NATIONAL DEVELOPMENT PLAN

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Shannon International River Basin District Project

Freshwater Morphology POMS Study

Analysis of Irish Recovery Datasets

CENTRAL FISHERIES BOARD

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Foreword

This report was researched and written by Martin O'Grady and Ciara O'Leary with considerable assistance from Karen Delanty, Sandra Doyle and Brian Coughlan – all Central Fisheries Board employees.

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Summary

1. Available monitoring data bases in relation to the effectiveness of salmonid riverine enhancement programmes were digitised and subsequently statistically analysed.
2. Analysis indicate a number of definite trends:-

   a – Enhancement of small (basewidth <3m) spawning and nursery streams is very effective in relation to increasing their 1+ year-old trout carrying capacity. Data indicate that salmon rarely utilise these channels for spawning or nursery purposes.

   b – Enhancement programmes in larger (3m to 6m basewidth) channels are also very effective in relation to trout stocks. They are also beneficial to 1+ year-old salmon parr up to the springtime period of their second year. Data suggest that, subsequently, 1+ year-old salmon, in the summer of their second year, migrate downstream from these reaches into bigger channels.

   c - Analysis suggest that in enhanced streams where, either juvenile salmon or trout, were the dominant species present pre-works the same species remains dominant in the post-works phase.

   d – The enhancement of larger channels (>6m basewidth) is a successful process in relation to increasing standing crops of both 1+ year-old salmon and trout and adult trout.

   e - Poor water quality (Q3-4 for salmon parr and Q3 for trout) can negate the positive effects of stream enhancement.

   f - Data suggest that the enhancement of very small sub-catchments ($\leq 4.28km^2$) is relatively ineffective probably because of low Q values (volume discharges) in summertime.

   g - Restoration of the natural morphological form in channels can also enhance salmonid spawning opportunities, increase fish food production in certain circumstances and increase angling opportunities for trout and adult salmon.

3. Care is required to ensure that morphological alterations to drained rivers do not impact negatively on ecological aspects of the channel.

4. The data sets indicate that arterial drainage programme and any other activities which alter the natural morphology of channels are likely to impact negatively on salmonid stocks.

5. Recovery rates of salmonid stocks, post-enhancement, are fast. The capacity of smaller channels to support 1+ year-old salmon and/or trout usually increases very significantly only one year after works. Substantial increases in adult trout numbers have been recorded in as little as one year post-works. In most cases data suggest that adult trout populations will probably not reach optimum levels until *circa* 5 years post-enhancement.

6. The question of the effectiveness of individual enhancement measures in specific stream types is addressed.

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1. Introduction

The Central Fisheries Board was contracted to undertake specific elements within the Shannon International River Basin District Freshwater Morphology POMS Study (Work Package 2). The primary objective of this particular exercise was to provide evidence of the effectiveness of enhancement measures (instream and bankside) in arterially drained channels with a view to developing a framework for "best practice" in relation to river morphology adjustments. Sub-sets of the primary objective were to include:-

i - Assessing the effectiveness, in statistical terms, of salmonid riverine enhancement programmes in arterially drained channels.

ii - Using (i) above as a measure of the "minimum impact" of arterial drainage programmes on salmonid populations.

iii - Recommending best practice in specific circumstances.

The methodologies used in this analysis are outlined.

Results are presented for various categories of streams and these data are subsequently used to address the other objectives of the study.

2. Methodologies

Over the period 1995 to 2001 the Central and Regional Fisheries Boards carried out numerous salmonid riverine enhancement programmes in many parts of Ireland. These were funded through the Tourism Angling Measure (T.A.M.), a sub-set of the National Development Plan (1994-1999). Catchment wide baseline surveys were carried out initially to pin-point habitat degradation problems. Subsequently enhancement programmes were designed and implemented. Specific enhanced reaches in many channels were monitored, pre- and post-works, to look at the effectiveness of particular programmes. In relation to arterially drained channels enhancement programmes were carried out and monitored in a number of areas – Loughs Ennell and Sheelin (Shannon), the Lough Carra, Mask and Corrib streams (Corrib), Lough Arrow streams, (Ballisodare system), and channels in the Moy Catchment. Some historical data in relation to the enhancement of the main Boyne channel, Shanvaus River (Bonet) and the Rye (Liffey catchment) is also reviewed. All of the above channels, with the exception of the Lough Arrow streams, had been subjected to arterial drainage programmes by the Office of Public Works at some point between the 1950's and early 1980's. The Lough Arrow streams were also drained in a "piecemeal" fashion by local landownders over the last century. Not all rivers in all of these catchments were subjected to arterial drainage. Rivers which were not drained were excluded from this analysis.

