These would include smolts from the other smaller tributaries of Llyn Tegid, as well as the remaining reaches of the Tryweryn catchment still accessible to adult salmon. Unfortunately no comparable figures are available for the period before the Llyn Celyn scheme.)

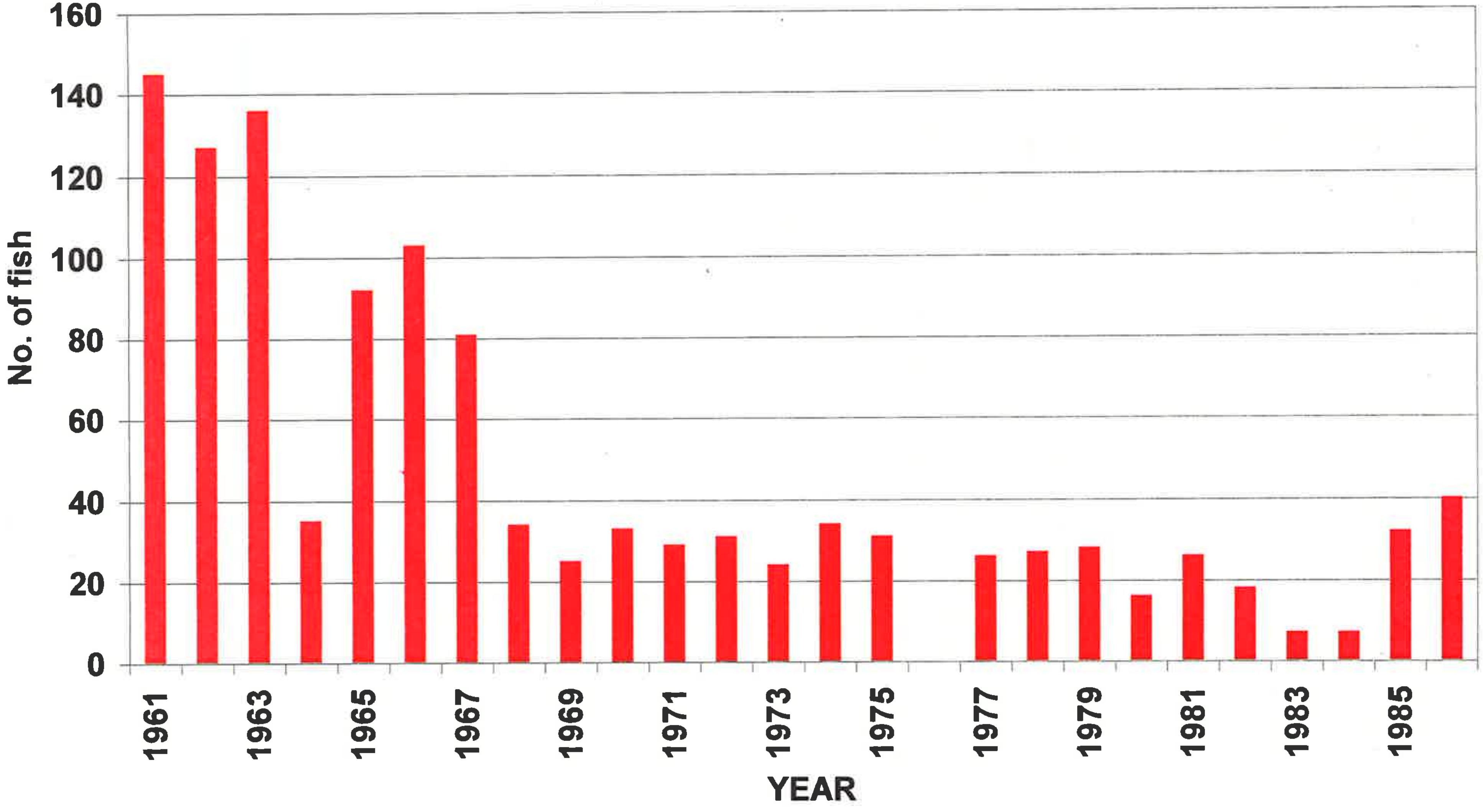
b) Potential Yield from the Mitigation Arrangements

(i) In theory, the additional output from Maerdy hatchery should have been adequate to make good the lost natural production. If only 28% of the proposed 100,000 underyearling parr survived to 1+ parr, and of these 35% survived to migrate as 2 year smolts (survival rates taken from Harris, 1994, quoted from Symons, 1979), the number produced, 9,800, would have compensated for the lost production in the Tryweryn. The 14,000 smolts and presmolts would have added to this number, although their viability would have been significantly less than that of wild smolts.

(ii) In practice, as indicated above, the actual output from the hatchery was considerably less, presumably because the yield of broodstock from the Tryweryn trap (Figure 6.1) was much lower than had been anticipated, and the numbers of parr and smolts/pre-smolts stocked were only about two-thirds of those planned. In addition, figures for percentage returns of tagged hatchery parr and smolts as adults obtained during the current Dee Stock Assessment Programme (EA, 1997) indicate that actual survivals of these fish may have been significantly lower than the expected values.

Stockings of parr and smolts have been supplemented by the planting out of unfed fry. Iremonger (1971) gives details of the utilisation of streams in the upper Brenig catchment above the impassable falls at Pont yr-Rhuddfa as nurseries. Some 8 or 9 miles of stream were stocked every two years with between 150,000 and 200,000 ready-to-feed salmon fry, after removal of the native trout by electric fishing. Surveys of the fish populations in these streams were carried out by students from Liverpool University in the period just before the commencement of the construction of the Llyn Brenig Reservoir (Cane, 1972; Pritchard, 1973). Estimates of the standing crops of salmon parr ranging from 0.5 to 10 per 100 m sq, averaging about 6 parr per 100 m sq, were obtained. From data on channel widths of sampling sites the average stream width in the stocked area would have been about 4.2 m, giving a total stocked area of

Fig. 6.1 Tryweryn trap catches 1961-86



about 58,800 m sq, and a total resulting standing stock of parr of about 3,500. Assuming a parr to smolt survival of 35%, the expected smolt production in alternate years would have been 1,225 fish, which is considerably lower than Iremonger's assumption that 4,000 to 10,000 pre-smolts would result from this stocking. However, it is likely to have made a useful contribution to the overall mitigation, particularly as these would, in effect, have been wild smolts. Unfortunately, with the construction of Brenig Reservoir, this smolt production was lost after the dam was closed in 1975.

6.3 Overall Effectiveness of the Mitigation Arrangements.

As has been mentioned above, mitigation for the 1950's works on Llyn Tegid were initially successful, although more recently other factors in the subcatchments of the tributaries appear to have had a detrimental effect on salmonid production from the Bala tributaries. Hence in the longer term the mitigation arrangements for the initial Llyn Tegid scheme can no longer be considered relevant.

Following construction of Llyn Celyn, initial seeding of hatchery reared fish into the Brenig subcatchment was regarded as a successful component of the mitigation package. Following construction of Brenig Reservoir, no allowance appears to have been made to make good the lost production from these streams which were once part of the mitigation arrangements for Celyn. Further, the original mitigation targets for the hatchery aimed at compensating for the direct impacts of Celyn were never met.

However, even if smolt production had approached that initially anticipated, being of the order of 24,000 fish[11], given the typical survival rate of 1.0% - 1.2% for 1+ hatchery reared smolts[12] (Harris, in press, Milner, 1993), then 240 adult returns might be expected (although smolts derived from the underyearling parr might have been more viable). However, the known observed survival rate for wild smolts of 6% for the 7,000 smolts considered lost from the construction of Celyn would have resulted in 420 adults. Smolt survival rates commonly quoted from elsewhere are typically of the order of 9% (Harris, in press) giving possibly as many as 630 adults. Hence, even if achieved in practice, the mitigation arrangements as proposed would only account for between 30 to 50% of the lost salmon production.

Currently, no mitigation arrangements are in force for coarse fish.

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[11] 9,800 smolts from the 100,000 underyearling parr and 14,000 from the hatchery

[12] From Dee trap investigations.

6.3.1 Relative Effectiveness of Stocking with Different Life Stages.

The present–day production from Maerdy Hatchery differs both from that originally proposed and that outlined by Iremonger in 1971. Currently some 90,000 fed fry and 30,000 1+ parr/smolts are released each year (Davidson – pers. Comm.). It is difficult to predict potential adult returns from this stocking regime because of the lack of good data on survival of fed fry through to smolt and then to adult. Information on survival of stocked 1+ parr to adult is also inadequate, and according to the limited amount of data available from the Dee trap investigations is very variable, ranging from 0.09% to 1.97%.