No salmon or trout stocking programmes took place in any of these enhanced channels, except the Rye, prior to, during, after the completion of the works or while monitoring was in progress. In the case of the Rye the angling club introduced a small number of adult trout annually.

Monitoring the effectiveness of enhancement programmes in drained channels was carried out as follows:-

i - Reaches, which had all been drained, were selected and electro-fished prior to the implementation of the enhancement programme.

ii - One or more reaches, in every stream scheduled for enhancement, were purposely excluded from the enhancement programme. These undeveloped sections were subsequently known as control zones. All of the other selected reaches (Experimental zones) were subsequently enhanced. Generally speaking the control reach, or reaches, were the only sections not enhanced over many kilometres of stream length. Consequently, the enhanced reaches could not be regarded as "an oasis in a desert". On the contrary, the morphological and ecological conditions in the enhanced zones represented the "norm" in terms of stream condition in the post-enhancement phase.

iii - Control and experimental reaches were always ≥35m in length. In the larger channels they were often 200 to 300m in length. A critical length for an experimental or control reach was regarded as a reach length which should include at least one riffle / glide / pool sequence for the channel in question.

iv - Control and experimental reaches were refished annually at the same time of year as they had been fished prior to the implementation of the enhancement programme. With limited monitoring resources available (one or two monitoring crews) it meant that monitoring electro-fishing exercises had to be spread, temporally, from April through to September. Consequently, different data sets were not directly comparable. For example sites electro-fished annually in April, May or June would only provide data in relation to 1+ year-old and older fish – data on fry numbers were confined to sites sampled at some point between July and September.

v - Many sites were electro-fished repeatedly three times on each sampling location, to generate quantitative estimates of the stock density (after Zippin, 1958). At other locations only two fishing were carried out and estimates were calculated after Carle & Strub (1978). Sometimes only a single electro-fishing over the length of a site was completed because of gear failure or the onset of unsuitable weather conditions. Consequently it was decided to compare data sets using the first electro-fishing numbers generated at each site on each occasion – minimum density estimates (after Crisp *et al*, 1974). This approach had two advantages: it standardised and maximised the size of the data set thereby increasing the power of the statistical analysis.

vi - No two stream reaches are likely to be identical. In addition the overall stock density in any steam can vary significantly from year to year. Consequently, two null hypotheses had to be look at in the context of a statistical analysis. These null hypotheses were considered in relation to establishing, whether or not, the enhancement works had positive effects for salmonid stocks. These were:

a - Whether the fish numbers (for a particular year-class) at Experimental (enhanced) sites pre- and post-works were significantly different, or not.

b - Whether fish number (for a particular year-class) at Control (undeveloped) sites pre- and post-works were significantly different, or not.

c - If no significant differences were evident for & b above then a third hypothesis was examined – whether, or not, there were significant differences between the fish numbers in Experimental (enhanced) and Control (undeveloped) sites post-works. In these circumstances any such differences would only be significant statistically if the fish numbers in the Experimental and Control sites, pre-works, were not significantly different to begin with.

vii - The data was analysed in discrete batched:-

The Lough Ennell, Arrow, Carra and Mask and Sheelin data were all treated as discrete batches. All of these stream catchments support brown trout populations. There are no salmon stocks present in any of these areas.

In the case of the Moy channels two data sets were examined – channels ≤3m basewidth and channels with a 3 to 6m basewidth. The small Shanvaus data set (5 sites) was incorporated with the Moy 3 to 6m basewidth data set because it supports both salmon and trout and is, geographically, adjacent to the Moy catchment.

viii - The statistical analysis was carried out for spring and summer analysis separately if the data set was large enough. In cases where a dataset was too small an "all year" analysis was performed looking at the trout parr and salmon parr densities as the fry numbers would be distorted due to the lack of , or complete absence of, fry numbers in the spring data.

ix - The Corrib data set had already been statistically analysed (Gargan *et al*, 2002). The findings of this study are referenced in this documentation.

The data was transferred into SPSS v. 14.0 and examined. Examination of the data showed that the trout and salmon densities were not normally distributed. Log transformation of the trout densities resulted in a normal distribution however, all attempts to transform the salmon densities failed to normalise the data.

Due to non-normal distribution of the data non-parametric statistics were utilised on the data sets. In order to analyse the data using non-parametric statistics it is necessary to rank the data for each year-class of trout and juvenile salmon. Ranking consists of sorting the data into ascending order and then the lowest density value being given the rank of 1 and the next lowest density value being ranked as 2 and so on.

We then examined the densities and ranked data, to obtain values for the four variables (control pre, control post, experimental pre, experimental post) for each of the life stages e.g. Mean, Median, n, 95% confidence internals and standard errors were calculated.

A Kruskal-Wallis test was performed, examining the difference in densities of trout and salmon between Control pre, Control post, Experimental pre and Experimental post for each year-class. When a significant value is obtained for a life stage of trout or salmon a post-hoc test is performed in order to determine exactly where the different in density occurs, e.g. between which of the 4 variables. The Mann-Whitney test was used as a non-parametric post-hoc test. Firstly we examine the difference between experimental pre and post and control pre and post. If we did not find a significant value we then examine the difference between the experimental post-works and control post-works and the difference between the experimental pre-works and control pre-works. This latter test is very important. For example if fish figures, pre-enhancement, were evaluated in a wet summer and subsequently, post-enhancement, there were one or more drought summers the fish figures in he enhanced site could fall post-enhancement. A comparison of the pre- and post- enhancement data for Experimental and Control sites is crucial – i.e. in drought years the fish figures are likely to fall even more significantly in the Control site than the Experimental Zone.

3. Results

Data analysis are provided here in relation to individual batches of data.

3.1. <u>Lough Ennell Sub-Catchments</u>

3.1.1. Background Information

Lough Ennell is one of Ireland's premier wild brown trout fisheries. The adult trout population in the lake reproduce in a series of small sub-catchments which discharge directly to the lake.

These stream sub-catchments were drained in the 1970's. In 1996 funding became available to enhance these channels from a fishery viewpoint (O'Grady *et al*., 2002). The works programme involved:

i - A lowering and narrowing of channel basewidth back to pre-drainage basewidths.

ii - The excavation of a sinuous channel within broad canalised reaches using alternating stone deflectors.

iii - The construction of timber or stone weirs to recreate pool areas that had been lost.

iv - The reconstruction of banks using log/rock revetments (see O'Grady, 2006(a)) where bank trampling by cattle on sheep had occurred.

v - A loosening of gravel deposits where they were compacted.

vi - An extensive bank fencing programme to exclude stock. Drinking points were left along the channel for stock at the landowners request.

vii - No bankside tree planting programme was undertaken for two reasons – these were small channels, 2-4m basewidth. The Office of Public Works had not disturbed the riparian cover on one bank when draining the channels so they were not bereft of cover. It was felt that the growth of marginal herbaceous plants would provide adequate cover along these channels. There was also a concern that an extensive tree planting programme would lead to "tunnelling problems" (see O'Grady, 2006(a)) in less than 15 years post-works.

viii - The extent of the enhancement programme on each stream is illustrated (Appendix II, Figure 3. Headwater areas in all streams were excluded because many were not drained and others were known to dry up in summertime. The lower reaches of some streams (see Fig. 1) were also excluded from works because they were very low gradient channels (≤0.001%) many of which backwatered from the lake in winter time – pre-, or post-drainage, they could not be regarded as quality trout spawning or nursery areas.

3.1.2. The Monitoring Programme

A total of 31 reaches were selected for monitoring with all sites electro-fished once prior to the implementation of the enhancement programme. Subsequently four of these reaches, in the lower reaches of the Handstown stream were abandoned because of a pollution problem. Of the remaining 27 reaches, 17 were regarded as experimental zones – i.e. they were enhanced after the first electro-fishing exercise and the balance (10 reaches) were reserved as controls. The latter were excluded from the enhancement programme. Gradient values in the experimental and control zones varied from a minimum value of 0.09% to a maximum value of 1.7%. Most of the reaches had gradient values within the range 0.3% to 1.0%.

Post enhancement all experimental and control zones were electro-fished at least one year post works, while monitoring continued at other sites for up to 6 years annually. Most experimental and control site were refished annually, on average, for each of three years post enhancement.

3.1.3. Expectations and Findings

Given the artificially wide shallow nature of these channels pre-enhancement and the fact that the enhancement programme was designed to restore natural depth profiles and increase bank cover one would expect to see a decrease in fry numbers and an increase in the stream carrying capacity for 1+ year-old fish.

A Kruskal Wallis test was carried out for both trout fry and trout par across all four categories – i.e. Experimental reaches pre- and post-enhancement and Control reaches pre- and post-enhancement (Table 1).

Table 1. Kruskal Wallis test for Trout Fry and Parr: Experimental Code.

	Ranked Trout Fry	**Ranked Trout Parr**
Chi-square	3.345	11.964
Df	3	3
Asymp Sig.	0.341 ns	<0.05

The Kruskal Wallis test was not significant for the trout fry (p=0.341), but was significant for trout parr (p<0.05). To find out where the significance lay between the four categories (Control pre-works, Control post-works, Experimental pre-works and Experimental post-works) a Mann-Whitney Post hoc test was performed on the trout parr data. A bonferroni correction is applied to the significance value; the significance value (.05) is divided by the number of post hoc tests carried out on the data. In this case two post hoc tests are carried out and a significance value of $p<0.025$ is required.