Milner (1993) and Harris (1994) both reviewed available information on survival rates and cost effectiveness of stocking with different juvenile stages, and both concluded that 0+ parr released in September gave better returns and were more cost effective than fed fry. From figures given by Milner (1993) one can calculate that survival of fed fry to smolts is approximately 1.0% and to adult returns is 0.0359%, and from 0+ parr (September) to smolt is 4.43% and to adult is 0.106%. Looked at another way, to produce one adult salmon returning to the river would require the release of 2785 fed fry or 943 0+ parr. Cost was estimated to be £189 per returning adult produced from fed fry and £167 per adult return from 0+ parr (unit costs assumed were 6.8 pence and 17.7 pence for fed fry and 0+ parr respectively). Harris (1994) assumed an even greater survival rate of 0+ parr relative to fed fry, using figures of 1.0% for survival of fed fry to smolt and 20% from 0+ parr to smolt, and survivals of 0.09% and 1.8% to returning adults for fed fry and 0+ parr respectively. His estimated cost per returning adult was £144 for fed fry, but only £25 for 0+ parr (assumed unit costs were 9p for fed fry and 45p for 0+ parr). (N.B. The figure from Symons (1979), quoted previously, of 9.8% survival from 0+ parr to smolts falls within these two extremes.)

Milner (1993) and Harris (1994) also considered the effectiveness of stocking with hatchery reared smolts. Milner used a return rate of 1.2% for 1+ smolts in his analysis, and Harris adopted a slightly more conservative figure of 1.0%. On the basis of Milner's figures, 83 smolts would need to be released at an estimated cost of £86 to produce one returning adult. Using Harris's figures, 100 smolts would be required at a cost of £114 per adult return.

Harris also considered the effectiveness of releasing 1+ parr, which it was assumed would migrate as 2+ smolts. He assumed a survival rate of 30% from 1+ parr to 2+ smolt, but then a much higher marine survival of 9% for these smolts, making an overall survival of 2.7% from parr to returning adult. (In fact, this figure is not that much higher than the best figure of 1.97% survival obtained from the Dee trap results.) Harris estimated that to produce one returning adult, 37 1+ parr would be needed at a cost of £42.

In terms of cost effectiveness, Milner considered stocking with smolts as being the most economical followed by 0+ parr, whereas Harris considered 0+ parr as being the most cost effective, with releases of 1+ parr being ranked second.

6.3.2 Possible Modifications of Current River Dee Stocking Programme.

From the analyses examined above, it would appear that stocking with fed fry is not likely to be particularly effective, either in terms of numbers of returning adults produced or cost effectiveness. Consideration should therefore be given to retaining fry for longer at the hatchery and planting them out as 0+ parr in the late summer.

The return rates of microtagged 1+ smolts and of one release of microtagged 1+ parr measured during the Dee trapping studies (EA, 1997) have been disappointing, and are considerably less than one would expect from studies elsewhere. This obviously raises the question as to whether releases of fish at these life stages are worthwhile. However, the fact that reasonable returns, at reasonable comparative costs, have been obtained elsewhere (and for 1+ parr for one year on the Dee), indicate that it would be worthwhile persisting with this approach. However, steps should be taken to optimise the chances of the fish surviving during the initial period in the river after release. The trials with release ponds presently underway should therefore be continued and extended if suitable sites can be found.

In summary, it is recommended that stocking with fed fry should be discontinued and replaced by stocking in late summer with 0+ parr. It is understood that there is capacity at Maerdy Hatchery to hold the 90,000 fed fry through to the end of the summer, and although this will increase the costs, the anticipated better returns should provide better value for money. Stocking sites should be areas where there is a scarcity of wild juveniles, and preferably stocking should be well up in the catchment, on the assumption that any resulting adults will return to the same areas to spawn. The practice currently being adopted of stocking juvenile salmon to the Llyn Tegid tributaries and to the Alwen system, where juvenile densities are known to be low, should therefore be continued, although areas where there are suspected water quality problems should be avoided until these have been resolved.

Rearing of parr through to the 1+ smolt/presmolt should be continued, but with the fish being released to the river via release ponds situated well up the catchment, rather than planting them directly into the river. Release ponds may not be as effective for 1+ parr, as they may be reluctant to leave, and direct release to the river may therefore be necessary. Some degree of "conditioning" of fish before release by increasing the water throughput, and hence velocity, in the ponds or tanks before release should be attempted.

6.3.3 Acquisition of Brood Stock.

With the failure in most years of the Tryweryn trap to yield significant numbers of brood fish, reliance has been placed on the use of the Pont Barcer trap on the River Alwen. This raises two questions. Firstly, were juveniles from this source the most suitable for planting out into other parts of the catchment, in view of present knowledge of the existence of local races within river systems? In terms of conservation of genetic composition, probably not.

However, evidence on the extent to which local environmental factors experienced by young salmon during their development in freshwater interact with inherited tendencies to affect their eventual return patterns is inconclusive.

However, there is abundant evidence that smolts released in catchments other than the one in which they have been reared return to the release river, rather than to the one in which they were previously reared. Thus in the absence of firm evidence to the contrary, there is no valid reason for abandoning the use of broodstock from Pont Barcer for general restocking.

Secondly, and more seriously, there is the possible impact on smolt recruitment from the Alwen system resulting from the removal of considerable numbers of adult salmon from the river prior to spawning. Table 6.1 gives details of trap catches of salmon at Pont Barcer and redd counts for the Alwen system upstream of the trap for those years for which data are available. To obtain a measure of the total run of female spawners into the Alwen system, the number of female salmon taken at Pont Barcer has been added to the redd count. The trap catch has then been expressed as a percentage of the estimated total run of female fish. The assumption has been made that one redd is equivalent to one hen fish. As mentioned earlier in this report, one hen fish may be responsible for more than one redd, hence the percentages given in Table 6.1 are minimum estimates. Also, some of the redds counted may have been those of large sea trout. It can be seen that in many years the trap has removed a very significant proportion of the total female run. This was particularly so in the mid 1970's, when in three years more than 50% of the potential spawners were removed at Pont Barcer. This occurred at a time when the total spawning run in the Alwen was reduced considerably compared with the 1960's. It seems reasonable to conclude that recruitment of wild smolts from the Alwen subcatchment would have been adversely affected by the operation of the trap, although this loss would have been offset to some extent by the stocking of some of the hatchery production back into the Alwen system.

Table 6.1 Pont Barcer Trap Catches (Salmon) and River Alwen Redd Counts*.

Year	Trap Catch		Redd Count	Redd Count plus Female Catch	Female Catch as % of Total Female Run
	Males	Females			
1986	28	105	(29)	(134)	(78.4)
1985	51	36	287	323	11.1
1984	14	8	189	198	4.0
1983	?	?	166	(166)	?
1982	?	?	223	(223)	?
1981	?	?	259	(259)	?
1980	60	58	99	157	36.9
1979	25	35	52	87	40.2
1978	37	61	97	158	38.6
1977	32	65	54	119	54.6
1976	15	10	175	185	5.4
1975	87	163	75	238	68.5
1974	24	51	156	207	24.6
1973	35	69	64	133	51.9
1972	148	159	341	500	31.8
1971	100	99	494	593	16.7
1970	129	108	306	414	26.1
1969	230	263	627	890	29.6
1968	43	59	1024	1083	5.4
1967	47	73	(No count)	(73)	?
1966	84	126	1341	1467	8.6
1965	74	85	(61)	(146)	(58.2)
1964	?	?	1079	(1079)	?
1963	?	?	?	?	?
1962	75	67	(92)	(159)	42.1
1961	52	148	846	994	14.9
1960	?	?	868	(868)	?

Figures in brackets are for years in which the redd count is reported as being incomplete, usually because of high water levels.

* Counts are for River Alwen and tributaries upstream of Pont Barcer.

Although historically the catch of salmon at the Tryweryn trap has been poor, the number caught in 1997 was greater than in most previous years. It has been suggested (Brassington – personal communication) that this may have been a result of a change in the pattern of releases from Llyn Celyn during the autumn of 1997. In previous years, a flow of 12 – 13 cumecs was released over a 2 day period to try to entice salmon to move up into the trap. In 1997, releases were used instead to maintain naturally occurring spates in the Tryweryn at 6 – 7 cumecs for up to a week. This appears to have been a more successful approach, and should be repeated in future years.

The only other trapping facility available on the Dee at the present time is the Chester Weir trap. Presumably this could only be used for broodstock collection after the end of the angling season, and would therefore be taking late-running fish. Whether such fish are suitable as brood fish is open to question. Other methods of collecting broodstock, such as electrofishing and trammel netting are both labour intensive and potentially damaging to the fish. Thus if the stocking programme is to continue, reliance will have to be placed on continued use of Pont Barcer to supplement the Tryweryn trap catch. However, the potential impact on recruitment of wild smolts from the Alwen system could be reduced by keeping the catch of broodstock at Pont Barcer to the minimum needed to meet the requirements of the hatchery. Assuming that 30,000 1+ parr/smolts and 90,000 0+ parr are to be produced each year, and using knowledge of historical survival rates through different stages at Maerdy, it will be possible to calculate the number of ova which need to be laid down and hence the likely number of female brood fish required. When this number, plus a margin to allow for some pre-spawning mortalities, and sufficient male fish, have been taken at Pont Barcer, trapping could cease, and any later running fish allowed upstream.