Table 2. Mann-Whitney Post hoc test: Experimental post-works v Experimental pre-works for Trout Parr.

	Experimental	**Control**
	Ranked Trout Parr	**Ranked Trout Parr**
Median Exp. post-works	36.5	24.0
Median Exp. Pre-works	14.0	25.5
Mann-Whitney U	24,00	15.4
Z score	-3.744	-0.951
Effect Size r^2	-0.624	-0.218
Sig. (Bonferroni Correction p<0.025)	<.001	0.359 ns

Data indicate a highly significant difference in trout parr numbers ($p<0.001$) between the experimental reaches, pre- and post-works (0.359 ns) (Table 2). No such change was evident in the Control zone values pre- and post works.

In overall terms the estimated changes in the trout population in these streams post-enhancement involved a 46.4% reduction in fry standing crops and an 8.89 fold increase in 1+ year-old fish numbers (O'Grady *et al*., 2002).

O'Grady *et al* (2002) also illustrated that trout migrating from the Lough Ennell streams to the lake, as 1+ year-old fish, survived in far greater numbers than 0+ year-old migrants in the pre-enhancement era – i.e. scale samples from 398 adult trout captured in Lough Ennell from 1983 to 1992 indicated that they had migrated to the lake in a ratio of 1.35 1+ year-old fish to 1.0 0+ year-old fish. This was despite the fact that in 1995 (pre-enhancement) the ratio of 0+ to 1+ year-old fish in the streams was 22.3 : 1. One might expect therefore to see an increase in adult trout populations in Lough Ennell in the post-enhancement era (after 2001). This was the case (Table 3) (O'Grady, 2006(b)).

Table 3. Fluctuations in the adult trout stock in Lough Ennell over the period 1983 to 2006.

Year	**Trout C.P.U.E. Values**
1983	1.47
1984	1.93
1985	1.57
1992	2.68
1999	2.57
2002	4.0
2004	3.4
2006	4.1

A standard fish stock monitoring exercise (O'Grady, 1983) was used to carry out these surveys. C.P.U.E (Catch per Unit of Effort) values were generated by dividing the total number of trout caught in a particular survey by the number of survey net gangs fished. All surveys were carried out in March each year. Data indicate major increases in C.P.U.E. values from 2002 to 2006. The stream enhancement programme had been completed in 2001.

The Lough Ennell stream catchment enhancement programme is the most comprehensive data set which the Central Fisheries Board has compiled in this work area. It reflects the value of such exercises particularly well because the changes post-enhancement are evident from the juvenile fish stages in the streams through to the "final product" – the adult fish numbers in the lake.

3.2. The Lough Sheelin Programme

Lough Sheelin like Lough Ennell, is another lake trout fishery in the upper Shannon River Basin. The Lough Sheelin stream catchments were also subject to an arterial drainage programme in the late 1970's.

3.2.1. Background Information

Not all streams in the Lough Sheelin sub-catchments were drained. The stream enhancement programme was confined to drained stream reaches (Appendix II, Fig. 6) – zones in a total of 13 tributary streams were enhanced.

The nature of the enhancement programme was very similar to that already described for the Lough Ennell stream sub-catchments. This was essentially because these channels were similar or smaller than the Ennell streams in terms of basewidth and streams gradient and had, largely, the same suite of problems. Gradient values for stream reaches monitored varied between 0.1% and 0.7% with the exception of one site in the middle reaches of the upper Inny channel with a gradient value of 2.7%. The only additional instream techniques employed in the Lough Sheelin streams, compared to Ennell channels, were the construction of vortex stone weirs in the lower reaches of the Mount Nugent where channel basewidths were 4.5m to 5.5m and rubble mats in the middle reaches of the upper Inny where the gradient was very steep (2.7%). These alternate structures were used simply to ensure a high stability of structure post-works. Both type of structures were used to maintain newly excavated pool areas.

Of the 13 streams enhanced in the Lough Sheelin sub-catchments 7 were significantly smaller than the Lough Ennell sub-catchments (Table 9). Channel basewidths in the latter streams, even in their lower reaches, ranged from 0.5m to 1.0m. This group of channels will subsequently be referred to as "the smaller L. Sheelin sub-catchments" in this document.

There is no atlantic salmon population in this catchment.

3.2.2. Expectations and Findings

Expectations were that the enhancement programmes would result in similar changes to 0+ and 1+ year-old trout stocks as were observed in the Lough Ennell sub-catchment i.e. some decline in fry production and an increase in the numbers of 1+ year-old fish.

A total of 33 reaches were electro-fished pre- and post-works – 17 experimental and 16 control zones. There were at least one control and one experimental reach in each stream sub-catchment. All of these sites were electro-fished pre-works in either 1998 or 1999. Subsequently all sites were electro-fished at least one year post-works and in a few cases up to four years post-works. On average most reaches were refished annually, at the same time, on 2 to 3 occasions. Some of these data were compiled for sites in springtime (11) in which case no fry data was available.

A slightly different approach was taken to a statistical analysis here because we were dealing with a smaller number of sites than in the L. Ennell study.

Firstly a Kruskal Wallis test was carried out on the entire data set (33 spring and summer sites) in relation to trout parr. The result was not significant ($p = 0.073$) (Table 4).

	Ranked Trout Parr
Chi-square	6.970
Df	3
Asymp Sig.	0.073 ns

Table 4. Results of a Kruskal Wallis test for the entire Lough Sheelin stream data set in relation to trout parr.

Secondly Kruskal Wallis tests were performed in relation to trout fry and trout parr data at all sites monitored in summertime – a total of 22 reaches of which 11 were Experimental zones and 11 were Control reaches. Again the results were not significant in relation to either the fry ($p = 0.985$) or parr ($p = 0.763$) groups (Table 5).

	Ranked Trout Fry	**Ranked Trout Parr**
Chi-square	0.153	1.158
Df	3	3
Asymp Sig.	0.985	0.763 ns

Table 5. Results of a Kruskal Wallis test for trout fry and parr all Sheelin tributary site monitored in summertime.

A third Kruskal Wallis test was performed for trout parr in relation to experimental and control sites in the five largest sub-catchments in the Lough Sheelin data set – Millbrook, Finnaway, Upper Inny and Mount Nugent Rivers (Table 6). This included 14 sites of which 7 were Controls and 7 were Experimental zones in the 5 tributaries.

	Ranked Trout Parr
Chi-square	10.036
Df	3
Asymp Sig.	<0.05

Table 6. Results of a Kruskal Wallis test for trout parr in the five largest L. Sheelin sub-catchments.

A significant difference ($p<0.05$) was evident in this case in relation to trout parr. The nature of this significance was established by carrying out two Mann-Whitney post hoc tests.

The first of these tests for trout parr compared the Experimental zone pre-works and Experimental post-works data and the Control reach pre- and post-works data. No significant difference was evident in either case (Table 7).

Ranked Trout Parr	Experimental	Control
Median post-works	32.0	19.25
Median pre-works	10.5	11.5
Mann-Whitney U	13.0	43.5
Wilcoxon W	23.0	64.5
Z score	-1.7	-0.700
Effect Size r^2	-0.390	-0.143
Sig. (Bonferroni Correction p<0.0125)	0.089 ns	0.484 ns

Table 7. Mann-Whitney post hoc tests for trout parr numbers in which the Experimental pre-and post-works data sets and the Control pre-and post-works data sets compared.

A second pair of Mann-Whitney post hoc tests were carried out here. Both the Experimental and Control zone pre-works figures were compared and the Experimental post-works and Control post-works were analysed. These tests indicated no significant different (p=0.831) between the Experimental and Control zone figures at the pre-works phase. However, there was a significant difference (p<0.0125) between the Experimental Control data bases for the post-works data indicating that the enhancement programme had a positive effect in relation to trout parr populations (Table 8).

Ranked Trout Parr	Post-Works	Pre-Works
Median Experimental	32.0	10.5
Median Control	19.25	11.5
Mann-Whitney U	59.5	11.0
Z score	-2.730	-0.213
Effect Size r^2	-0.475	-0.067
Sig. (Bonferroni Correction p<0.0125)	<0.0125	0.831 ns

Table 8. Mann-Whitney post hoc tests in which the trout parr numbers in the Experimental and Control zones in both the pre-works and post works era are compared.

A similar test for fry numbers was not possible because of the small data set. However, given the decline in fry numbers in the Lough Ennell data set, post-enhancement, it is likely that a similar trend took place in the Lough Sheelin streams – reduced standing crops of fry post enhancement.

A failure to record any significant increase in fish numbers in the 7 "smaller L. Sheelin sub-catchments" does not necessarily imply that the enhancement programme was entirely unsuccessful – many fry may have migrated downstream to the lake or, into larger channels during low summer flow periods. However, in the absence of fish trap data one can only speculate in relation to this issue.

The data set for these "smaller L. Sheelin sub-catchments" is of significance in terms of long term planning nationally. It suggests that very small drainages, with low summer Q values should not be prioritised in relation to large scale catchment wide enhancement programmes. A table is provided here to show the approximate size of all of the sub-catchments in Lough Sheelin.

Sub Catchment	**Drainage Area (km^2)**
Crover	2.62
Maghera	2.75
Rassan	4.28
Carrick	2.44
Summerbank	1.33
Millbrook	27.60
Finnaway	4.36
Upper Inny	69.7
Mount Nugent	27.6

Table 9. The approximate drainage areas for the individual enhanced streams in the Lough Sheelin Catchment upstream of enhanced zones.