In the longer term, to obtain suitable broodstock for production of juveniles to stock out into the upper parts of the main Dee catchment to mitigate effectively for Llyn Celyn, either the Tryweryn trap should be made more effective, e.g. by use of manipulation of releases from Llyn Celyn described above, or another trapping facility will be required to replace the ineffective trap. During the initial discussions between the River Board and Liverpool Corporation about mitigation for the loss of the main Treweryn nursery area it was anticipated that this trap might not be successful, and it was agreed that if this should prove to be the case, an alternative catching point, possibly at the junction of the Treweryn with the Dee, should be provided by the Corporation. (Agreed at a meeting held between representatives of the Dee and Clwyd River Board and Liverpool Corporation on 16th August, 1960.) Presumably Liverpool Corporation's responsibilities in this matter now rest with North West Water plc, but whether they would respond positively to an approach on this matter after such a long period had elapsed is questionable! However, an approach might be worthwhile, particularly if further development of the water resources of the Dee system is proposed.

The possibility of using reconditioned kelts as broodstock has been suggested. Kelts have been held and reconditioned in both freshwater and saltwater, and have been shown to produce viable ova which in turn produced adult returns comparable with those obtained from hatchery reared juveniles derived from first time spawners. (Gray, Cameron and McLennan, 1987) Some reconditioned fish matured after one year, but the majority, particularly the females, required two years conditioning. There has been little if any use of this technique in the British Isles, other than on a limited trial basis, and further investigation is required.

6.3.4 Alternatives to Restocking

a) Habitat Improvement.

There is an increasing interest in the use of habitat improvement and restoration as an alternative to restocking, and in many situations this can be shown to be cost effective (APEM, 1995). In the case of migratory fish rivers, restoration of spawning gravels, protection of banks to prevent erosion and siltation of gravels, and creation of suitable juvenile habitat have become accepted as effective techniques. However, before such improvement and restoration schemes can be planned and implemented, knowledge is required about the condition of those parts of the catchment likely to provide nursery grounds. Presently, anecdotal evidence suggests problems such as siltation of spawning gravels and vegetative encroachment are occurring although there is no direct evidence to confirm this.

Therefore it is neither possible nor advisable to comment on the potential for habitat improvement as a stock improvement strategy. In any case, this would be a long term solution, and would not address the present shortfall in meeting egg deposition targets.

Hence, detailed and focused habitat survey is required following the guidelines identified in the Agency salmon habitat restoration manual (Hendry & Cragg-Hine, 1997). It is proposed that the entire catchment is mapped in a co-ordinated systematic manner, from the limits of salmonid spawning in headwater streams through juvenile rearing areas to the coarse fish zones in both tributaries and the main river to Chester. The length of river to be covered is obviously considerable and hence it is suggested to proceed by sub-dividing the river into smaller sub-catchments (Table 6.2).

Fig. 6.2 River Dee. Length of main river and tributaries

WATERWAY	LENGTH (Km)
Main river. Chester Weir – Bala Sluice	123
Bala Lake tributaries (Incl. Tryweryn)	48
Minor tributaries. Bala sluice – Alwen jnct.	31
R. Alwen and tributaries	49
Minor Mid-Dee tributaries	20
R. Ceiriog and tributaries	43
Minor Lower-Dee tributaries	53
R. Alwen and lower tributaries	68
TOTAL	435

The survey 110 man days of field survey time, plus 55 man days for working up habitat maps and a further 10 man days for interpretation and reporting (total 175 man days). Based on an average £200 a day manpower figure, a budget of around £35,000 would be required.

should also be noted that the survey would be of equal importance to the coarse fishery.

b) "Buy-out" of Estuary Nets.

Another possible alternative to restocking which might be investigated is a "buy-out" of the commercial nets operating in the Dee estuary, i.e. pay the licensed netsmen not to fish, as has been done recently on the Clwyd. (It is appreciated that the Clwyd "buy-out" is funded by private money, and that it might not be possible for public funds to be used for this purpose.) Over the five-year period 1991 to 1995 the Dee draft nets total catch averaged 771 salmon, with on average 17 nets operating, and for the four trammel nets the average catch was 348 salmon (DSAP Reports, 1992 – 1995 – EA, 1997). Average annual catch per net for the draft nets was therefore 45 fish, and for the trammel nets 87 fish. Assuming the carcass value of a salmon at first sale to be £20, the typical gross income for a draft license holder would have been £900, and for a trammel net license holder £1740.

If a fisherman were to be offered the equivalent of 10 years income (the duration of a net limitation order) not to fish for a 10 year period, the cost would be £9,000 paid to a draft net license holder, and £17,500 to the holder of a trammel net license.

The benefits which would be gained can only be speculative, but in theory, each draft net removed would "save" 45 salmon per year. However, these would still be vulnerable to capture by the other nets still operating. The nominal exploitation rate by the nets has been estimated at 0.3 (EA, 1997), thus one can assume that about 32 fish (0.7 x 45) would survive to enter freshwater. From tracking studies (Purvis, 1996), about 61% of these would be likely to survive to spawning, i.e. about 19 fish. From the DSAP studies, at least half these would be females, say 10 fish. Assuming an average egg deposition of 6000, a total egg deposition of 60,000 would result. Some extra fish would also have been taken by the rods, perhaps 5 fish on the basis of an average exploitation rate of 0.15. On the same basis, removal of a trammel net might "save" 87 salmon, resulting in 19 extra female spawners yielding 114,000 ova, with perhaps 9 extra fish to the rods.

By way of example, a possible scenario would be to spend £18,000 per year on buy-outs, initially of draft nets. By year 8, and assuming the fishermen were co-operative, all the draft nets would be out of use. In each of the next two years, one of the trammel nets could be bought out, and with the new net limitation order which reduces the number of trammel net licenses to two eventually, it is likely that by this time all the nets would be out of action. Obviously as more and more nets stop fishing, the overall exploitation rate by nets on the survivors will decline from the present 0.3, resulting in proportionally increasing returns from further buy-outs. From year 11 onwards, expenditure would be required to recompensate each fishermen as their individual 10 year "fallow" periods expired. However, a new net limitation order will have been sought by that time, so the whole situation could be changed.

With the scenario outlined above, on the basis of the 1991 – 1995 average net catch of salmon, cessation of netting would result in an additional 1119 fish entering the freshwater river. About 680 of these would be likely to survive to spawn, and

With the scenario outlined above, on the basis of the 1991 – 1995 average net catch of salmon, cessation of netting would result in an additional 1119 fish entering the freshwater river. About 680 of these would be likely to survive to spawn, and assuming at least half were females, an extra 2.04 million eggs should result. This would exceed the shortfall in egg deposition of 0.7 million estimated for 1995, but would still fall short of the 4.1 million and 3.5 million estimated for 1993 and 1994. (EA, 1997) The additional escapement to the river might increase the rod catch by about 170.

By way of comparison, to produce an additional 1119 salmon by stocking with hatchery-reared smolts or presmolts would require the release of about 112,000 such fish, assuming that a smolt to returning adult survival rate of 1.0% could be achieved. Currently Maerdy Hatchery produces 30,000 smolts/presmolts per year, but to make up the shortfall with 0+ parr would require 45,500 fish if Harris's figures are used, or 773,000 from Milner's analysis! Using Symon's figures (Symons, 1979) the number required would be 140,000. Harris's figure may be unduly optimistic, and on balance it seems that it is unlikely that the hatchery could provide the requisite number of fish. The returning adults would of course still be subject to commercial exploitation as the nets would still be operating, thus even more hatchery fish would be required to achieve an escapement of 1119 fish to freshwater. On the basis of this crude analysis it would seem that a buy-out of the nets would be more cost effective than continuing with a rearing programme with obvious environmental benefits.

6.3.5 Measures to Improve Coarse Fish Stocks

As indicated earlier, there is evidence that regulation has had an adverse effect on some coarse fish populations in the lower Dee, particularly on roach (Hodgson, 1993). To date, no specific remedial action has been taken, other than various attempts at restocking in the past. None of these gave anything other than very short-term benefits, (Pearce, 1983b), and recent studies by the Water Research Centre (WRc, 1995) concluded that stocking to rivers generally has only very limited success. Thus it is not recommended that any reliance should be placed on restocking with coarse fish. There are certain other measures which could be taken and which would be likely to be beneficial, and these are outlined below.

(a) Provision of off-line spawning and early rearing lakes in the flood plain. The feasibility study carried out in 1997 (APEM, 1997) identified a suitable site for an off-line flood plain lake just upstream of Aldford. It was demonstrated that over a 10 year period such a lake should produce worthwhile improvements in the roach stock of the lower river although the overall cost of the scheme may prove prohibitive.

(b) The recent study by SGS Environment (SGS, 1997) identified various riverine habitat improvements to the Dee concentrating on its tributaries which would benefit coarse fish by providing extra cover and spawning habitat. Implementation of the improvements on as wide a basis as is feasible should be undertaken as a priority.

6.4 Monitoring Arrangements

6.4.1 Microtagging

To monitor returns from any stocking programme which may be undertaken, it will be necessary to continue to microtag substantial numbers of fish before release. Parr and presmolts due for release at age 1+ should be microtagged during the winter months, before the smolt change begins, to avoid additional stress on the fish during the physiological changes associated with smolting. Parr can be microtagged when they reach a length of 7 cm, so it may be possible to tag some 0+ parr prior to release if a policy of stocking with late summer 0+ parr is adopted. It is assumed that the Dee Stock Assessment trapping work is to be continued, as this provides a unique opportunity for monitoring returns.