3.2.3. The Lough Sheelin Lake Trout Population

O'Grady (unpublished) has been monitoring the status of fish stocks in Lough Sheelin, annually, since 1978. Following the completion of the stream enhancement programme an increase was noted in the trout standing crop in Lough Sheelin. However, ecologically Lough Sheelin, unlike Lough Ennell, is in such a "state of flux" that increases in the lake trout population are not necessarily attributable to a successful stream enhancement programme. Lough Sheelin has outstanding cultural eutrophication problems since the early 1980's. A non-indigenous fish species (roach) was introduced some twenty years ago – stocks of this fish have fluctuated widely since its introduction. In addition, a zebra mussel population introduced, *circa* 2000, has thrived and further destabilised the lakes ecology.

3.3. The Lough Arrow Enhancement Programme

3.3.1. Background

Lough Arrow, a prime wild brown trout fishery, is located in the upper reaches of the Ballisodare River Catchment in Co. Sligo. All of the tributaries to the lake were subjected to drainage programmes by individual landowners over the last century.

A stream enhancement programme was undertaken on the four main tributaries to the lake and on a kilometre long section of the Kilmorgan Stream which discharges to the Unshin River downstream of Lough Arrow (Appendix II, Fig. 7). Adult lake trout from Lough Arrow were known to spawn in the latter channel. There were no atlantic salmon populations in any of these sub-catchments. The entire length of each of four streams discharging to Lough Arrow, accessible to lake trout, were enhanced (except for control zones). This mean that the upper reaches of two tributaries, the Ballinafad and Douglas stream were excluded – both channels have a lengthy sub-terranean passage in their middle reaches which are impassable to lake trout.

3.3.2. Nature of the Enhancement Programme

Essentially the works programme here was very similar to that already described for the Lough Ennell programme. The enhancement programme in the Lough Arrow streams differed from the other schemes in that weir construction was confined principally to stone structures. The Lough Arrow programme was the last major enhancement exercises to be undertaken under the Tourism Angling Measure Programme – at this point there was a realisation of stone weirs were as effective as timber structure in terms of maintaining pool areas and cost less to build.

3.3.3. The Monitoring Programme

A total of 17 reaches were monitored in the five sub-catchments pre- and post-works – 10 were experimental sites and 7 were control zones. There were a minimum of one experimental and one control reach in all five streams. All sites were electro-fished for a minimum of one year pre- and one year post-works. Most were refished, annually, over a two or three year period. The maximum number of monitoring occasions, post-works, was over a four year period. All monitoring events took place in summertime so that fry and parr figures are available for all sites. Each location was refished at the same time each year.

Most of the zones monitored were in very small streams with basewidths varying from 1.0 to 1.5m. Only sites in the Ballinafad and Kilmorgon Rivers were bigger channels where basewidths were ~3.5m. The gradients in the 17 reaches monitored ranged from a minimum value of 0.024% to a maximum of 1.147%. The gradient at a majority of sites was between 0.188% and 0.548%.

3.3.4. Expectations and Results

Post-enhancement one would hope to see increases in fry numbers and some expansion in parr populations. Analysis indicate that this was the case.

An initial Kruskal Wallis test for trout fry and trout parr indicated significant change (<0.05 in both cases) pre- and post-works (Table 10).

	Ranked Trout Fry	Ranked Trout Parr
Chi-square	14.834	10.137
Df	3	3
Assymp Sig.	<0.05	<0.05

Table 10. The initial Kruskal Wallis test for the Lough Arrow fish figures in Experimental and Central stream reaches pre- and post-works.

Subsequent Mann-Whitney post hoc tests indicated the nature of the changes. A comparison of the Experimental zones pre-works and post-works figures for trout fry and a second comparison of the Control reaches pre- and post-works figures for trout fry indicated no significant change in either test (Table 11) (0.629 and 0.385) respectively.

	Experimental	Control
Ranked Trout Fry	37.0	11.75
Median post-works	34.0	15.0
Mann-Whitney U	68.0	29.5
z score	-0.483	-0.868
Effect Size r^2	-0.085	-0.189
Sig. (Bonferroni Correction p<0.0125)	0.629 ns	0.385 ns

Table 11. Results of Mann-Whitney post hoc tests comparing trout fry numbers for the Experimental zones pre- and post-works and also the Central reaches pre- and post-works.

A Mann-Whitney post hoc test comparing the trout fry figures for the Experimental pre-works and Control pre-works data indicated no significant difference (0.044) (Table 11). However, a final Mann-Whitney post hoc test comparing trout fry figures for the Experimental and Control reaches post-works were significantly different ($p<0.001$).