6.4.2 Juvenile Surveys

The five minute fry surveys provide a quick and easy means of monitoring distribution and success of spawning over the catchment. Monitoring of the survival of stocked hatchery-reared fish will require a different approach, however, particularly if the stocking programme is changed to releasing fish as late-summer 0+ parr, rather than fed fry. Quantitative multiple catch surveys, supplemented by single catch sites calibrated against multiple catch sites, in the stocked areas are recommended.

6.4.3 Manley Hall Fish Counter

Although resistivity counters cannot be relied on to give accurate counts of salmon at all times of year because of the difficulty of distinguishing large sea trout from grilse, during the early months of the year any fish counted are likely to be salmon. Thus the counter should enable any significant changes in the run of multi-sea winter spring fish to be detected. An important role for the counter will be in monitoring the effects of changes in river flow on fish movement if any special releases are made to try and encourage upstream migration.

6.4.4 Catch Returns by Anglers

Although known to be incomplete, the compulsory catch returns made by salmon and sea trout anglers do give an indication of trends, both in the abundance of fish and in the timing of runs. Historically, better information on catches in the Dee was obtained directly from the fishery owners and tenants, who allowed the bailiffs access to the diaries kept in fishing huts. It would be advantageous if this sort of arrangement was still in operation. A shortcoming of the standard catch return is the absence of any reliable information on fishing effort, but this can be addressed by the angler log book exercise, which should be continued and extended if possible.

6.4.5 Hydroacoustic Surveys.

The use of side-scanning sonar has been shown to have potential for carrying out estimates of the densities and biomass of fish in lowland rivers (Duncan and Kubecka, 1993). The possibility of using this technique in the lower Dee should be explored together with cross calibration of angler's match data to add to the reliability of angling records.

6.4.6 Summary of Recommendations for Monitoring.

i) Continue with microtagging programmes to monitor effectiveness of stocking programme.

ii) Continue with 5 minute fry surveys to assess natural spawning distribution and success. Develop an appropriate quantitative survey programme to monitor the survival rates of stocked hatchery fish.

iii) Use output from Manley Hall counter to monitor timing and abundance of salmon runs and effectiveness of releases of water in encouraging upstream migration.

iv) Maximise quality of returns of salmon catches from anglers and use results of angling matches to monitor status of coarse fish populations.

v) Investigate the potential for using hydroacoustic methodology for monitoring coarse fish populations in the lower Dee.

6.5 Summary

Current Mitigation Programme

- No mitigation arrangements were found for Brenig to compensate for spawning grounds inundated following construction.
- No mitigation arrangements discovered for loss of spawning on the Alwen following the construction of Alwen reservoir.
- Following alterations to Llyn Tegid sluices, mitigation effort was concentrated on enabling access for adults. This was considered successful for up to 15 years after construction, although recently other factors out-with the scope of mitigation have impacted on stocks.
- The original mitigation targets for Llyn Celyn to compensate for the lost 10 miles of spawning habitat have never been met (based on 100,000 yearling parr and 14,000 smolts - Liverpool Corporation). However, the agreed mitigation package only accounted for between 30 and 50 % of the lost salmon production.

- Tributaries in the Brenig sub-catchment were originally part of the mitigation package for Celyn, ready to feed fry (150,000 to 200,000) being seeded into nursery streams. Following construction of Brenig, no compensation for this loss to the mitigation arrangements was made.

- Most brood stock for the mitigation programme are obtained from the Alwen, not the Tryweryn as originally intended. The level of brood stock collection from the Alwen has had a marked impact on the residual spawning population.

- No mitigation arrangements were made for coarse fish.

Suggested Improvements

- Fry should be retained for longer in the hatchery, planting as 0+ parr in late summer.

- Smolt stocking should continue but experiments with smolt release ponds should be pursued.

- Brood stock collection should be focused on the Tryweryn, particularly following success with autumnal artificial freshet releases.

- Kelt reconditioning should be explored further.

- A detailed habitat survey should be undertaken to determine whether habitat improvements, particularly gravel cleaning, are necessary.

- A rolling buy-out programme for estuary nets offers a cost effective and environmentally sensitive means of protecting returning adult stock to significantly increase spawning escapement.

- For coarse fish an off-line spawning lake has been proposed but may be considered too capital intensive.

- Riverine, habitat improvements for coarse fish, particularly in the tributary streams, should be implemented on as wide a basis as is feasible. ?

- A variety of monitoring arrangements are proposed to assess the effectiveness of the suggested alterations to the current mitigation scheme.

7. CONCLUSIONS

Examination of the information contained in this report leads to the conclusion that there are a multiplicity of factors operating which impact upon the fish populations of the Dee. Notable issues which give cause for concern are:-

- Water quality in Llyn Tegid and the feeder tributaries.
- Land use changes to pasture, sheep overgrazing etc.
- Acidification in the Alwen sub-catchment.
- Sheep dip impacts on the invertebrate community.

However, in addition to these issues, and probably of greater significance to the Dee fish community overall, regulation is affecting fisheries by;

- Damping freshets and hence affecting upstream migration of salmonids.
- Reducing scouring flows, promoting siltation of salmonid spawning and juvenile rearing areas.
- Influencing the location of catches and hence the economic viability of the salmonid fishery in some locations.
- Altering the temperature regime, which impacts negatively upon the coarse fish populations and may be responsible for a shift in smolt age.
- Inducing habitat and temperature changes encouraging the expansion of the grayling population and the dominance of the coarse fish community by dace.

With the notable exception of the grayling population, the general conclusion of the study is that regulation has resulted in an overall reduction in fish populations, but specifically in the years immediately following the construction of Llyn Celyn.

As regards mitigation, it is apparent that the original mitigation package for Celyn has never been realised. Rather, following construction of Brenig, the mitigation package has been eroded, whilst no mitigation arrangements have ever been in force for coarse fish. Various suggestions have been proposed to augment the current inadequate mitigation arrangements which include;

- Retaining fry for longer in the hatchery and planting as 0+ parr in late summer.
- Concentrating on brood stock collection in the Tryweryn,

- Initiating a rolling buy-out programme for estuary nets.
- Implementing riverine, habitat improvements for coarse fish
- Undertaking a detailed habitat survey of the entire catchment.

8. RECOMMENDATIONS FOR THE DEE REGULATION OPERATING RULES

This section provides recommendations for the use of special releases of stored water to benefit salmonid fisheries in the river Dee.

8.1 The Existing Water Bank.

A bank of water is held in reserve to allow limited special releases for fishery, water quality, recreation, river management, or other operational purposes. Under normal conditions, the volume of water available is 119 cumec days, with 100 cumec days being held in Llyn Celyn and 19 cumec days in Llyn Brenig. However, the amount of special release water actually available is determined as of 1st May in each year, and if the winter and spring recharge of the reservoirs has been inadequate, the volume of special release water will be reduced. However, it can be reinstated in the event of adequate summer rainfall and recharge. Special releases are likely to be reduced when Drought General Directions are in operation.

Discussions with staff of the Water Resources Department have indicated that there is also potential to build up water levels in Llyn Tegid sufficiently to generate freshets in the Dee without using special release water. Natural inputs to the lake would be allowed to accumulate by retaining them within the system and then releasing them over a short period of time. Freshets of up to 30 cumecs could be generated in this way. It is recommended that discussions should take place within the Agency to explore ways in which this additional storage might be achieved, whilst having due regard to flooding issues.

8.2 The Use of the Water Bank

The principal use which has been made of special releases to date has been to maintain water quality in the river, either by "flushing out" contaminants after pollution incidents, or to maintain water quality in the estuary during times of high temperatures and low flows. Obviously the maintenance of good water quality to preserve fish life is the highest priority, and as far as the estuary is concerned, July and August are likely to be the critical times. However a prolonged, hot, dry spell in May or June, when smolts are migrating out through the estuary, could also produce unfavourable conditions. There are other potential uses of releases to benefit the migratory fisheries which could be considered, namely: -

i) releases to encourage upstream movement of adult salmon.

ii) releases just prior to the spawning season to flush gravels to clean out fine sediment which could be harmful to incubation of eggs and emergence of alevins.

8.2.1 Releases to Facilitate Upstream Migration of Adult Salmon.

The results of the radio-tracking studies carried out on the Dee between 1991 and 1993 (Purvis, 1994, 1996) need to be taken into account when considering the possible use of special releases to encourage upstream migration of salmon. (See Appendix III)

From consideration of these findings it would seem that the potential for using special releases to encourage more rapid upstream migration, once fish are into freshwater are not that great. The majority of salmon undergo prolonged quiescent stops prior to their final migration to the spawning reach, during which they are unlikely to respond to even significant increases in flow, whether artificially generated or natural. Releases which are most likely to be beneficial are:-

i) Those designed to encourage fish to leave the tideway and enter the freshwater river during prolonged spells of low flows, when passage of salmon over Chester Weir may be delayed.

ii) Maintenance of higher flows or generation of freshets to encourage fish to prolong their initial migration phase and to assist their passage of Erbistock Weir. This would also be likely to increase exploitation by angling by prolonging the phase of vulnerability to capture.

iii) Generation of artificial freshets in the autumn and early winter to encourage fish to make their final migration to the spawning reach, particularly during dry periods, and thus facilitating a good distribution of spawning effort. Also to entice salmon to enter the Tryweryn trap for brood stock collection.

The potential for making such releases and the need for them will depend on factors such as the availability of release water, numbers of salmon in the river, weather conditions, etc which will vary from year to year. However, from the tracking and DSAP studies it is apparent that residual flows of 13 cumecs or greater over Chester Weir, i.e. some 9 cumecs greater than the normal residual flow of 4.2 cumecs, are likely to reduce the delays in entry to freshwater detected at lower residual flows. To achieve this flow, an additional 9 cumecs will need to be released, which on top of the normal regulation release would be likely to generate a flow of about 20 cumecs at Manley Hall.

Freshwater flows in the range 20 to 30 cumecs, measured at Manley Hall, are likely to maintain upstream movement of fish that are still actively migrating and reduce delays in the passage of fish over Erbistock Weir. Thus any releases made to encourage fish past Chester Weir should be maintained for a sufficient period of time to allow them to reach Erbistock Weir. Salmon typically move quickly through the lower reaches of the Dee (Purvis, 1996), and the majority would be expected to reach Erbistock within 2 – 3 days, particularly at flows of the order of 20 cumecs.

Thus a release of 4 days duration should both encourage salmon to move into the freshwater river and provide good conditions for their passage over Erbistock Weir. A decision tree for making such releases is given in Scheme A of Figure 8.1.

The generation of artificial freshets by using water held back in Llyn Tegid would be most beneficial in the autumn from September onwards, when quiescent salmon would be much more likely to respond. Long duration, "flat-topped" freshets are unlikely to be successful in promoting migration. Instead, freshets of a few days duration, increasing stepwise to a peak of at least 3 times the base line starting flow at Bala sluices, preferably 4 to 5 times, and then stepped back down again should be generated. That is, the natural hydrograph of a freshet should be simulated as far as possible, with the rise to the peak being rapid and the recession more gradual. Ideally these releases should coincide with rainfall events within the catchment which have generated small natural freshets lower down the river system. A decision tree for making such releases is given in Scheme B in Figure 8.1.

It is appreciated that such releases over and above the normal special release allocation are only possible from Llyn Tegid, but where special release water is available in Llyn Brenig, consideration should be given to using these to prolong naturally occurring freshets in the Alwen during the autumn months. In the event of any further water resources development of the Dee system, consideration should be given to increasing the availability of special release water from Llyn Brenig to increase the potential for managing flows for fishery and conservation purposes in the River Alwen.

During a meeting with the Agency staff it was suggested that consideration might be given to increasing the compensation water release from Llyn Brenig at times when the Alwen Reservoir was overtopping, to provide some dilution of the low pH water likely to be entering via the upper River Alwen. This could protect juvenile salmon in the main Alwen. However subsequent discussions with the Water Resources Department have indicated that the slow refill characteristics of Brenig Reservoir effectively rule out this proposal. As an alternative it was suggested that the existing facility for pumping water from the Alwen Reservoir to Brenig might be utilised, to reduce the likelihood of Alwen overtopping. It is recommended that this possibility should be explored, but with due regard for potential impacts on water quality in Brenig.

The management of releases from Llyn Celyn during the autumn to encourage salmon to move up to and enter the Tryweryn trap has already been discussed in section 6.3.3. It is recommended that the procedure adopted during the autumn of 1997, i.e. making releases from Llyn Celyn to prolong naturally occurring spates in the River Tryweryn at a flow of 6 to 7 cumecs for a week, should be continued in future years and its effectiveness monitored.

8.2.2 Releases for Gravel Cleaning Prior to the Spawning Season.

A potential disadvantage of river regulation and the reducing of peak flood flows is the possible increased deposition of fine sediments in the gravel areas used by salmonids for spawning. It is recommended that investigation of the condition of the gravels in the upper Dee between Llyn Tegid and the Alwen junction should be carried out to determine their condition, and to establish if cleaning is required. A budget of £10,000 should be allowed to establish if siltation is a problem, although the study should be undertaken after the habitat survey of the areas of concern is complete.

If a siltation problem is identified, artificial freshets of sufficient magnitude generated from Llyn Tegid during the autumn could be used to flush and clean the gravels in the upper reaches of the main River Dee which are the principal spawning area for the multi sea winter early entrant fish. Effective flushing flows are likely to be of the order of 1.7 cumecs per metre of channel width, and should be of 48 hours duration, if possible. [illegible] [illegible]

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[illegible]
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It is appreciated that this would involve the release of substantial quantities of water, perhaps as much as 85 cumec days assuming a channel width of the Dee below Bala of 25 metres, and this quantity might not be available in some years. Recent work from North America has indicated that habitat preservation flows (for de-silting) may only be required once in every 3 years (Moyle *et al*, 1998). However, it should be noted that flows of this magnitude would also be likely to encourage upstream migration of salmon, and would therefore serve a dual purpose.

8.2.3 Priorities for Use of Special Release Water.

The following hierarchy of priorities is recommended for use of special release water: -

i) Releases to maintain water quality in the estuary and to minimise the impact of pollution incidents, i.e. preservation of fish life is the first priority.

ii) Releases to encourage incoming salmon to leave the tidal reach and enter freshwater and to prolong the initial migration phase of new entrants to the river thereby widening their distribution.

iii) Releases from Llyn Tegid, and if possible from Llyn Brenig, during the autumn to encourage fish to move up to the spawning reaches and from Llyn Celyn to encourage fish to enter the Tryweryn trap.

iv) Releases from Llyn Tegid to "flush" spawning gravels in the upper Dee should siltation prove to be a problem, on at least a 3 yearly cycle.

8.2.4 Potential Negative Impacts Resulting from Special Releases.

The most significant risk resulting from the use of the water bank for special releases to encourage fish migration or to cleanse spawning gravels is that there may be insufficient water remaining in the bank to provide a flushing release in the event of a major pollution incident.

Special releases made during the late spring and summer would also be likely to result in even lower water temperatures in the lower Dee, thus having a negative impact on the growth of young-of-the-year cyprinids. However, as the duration of the releases would not be very long, the impact would not be very significant.

Figure 8.1 Decision Tree for the use of the water bank in Llyn Celyn & Llyn Brenig and any additional stored water in Llyn Tegid.

		May June July August			**September October November December**	
		← Scheme A →			← Scheme B →	
Do Nothing	N	Flow at Chester Weir <5 cumecs for >15 days?	Do Nothing	N	Flow from Llyn Tegid <7 cumecs for >15 days?	
		Y			Y	
	Y	Wet weather forecast?		N	Wet weather forecast?	
		N			Y	
	Y	Have 2 releases been made?		Y	Have 2 releases been made?	
		N			N	
		Increase residual flow to 13 cumecs for 4 days			Make releases over 4 days to generate flows 2x, 4x, 3x and 2x baseline flow.	
					Y	
					Are both water bank and additional water held in Llyn Tegid used up?	N
					Y	
		No further releases			No further releases	

Note Typical baseline flow from Llyn Tegid during dry autumns is 7 cumecs.

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APPENDIX I

Studies on the River Dee Undertaken by Liverpool University.

1. Introduction

Part of the project brief was to obtain and analyse available sources of data, including the impact studies undertaken by Liverpool University at the time of the Llyn. Celyn construction. Much of this work was carried out under the supervision of Dr. J. W. Jones under research contracts from the Water Resources Board and the Natural Environment Research Council. A preliminary report entitled "River Regulation and the Fishes of the Dee Catchment" covering the period 1968 to 1972 was prepared by the Freshwater Fisheries Unit of Liverpool University, but unfortunately no final report was published. For the most part the studies were undertaken by postgraduate students registered for Ph.D.'s, and results were presented in their various theses. Some smaller investigations were also carried out by B.Sc. Honours students as final year projects. Although the output from some of these studies was published in papers in scientific journals, a great deal of it was not. It has therefore been necessary to go back to the source material, i.e. the Ph.D. theses and B.Sc, project reports. These were accessed at the Harold Cohen Library of Liverpool University and at the School of Biology.

A list of the individual theses and reports examined is given below, together with brief synopses of their contents. However, material extracted from these various documents is used and referred to at relevant places in other parts of this report.

2. Ph.D. Theses.

Siddiqui, M.S. (1969) Studies on the brown trout, grayling and rudd of natural regulated waters and regulated reservoirs in North Wales.

Waters studied were Llyn Tegid, Llyn Celyn and Cefni Reservoir (Anglesey). Age, growth and diet of brown trout and grayling were studied in Llyn Tegid, of trout in Llyn Celyn, and of trout and grayling in the Cefni Reservoir.

Lees, P.R., (1972) The salmonid fish of the Dee and Clwyd. (N.B. Unpublished thesis, not available in Harold Cohen Library, can only be consulted in School of Biology)

This thesis includes a brief overview of distribution of spawning and rearing areas in the Dee catchment. It gives an analysis of readings of 2500 sets of salmon scales collected from salmon taken in the commercial nets during 1967 - 69. There are analyses of the distribution of rod catches of different sea ages of salmon between different beats and of the monthly distribution of catches by beat. Data are presented on growth rates of salmon parr and lengths and ages of smolts. An account is given of the history of the rod and net fisheries of the Dee, using mainly data drawn from the Dee and Clwyd Fishery Board/River Board Annual Reports. Some experimental work was carried out on survival of salmon ova planted out in various tributaries. Diets of salmon parr, trout and grayling in the Dee system were studied. There is a brief discussion of the implications of river regulation on the salmon and sea trout fishery.