This illustrates improved trout fry stocks in the experimental zones post-enhancement compared to the control zones (Table 12).

Ranked Trout Fry	Post-Works	Pre-Works
Median Experimental	37.0	34.0
Median Control	11.75	15.0
Mann-Whitney U	79.5	4.0
z score	-3.328	-2.013
Effect Size r^2	-0.513	-0.607
Sig. (Bonferroni Correction p<0.0125)	<0.001	0.044 ns

Table 12. Results of Mann Whitney post hoc tests comparing trout fry numbers in the Experimental and Control zones pre-works and also for the Experimental and Control zones post-works.

The trout parr data for the Lough Arrow monitoring sites were subject to the same Mann-Whitney tests as have been outlined above for the trout fry numbers (Tables 13 and 14). The same result was evident ($p<0.0125$) – trout parr numbers increased significantly post-works in the Experimental zones relative to the Control areas. The level of significance was lower in relation to the parr figures compared to fry value. This is not surprising given the small size of many of the channels in question.

Ranked Trout Fry	Experimental	Control
Median post-works	26.0	12.0
Median pre-works	10.75	11.0*
Mann-Whitney U	15.5	4.0
z score	-2.183	-0.174
Effect Size r^2	-0.405	-0.055
Sig. (Bonferroni Correction p<0.0125)	0.029 ns	0.862 ns

Table 13. Results of Mann-Whitney post hoc tests comparing trout parr numbers for the Experimental zones pre- and post-works and also the Control zones pre- and post-works.

Ranked Trout Fry	Post-Works	Pre-Works
Median Experimental	26.0	10.75
Median Control	12.0	11.0
Mann-Whitney U	47.5	2.0
z score	-2.538	.000
Effect Size r^2	-0.435	0
Sig. (Bonferroni Correction p<0.0125)	<0.0125	1.0 ns

Table 14. Results of Mann-Whitney post hoc tests comparing trout parr figures for Experimental and Control zones pre-works and also Experimental and Control zones post-works.

3.3.5. Fluctuations in the Lough Arrow Lake Trout Population

Monitoring data is available for the Lough Arrow lake trout population for some individual years before and after the stream enhancement programme was completed (O'Grady, unpublished data). While an increase was evident in the lakes trout population following the completion of the enhancement programme an infestation of zebra mussels took place at the same time (post 2000). The authors are reluctant to draw any conclusions in relation to fluctuations in the lake trout population because of this major ecological change.

3.4. The Moy Catchment

3.4.1. Background Information

The Moy is one of Ireland's larger salmonid catchments. Taken in its entirety, from a salmonid perspective, it is a complex resource. There are substantial brown trout populations in two of its larger lakes, Conn and Cullin. There are resident brown trout stocks in some of its larger rivers and a sea trout population. Currently the extent to which these individual trout stocks mix, or not, at spawning time is unknown.

The Moy Catchment also supports a mixed salmon stock – spring fish, summer salmon and grilse with the latter group being numerically dominant. Like the trout, the distribution of these groups in spawning and nursery terms is not yet clearly defined.

The two major lakes in the system Lough Conn and Cullen have been ecologically unstable for some time (O'Grady, internal reports). A large Char population in Lough Conn had become extinct by 1990. Fish stocks surveys of Lough Conn, carried out at intervals form 1978 to 2006, indicated the presence of a very large population of relatively small (≤30cm) adult trout in this water up to 1990. Thereafter, and to date, a major reduction in trout stock densities was evident and the surviving adult trout are now growing to a larger average size with many 40cm to 50cm fish in the population. Further instability was evident in these waters from 2001 onwards when very large rudd and roach population became established in Loughs Conn and Cullin (O'Grady, internal reports). These changes in fish stocks took place against a backdrop of cultural eutrophication problems in both lakes. Further ecological instability was evident on these waters in 2006 where a zebra mussel population was noted in Lough Conn for the first time.

The Moy Catchment was arterially drained by the Office of Public Works in the 1960's. This was a systematic and comprehensive scheme involving the drainage of all sub-catchments except for some headwater reaches.

3.4.2. The Enhancement Programme

A fishery baseline survey of the Moy Catchment was undertaken 1993-1994 (O'Grady, 1994). One objective of this exercise was to identify morphological imbalances in channels in the catchment caused by drainage and other land management practices. Thereafter a major enhancement programme was undertaken in specific reaches across the catchment from 1996 to 2000.

Given the complexity of the salmonid stocks in this catchment, as outlined above, there was no agenda in relation to trying to enhance a particular type/strain of salmon or trout. The modus operandi, in terms of designing the enhancement programme, was simply to identify morphologically damaged reaches in the catchment which might be enhanced, at reasonable cost and, thereafter, allow nature to decide on the balance of fish stocks in individual channels.