Woolland, J.V.,(1972) Studies on salmonid fishes in Llyn Tegid and the Welsh Dee.

Most of this thesis deals with the biology of grayling in Llyn. Tegid and the upper River Dee as far down as Corwen.

Growth rates, diets, movements and population densities are covered. Studies were also carried out on movements, abundance and growth of juvenile salmon and trout in tributaries of Llyn Tegid, and on salmon smolts in the lake.

Cane, A., (1974) Some aspects of the ecology of the Alwen river system, North Wales.

Diet, movements, growth and population densities of juvenile salmon and trout were studied at sites on the rivers Fechan, Brenig and Alwen, with most work being concentrated in the upper portion of the catchment. Some sampling of the invertebrate benthos was also carried out.

(N.B. In his general discussion about the proposed regulation of flows in the River Alwen, Cane indicates that a flow of 2.3 cumecs at Pentre-llyn-Cymmer could start movement of small gravel, and suggests that releases should be restricted to this level to aid gravel stability. He also mentions that the Brenig Reservoir Order provides for "river improvements" in the Alwen down to the Ceirw junction so that higher flows can be contained. Were such works ever carried out, and if not could they be incorporated into the Agency's current plans?)

Rahim M.A. (1974) Biological investigations in the regulated, unregulated and polluted streams of the Dee watershed.

This study covered three topic areas:-
1) The ecology of the bottom fauna with reference to food and feeding habits of trout and salmon parr in five Llyn Tegid feeder streams (all unregulated)
2) The ecology of the bottom invertebrates of the regulated River Dee between Llyn Tegid and Corwen.
3) The ecology of the bottom fauna and biology of trout in the polluted River Alyn

Under topic 2) it was observed that Turbelleria, Hirudinea, Oligochaeta, Lamellibranchs, Amphipoda, Isopoda, Hydracarina, Megaloptera and Coleoptera were apparently favoured by the Dee regulation, whereas Gastropoda, Plecoptera, Hemiptera and Diptera were found relatively more in the Bala feeder streams. There seemed to be no effect of regulated versus unregulated conditions of the river on Ephemeroptera. There was a higher standing crop of invertebrates in the main river than in the unregulated tributaries, and this was attributed to the 'fixed substrate' and less physical disturbance in the former compared with the flooding and instability of the substrate prevalent in the unregulated tributaries.

Wilkinson, D. R. (1974) Studies on dace, *Leuciscus leuciscus* (L.) in three Welsh border streams.

The population dynamics of dace was studied on the Worthenbury, Emral and Wych Brooks between September 1970 and March 1973. Data were collected on the age structure, growth rates, sex ratios, mortality rates, population densities, biomass densities and fecundities of the dace populations. Large seasonal fluctuations in the densities, biomasses and age structures of the population were observed, and these were attributed to the shoaling behaviour of the species, the immigration of dace from the River Dee which may have been associated with periods of high water in both the Dee and the tributaries, and the probable spring migration of many mature dace into the Dee to spawn.

Laird, L. M. (1976) Growth and movements of juvenile Atlantic salmon and brown trout in the Afon Mynach.

Laird regarded the Mynach as being the major spawning and nursery area for salmon and trout in the Tryweryn system after the closing off of the upper reaches by the Llyn Celyn dam. The main focus of her study was on the growth rates and migrations of juvenile salmon and trout at six sites within the Mynach, using electric fishing as the sampling method. Population density estimates were also made at some of the sites on a number of occasions, and these data are quoted elsewhere in this report and compared with data from more recent surveys. Laird also gives a limited amount of data on the ages of salmon and sea trout smolts entrained at the Huntington intake, again quoted elsewhere in this report.

O'Hara, K.(1976) An ecological study of fishes, with particular reference to freshwater species, in the Welsh Dee at Chester.

This study concentrated on the tidal reach of the Dee, between Chester and Queensferry. A brief description is given of the hydrological and water quality conditions in the estuary at that time. Routine sampling of fish by seine netting at 13 sites between Chester Weir and Queensferry showed that most species of coarse fish were restricted to the area upstream of Saltney footbridge, but that dace were present for at least some of the time as far downstream as Queensferry, and were captured in salinities up to but not exceeding 11.2 parts per thousand. O'Hara concluded that dace were opportunistic, quickly exploiting areas offering only a temporary habitat during favourable conditions. The thesis includes data on general aspects of coarse fish biology, such as growth rates abundance and diet in the tidal reach and comments on the ecological implications of possible future environmental changes, particularly if a Dee barrage were to be built

Almukhtar, E.A. (1982) An ecological study of the Alwen river system, North Wales, with particular reference to the impoundment of the River Brenig.

This study was concerned with the possible impacts of the Brenig impoundment on the invertebrate benthos of the River Alwen in the period immediately following the completion of the reservoir scheme, but before its regular use for augmentation of River Dee flows began. A limited amount of data on the temperature regimes in the Alwen pre- and post-impoundment is also included which indicates that temperatures tended to be lower in summer and higher in winter after the impoundment. Impoverished conditions were found in the section of the Upper Alwen between the Alwen Reservoir and the confluence with the River Brenig which were attributed to intermittent low pH and dissolved oxygen levels in the compensation water from the reservoir and deposits of ochreous floc. Although there was evidence that the Brenig impoundment had allowed the Upper Alwen influence to extend more strongly into the main River Alwen, the overall conclusion was that at the time of the study in 1977/78 there was little evidence of faunistic change in the lower Alwen.

Weatherley, N. S. (1985) The feeding ecology of juvenile fish in a lowland river. The species covered by this study were the dace, roach and flounder, and effort was concentrated on determining their diets during the first year of life. The impact of regulation is considered briefly, and it is concluded that the four-fold increase in summer flows has degraded the ecosystem as far as juvenile cyprinids is concerned

Other Studies

The Reports of the Fishery Officer in the Annual Reports of the Dee and Clwyd River Authority indicate that other studies were being undertaken during the 1970's by G.N.Swinney and H.G.Pearce. Swinney worked on the ecology of the fish populations of the River Alwen during the period 1971 - 1974 and Pearce studied the lower Dee coarse fishery during 1978. Unfortunately these studies were not completed and no theses prepared, so it has not been possible to review this work.

3. B.Sc. Honours Project Reports.

Pritchard, R. (1973) Standing crop and movements of salmonids in the River Brenig system.

Sampling sites for this project were located in the upper part of the Brenig and in the Fechan, in the area now submerged within the Brenig reservoir. The study concentrated on movements of trout, but included some population density information for salmon which has been used in this APEM report to assess the potential productivity of this area as a rearing ground for stocked salmon fry.

Bregazzi, P.R. (1974) A survey of the fish populations of the R. Alwen, North Wales.

This study covered the 2 km length of the River Alwen between the Alwen Reservoir and the confluence with the River Brenig at Pentr-llyn-Cymmer. Data on population densities, growth rates and diets of trout and salmon parr are presented for five sites on the Alwen and one site on a minor side tributary. Fish densities were low, but growth rates of both trout and salmon parr were not particularly poor.

Howell, R.K. (1977) The ecology of the upper Afon Alwen.

This study again dealt with that part of the River Alwen between the Alwen Reservoir and the River Brenig confluence. Three sites were studied, and data are presented on fish population numbers (not densities), benthic invertebrates sampled by 5 minute kick samples, and iron content from water samples. Principal invertebrate groups present were Plecoptera, Trichoptera and Tricladida, but Ephemeroptera were absent.

Grundy, I.G. (1979) A study of the salmonid populations in the upper Alwen river system, N.Wales.

The study area for this project was actually the River Brenig, from Pont-yr-Rhuddfa falls down to the Alwen confluence. Four sites were studied, one of which corresponded to one of Cane's sites (Cane, 1974) and another to an NRA/Agency RJSMP site.

Grundy gives data on salmon parr and trout population densities, and these are quoted elsewhere in this APEM report and compared with more recent population density data. Grundy concluded that there had been no significant changes in the trout population numbers and growth rates since Cane's 1972 surveys, but that there had been a dramatic decrease in salmon numbers.

APPENDIX II

‘NATURALISED’ FLOW CALCULATIONS

Naturalised flows were derived from measured flows using the following equations.

a) Bala

Bala naturalised monthly flows are Bala monthly measured flows + or – the change in storage in Bala Lake and Celyn Reservoir over the month.

The daily flows are then derived from New Inn as follows:

$$\text{New Inn measured flows x } \frac{\text{Bala monthly natural totals}}{\text{New Inn monthly daily totals}}$$

* * *

b) Alwen Druid

Druid naturalised monthly flows are Druid monthly measured flows + or – the change in storage in Brenig Res + or – the change in storage in Alwen Res over the month + Alwen Abstraction.

The daily flows are derived as follows:

$$\text{(Druid dmf – Alwen dmf – Brenig dmf)) x } \frac{\text{Druid natural monthly totals}}{\text{(Druid nat mon – Bren nat mon – Alwen nat mon tot)}}$$

* * *

c) Chester Weir

The residual Naturalised monthly flows are:

The monthly flows measured at Ironbridge + monthly Poulton abstraction + the lower Dee monthly inflows + change in Bala Lake storage + change in Celyn storage + change in Brenig storage + change in Alwen storage + British Waterways Board canal abstraction + Alwen abstraction:

> (Ironbridge dmf + Poulton daily abstraction + daily inflows) + Avg 2 days prev. Bala diff + Avg 2 days prev. Bren diff)
>
> The above is then multiplied by the monthly natural totals and divided by the monthly totals of the above.
>
> (Bala diff = Bala natural daily flow – Bala measured daily flow)
>
> (Brennig diff = Brenig natural daily flow – Brenig measured daily flow)

APPENDIX III

THE MIGRATION OF ADULT ATLANTIC SALMON IN THE FRESHWATER REACHES OF THE RIVER DEE, BASED ON TRACKING STUDIES

(Summary of Draft Report by W. K. Purvis, 1996)

1. Objectives of the Study.

The specific objectives of this study were:-

i) to describe the migration patterns of adult salmon using radio-tracking;

ii) to investigate the influence of natural flows and artificial releases on upstream (in-river) migration;

iii) to describe patterns of spawning behaviour;

iv) to examine in-river exploitation and survival to spawning and provide information relating to the salmon stock in conjunction with the DSAP.

2. Materials and Methods.

Salmon greater than 50cm in length were used, taken from the Dee commercial nets or from the Chester trap. Some of the trap-caught fish were relocated to the estuary before release. Fish were anaesthetised with 2-phenoxyethanol (100ppm dissolved strength) before insertion of radio-transmitting tags into the stomach and external tagging with Floy tags. CART tags were used in the estuary and plain radio tags in freshwater. Twenty five automatic listening stations were deployed for passive tracking between Chester Weir and Llyn Tegid, and on the tributaries Ceiriog and Alwen. Precise locations between ALS's were determined by active tracking using hand-held radios, with spotter plane or boat runs used to get approximate positions.

Freshwater flow data and daily maximum and minimum water temperatures were derived from Manley Hall.

The river was divided into five reaches for the purposes of reporting, namely:-

i) Lower River; Chester Weir to Bangor-on-Dee, distance c.37km.

ii) Lower Middle River: Bangor-on-Dee to Erbistock Weir, distance c.12km.

iii) Middle River; Erbistock Weir to Newbridge, distance c.16km. (N.B. includes Manley Hall Gauging Weir)

iv) Upper Middle River; Newbridge to Glyndyfrdwy, distance c.21km.

v) Upper River; Glyndyfrdwy to Llyn Tegid, distance c.35km. (N.B. including the main spawning tributaries Alwen, Tryweryn, Ceidiog and Hirnant.)

3. Results.

a) The Study Period.

The study covered three years, from 1991 to 1993. Contrasting weather conditions produced variable river conditions in different years.

1991 had a relatively wet April and May period, followed by a dry summer, but with more typical flows later in the autumn. 1992 and 1993 had dry early springs, wetter summers with generally elevated flows, but then with depressed flows in relatively dry autumns followed by wet Decembers with above-average flows.

Over the 3 year period 150 natural freshets were recorded, comprising some 48% of the hydrograph. Of these freshets, 30% peaked at flows less than the long-term average daily flow (ADF) of 30.56 cumecs, and 68% peaked at less than twice their starting flow, typically only 1 to 1.5 times.

Two artificial releases took place, under the provisions for special fishery releases, during July and August 1991. These elevated flows by 3 cumecs and lasted for periods of 20 days and 26 days. A third fishery release was made in autumn of 1993, but this was swamped by a larger natural freshet.

b) Tagged Samples.

292 salmon were tagged in total between June 1991 and December 1993 (65 during 1991, 108 in 1992, and 119 during 1993). Based on their date of entry into the freshwater reaches of the Dee, fish were ascribed to one of three categories:-

i) **early entrants** (76 fish, 26% of total): fish entering the river before 1st July, typically excluding grilse.

ii) **summer entrants** (110 fish, 38%): fish entering freshwater during July and August, mostly grilse.

iii) **autumn entrants** (106 fish, 36%): fish entering during September to December, again mostly grilse.

c) Fates of Tagged Fish.

Five fish left the river prior to spawning. A minimum of 176 fish, possibly as many as 206, survived to spawn, giving an escapement in the range 61.3% to 71.8%. Overall exploitation rate by anglers was 13.1% (6.8% in 1991, 10.7% in 1992, and 18.9% in 1993). Highest exploitation rate was on early entrants (22.7%), followed by summer entrants (11.7%) and autumn entrants (6.1%). Median date of capture for early entrants was 9.47 days after release, with a secondary peak in exploitation during the autumn. Summer entrants were less susceptible to capture in the period immediately after entry to freshwater, and their median date of recapture was 46.77 days, but they again showed an increased susceptibility in autumn. The autumn group was only lightly exploited, but many of these entered after the end of the angling season.

The spatial distribution of rod and line captures showed no statistically significant differences, but some trends were apparent. Capture of early entrants showed a bi-modal distribution, with peaks in the lower middle river, particularly close to Erbistock Weir, and again in the upper reaches. Modal peak for capture of summer entrants was in the upper river, and none were taken in the Erbistock reach.

Early entrants moved further and more rapidly through the system than summer entrants, and were available to anglers in the upper reaches for longer.

Other "losses" of tagged fish were attributed to natural mortality of approximately 10% (but biased by a particularly high mortality in one batch of fish released in 1992), suspected poaching losses of about 11 fish (3.8%) and a tag regurgitation rate of about 8%.

d) Migration Patterns.

Three basic patterns of migration were observed:-

i) Continuous (initial) migration: fish reaching their ultimate spawning reach without any significant (>5day) delay in their upstream progress.

ii) Three-phase migration: rapid initial migration, then a lengthy "quiescent" stop (>15 days), usually in a deep run or pool, then a resumption of migration to the spawning reach with no further significant delay.

iii) Stepped migration: more than one quiescent stop prior to the spawning migration.

Three phase was the most common pattern (55.6% of all fish), with stepped migration the next most common (31.4%) and continuous migration the least common (13%). There were no significant differences between the three years. There was a greater tendency for stepped migration in early entrants (exhibited by 54% of this group) than amongst summer entrants (38%), with only 19% of autumn entrants showing this pattern. Three stage migration was the most typical of summer entrants (59%) and slightly less prevalent amongst autumn (55%) and early entrants (46%). No early and few (3%) of summer entrants undertook continuous migration, but this was common in autumn entrants (26%).

e) Initial Migration Period.

Fish typically migrated rapidly through the lower river, as far as the Clywedog junction, with a median ground speed of 39.8km per day, and 80% of fish exceeding 20km per day. Migration was slower through the Bangor-on-Dee reach, and median over-ground speed fell to 17.07km per day. In general, early entrants migrated more slowly than summer entrants during this initial phase, and tended to have more brief stops. However overall distances travelled in this phase by both groups were not significantly different (48 - 49km).

Brief delays occurred most commonly in the vicinity of Erbistock Weir for all entrant groups, with early entrants particularly likely to delay here (67% of recorded delays). Summer entrants more often delayed in the lower river than early fish.

Prolonged "quiescent" delays (>15 days) were observed in all reaches, but were most common in the middle river, with the modal reach for this type of delay being below Erbistock Weir.

70% of early fish stopped for quiescent periods in this reach, compared with 45% of summer entrants and 48% of autumn fish. However, summer and autumn entrants were more likely to have quiescent stops in the Bangor-on-Dee area of the lower river (30% and 32% respectively) than early fish (3%).

f) Secondary Migration.

This was typically much slower than the initial phase, and the median over-ground speed was 4.25km per day. About 5% of tracks showed oscillation, with substantial movement back downstream. This was most frequent during the autumn when fish were on their secondary migration.

g) Migration and Environmental Factors.

i) Water Temperature.

Migration appeared to be inhibited at higher temperatures and the median migration temperature of 12.37 degrees C. was significantly lower than the median available temperature of 14.3 degrees during the migration period. Migration was most often observed at temperatures of 7 - 9 degrees, and not at temperatures greater than 19 degrees.

ii) Freshwater Flow.

Comparison of freshwater flow at river entry and upstream quiescent location showed that differences in available flow had no significant influence on the magnitude of the initial migratory phase. Salmon were clearly able to migrate substantial distances upstream, even when the river was at or close to regulation flow. [illegible]

[illegible] = Glyndyfrdwy.

Median and maximum ground speeds through the lower river decreased as flows increased, and under low flow conditions (<20 cumecs) median lower river migration was significantly more rapid than during higher flows (>20 cumecs). In contrast, migration speeds through the middle reaches increased with increasing flow over the range 20 to 30 cumecs, and then reached a plateau. Apparently benefits afforded to rapid migration in this part of the river during elevated flows outweighed increased physical demands on swimming speeds at such times, in contrast to the lower reaches where the additional swimming requirements at higher flows seemed to impede migration speeds. In the upper river, median ground speeds under higher flows was significantly higher than during low flows.

Examination of the relationship between flow and the resumption of upstream migration of all tagged salmon revealed no significant linear relationship. However, when quiescent salmon (>15 days delay) were considered separately from those delayed for shorter periods, it was found that there was a greater likelihood of quiescent fish resuming migration as flows increased over the range 25 - 30 cumecs, with migration probability peaking at flows of the order of 80 cumecs. Flows in excess of this were less likely to stimulate migration.

In contrast to the quiescent fish, amongst those delayed only briefly, there was no obvious trend in increased likelihood to migrate with increasing freshwater flow.

iii) Diurnal Patterns of Migration

Entry to freshwater at Chester was random with respect to time of day, but with a tendency for movements to be clustered around midnight and mid-day. This pattern may have reflected timing of overtopping of the weir by spring tides, particularly during low river flow periods. There was no obvious preference for night time passage under low flow conditions.

In the lower river the overall pattern of upstream movement again was not associated with particular times of day, although under low flow conditions upstream movement was more likely to occur during the dawn to mid-day period, and at higher flows (>20 cumecs) movements were concentrated round the afternoon period.

In the middle river where the physical nature of the river alters dramatically and the habitat becomes predominantly pool and riffle, a change in diurnal patterns of migration was evident. At higher flows, movement was still random with respect to time of day. However at lower flows (<20 cumecs), peak activity occurred at night, with 67% of movements recorded between 21.00 and 03.00. Near Manley Hall, 80% of movements were recorded between 21.00 and 03.00. In this area, movement at higher flows was also less random, and some inhibition of movement was apparent during the late morning and noon period.

Many of the movements in the predominantly shallow upper river were recorded during the autumn, with the bulk of the summer entrants not reaching this part of the river until October. Movements in the upper river during low flow periods were typically concentrated in the hours of darkness, with 50% recorded between 21.00 and 03.00, although with a secondary peak around 05.00 to 07.00, particularly during the autumn.

iv) Effects of Natural Freshets.

57% of upstream migrations were initiated by freshets in 1991, 79% in 1972, and 72% in 1993. Success of freshets in moving fish was very variable. Freshets in September and during the peak spawning season were most effective, but were less effective in summer.

There appeared to be no overall significant association between freshet effectiveness and freshet peak flow. However, during the smallest freshets, migration probabilities were lowest but were significantly elevated at flows in excess of 20 cumecs and rose to a peak during freshets in the range 25 - 30 cumecs, decreasing subsequently. The impact of different peak flow/starting flow quotients (Q_{ps}) on probability of migration was also examined. Probability was lowest with low Q_{ps} values and was only 0.2 at Q_{ps} values between 1 and 2, but rose to twice this value during freshets when the peak flow was 4 to 5 times the start flow. At quotients in excess of this the probability subsided.

Some differences in the responses of salmon delayed for differing periods were observed. There was no difference in the response of short delay and quiescent fish to freshets in the 15 to 30 cumecs range. However, for the 30 to 40 cumec range, a greater proportion of short delay salmon tended to resume migration than of quiescent fish. When freshet flows reached 90 cumecs, the cumulative distribution curves for the two groups of fish converged again. This suggests that quiescent fish require larger freshets to stimulate resumption of upstream migration than short delayed fish. The median flow for quiescent salmon migration at 74.14 cumecs was significantly higher than the median flow for shorter delayed fish of 34.71 cumecs. In general, quiescent fish resumed migration in response to freshets. Salmon resuming migration after short delays were not necessarily responding to freshets. In 1993 there was an apparent increase in the threshold flow for movement amongst short delay fish in comparison with 1991 and 1992. It is suggested that this may have been a response to the generally higher flows prevailing in 1993.

During small freshets the greater proportion of movement took place during the rising arm of the freshet, whereas when peak flows were greater, upstream movements were more likely to occur within the "tail" of the freshet. Salmon either avoided or were physically prevented from making substantial upstream movement during large freshets, and resumption of migration occurred closer to the peak of smaller freshets than of larger.

v) Effects of Artificial Releases.

Two artificial releases were made from Llyn Tegid in July and August 1991, both of 3 cumecs and lasting for several days, and one of which was overtopped by two natural freshets. In general these were not effective at stimulating upstream migration, particularly amongst quiescent fish. These releases gave a freshet flow/base flow ratio of only 1.25, and were small in relation to natural freshets. Comparisons were made with natural freshets of the same magnitude occurring at the same time of year and it could no be demonstrated that these were any more effective in stimulating migration.

h) Spawning Behaviour.

Spawning in the main river was recorded from Bangor-on-Dee as far upstream as the reach below Bala sluices, but the modal spawning reach was in the upper river, between Llandderfel and Llyn Tegid. Relatively few fish (7%) were recorded spawning in reaches above Llyn Tegid. Tributaries were significant spawning was recorded were the Ceiriog, Alwen/Ceirw and Tryweryn/Mynach. Overall survival of tagged salmon through to the spawning period was 61.3%.

Salmon entering the Dee before July were more likely to spawn at the top of the catchment (62% in the uppermost reach, 150 - 175km above Chester weir) and none spawned in the lower reaches. Spawning of summer entrants was concentrated in the upper and upper middle reaches, but with about 18% spawning in the lower middle and lower Dee. 48% of late entrants (September onwards) spawned in the middle reaches and 26% in the lower reaches.

The spawning distribution of early entrants was not affected by river flows. With summer entrants, the median spawning distance upriver when entry flows were less than 20 cumecs was not significantly different from the median at flows greater than 20 cumecs.

However there was a slight tendency for the proportion of summer entrant salmon spawning in the lowermost reaches to reduce when flows in the post entry/pre-spawning period were higher (>32 cumecs average available flow). Spawning destinations of autumn entrant salmon did not appear to be affected by the river flows prevailing during the freshwater migration phase.

j) Erbistock Weir as an Obstruction.

Delays at Erbistock weir were typically short, but could be very prolonged. Fish were observed to cross without significant delay at regulation flow levels (11 cumecs), but generally fish were delayed for longer at low flows. Delays decreased rapidly as flows increased over the range 10 to 30 cumecs, and the probability of passage of delayed fish increased over this range, peaking at 30 cumecs. Probability of passage appeared to decline somewhat at higher flows, but in the range 30 - 75 cumecs was still significantly higher than at regulation flows.

The reasons behind failure to cross were not apparently related to environmental conditions, and there was no significant difference between flows available to fish which crossed and river flows during residence below the weir of salmon which failed to cross. No meaningful relationship could be found between weir passage and water temperature. Overall it was concluded that that the weir does not present a substantial obstruction to upstream migration.

During low flow periods (<20 cumecs) weir passage took place primarily during darkness, whereas at higher flows successful passage was not associated with any particular times of day.

k) Kelt Behaviour.

62% of salmon believed to have spawned survived in the short term, and 26% were believed to have emigrated successfully from the freshwater reaches (17% of the tracked population as a whole). There was no evidence of significant differences in short-term survival of kelts from different entrant groups, although more downstream movement in the post-spawning period was attributed to female fish. Emigration from the upper river typically commenced during freshets. There was some evidence of delays during downstream movement by some fish at Erbistock, Manley Hall and Chester Weirs, but others were not held up.

4. Discussion/Conclusions.

Spawning of early entrant multi-sea-winter salmon in the upper Dee is important, as local sub-catchment or tributary phenomena could have a disproportionate effect on this component of the stock. Partial spatial segregation of spawning amongst different stock components suggests a degree of reproductive isolation.

Survival of kelts to return as previous spawners is poor - 17% of the initial freshwater entrants left the river as kelts, but only 2% of the adult run into freshwater are previous spawners. There is also significant post-spawning mortality in the river. Kelt reconditioning may therefore be worthwhile on the Dee.

The reaches in which quiescence of grilse was observed was consistent, despite variations in available flows in different years.

Catchability of salmon rapidly decreased once quiescence began, and only increased again during increased activity in the autumn. All rod recaptures at Erbistock were within 11 days of arrival there.

Responses of quiescent salmon to summer freshets were mixed, and flows which would produce significant upstream migration in early autumn were of limited success in August. Salmon responded to smaller increases in flow during low flow periods, i.e. relative changes in flow seemed important. The variation in migration flow threshold values, depending on previous experience, physiological condition and time of year complicates consideration of appropriate MAF's

Upstream movements in autumn, often associated with movement into the spawning reach or tributary, were almost exclusively associated with increases in flow. Small freshets in late September and early October were particularly important in 1991, whereas similar magnitude freshets in August had been ignored.

Freshets during times of low flow are important in encouraging fish still in their initial migration phase to resume or continue their upstream migration. However, quiescent fish are less likely to be stimulated to move by smaller freshets, except in autumn. A 20 cumec freshet in late September 1991 stimulated migration in 13 fish, while a similar freshet in August only moved 2 fish.

Failure of artificial releases to stimulate upstream movement of quiescent fish may have been related to the type of discharge. These consisted of a level supplement over and above the regulation release over many days. Stepped releases to follow a normal freshet pattern may be more successful.

Catchability by angling was highest during the pre-quiescence phase, and fish making step-wise progression up river were more vulnerable to capture. More frequent freshets which prolong this phase and stimulate more fish to follow this pattern would be the most likely mechanism to increase the rod catch. Early entrant fish tend to have an extended initial migratory phase with a brief holding period (3 - 14 days) in the middle river when they are particularly vulnerable to capture, i.e. the catchable period for these fish is extended.