A very wide range of habitat enhancement techniques were employed in the Moy programme. Virtually all of the techniques outlined in O'Grady (2006(a)) were employed at one or more locations in the catchment. Given the wide variety of channel types involved techniques employed varied considerably from one channel to another. The range of techniques employed in individual sub-groups are described below.

3.4.3. The Monitoring Programme

Because of wide range of channel type a statistical analysis of the monitoring data is only really meaningful if the data are divided into discrete categories in relation to channel basewidths. Three categories of channels were established – those with ≤3m basewidth, 3-6m basewidth and >6m basewidth.

3.4.3.1. Moy Experimental and Control Zones for Channel Basewidths <3m basewidth (Spring data only)

The programme of enhancement in these small channels included lengthy fencing programmes. Instream works included the construction of timber and stone weirs, log/rock and log/Xmas tree bank revetments, the provision of additional spawning gravels and the placement of random boulders.

A total of 23 reaches (14 experimental and 9 controls) were monitored pre- and post-works. A minimum of one pre- and one post-works electro-fishing exercises were carried out at each site. A maximum of five annual electro-fishing exercises were carried out. Most zones, in both categories (experimental and control), were monitored annually, post works on three occasions. All of these data were compiled in spring time each year between 1995 and 2001. Consequently no data are available in relation to salmonid fry (0+ year-old) numbers.

The gradients in these reaches varied over the range 0.17% to 1.33%. Gradients in most zones lay in the range 0.4% to 0.8%.

A Kruskal Wallis test indicated significant change (p<0.001) in the ranked trout parr data and no significant change in the ranked salmon parr values (p<0.0531) (Table 15).

	Ranked Trout Parr	Ranked Salmon Parr
Chi-Square	16.618	2.207
Df	3	3
Asymp Sig.	<0.001	0.531 ns

Table 15. Results of a Kruskal Wallis test for ranked trout parr and salmon parr data from 23 sites in six Moy tributaries with basewidths <3m.

A subsequent Mann-Whitney post hoc test indicated very significant increases in trout parr numbers in the experimental (enhanced) zones post-works compared to pre-works (p<0.001). No significant change was evident in the trout parr figures in control zones in the pre-, compared to the post-works era (p<0.419). Consequently one can assume that the enhancement programme was positive in relation to trout parr (Table 16).

Ranked Trout Fry	**Experimental**	**Control**
Median Exp. post-works	63.0	48.5
Median Exp. Pre-works	17.5	33.5
Mann-Whitney U	110.50	89.50
z score	-3.422	-0.824
Effect Size r^2	-0.431	-0.132
Sig. (Bonferroni Correction p<0.025)	<0.001	0.419

Table 16. Results of Mann-Whitney post hoc tests comparing trout parr numbers in both the Experimental Zones pre- and post-works and also the Control reaches pre- and post-works.

The fact that there was no significant increase in salmon parr numbers in these streams is important. Staff carrying out annual redd counts in the Moy stream catchments have rarely seen salmon spawning in most channels with basewidths of <3m. The minimum density estimates for salmon parr in these reaches (pre- and post-works) ranged from 0.004 to $0.27/m^2$ with a mean (x) value of $0.079/m^2$. It is likely that those salmon parr had moved upstream from larger channels where there were substantial salmon parr stocks. A number of small <3m streams in Moy, not included in this series, were found to support small salmon parr numbers but no salmon fry in summertime.

The results of this particular study are important in that they illustrate that, in what are essentially trout spawning and nursery streams and marginal salmon habitat, the beneficiary of the enhancement programme was the dominant species present prior to works. There were two exceptions to this trend within the stream category with basewidths <3m.

Salmon were the dominant salmonid species in only two of these (<3m) sub-catchments pre-enhancement – a tributary of the Owengarve River and the Castlehill Stream. A separate analysis of the fish data compiled for these two channels is of interest. The data set for these two streams included 7 reaches of which 2 were Control zones and 5 were Experimental reaches. There was one Control zone in each stream. There were relatively high gradient drained channels. Mean (x) values across all reaches in the Castlehill were 0.83% and the comparable value for the Owengarve tributary was 0.67%. Enhancement programmes were identical in both channels involving bank revetment works (log/Xmas tree) on excessively eroding banks and fencing programmes. No instream works were carried out.

The Kruskal Wallis tests for ranked salmon parr and trout parr values was significant (p<0.001) for salmon parr but not for trout parr (Table 17).

	Ranked Salmon Parr	Ranked Trout Parr
Chi-square	19.309	7.622
Df	3	3
Asymp Sig.	<0.001	P=0.054

Table 17. Kruskal Wallis tests for ranked salmon parr and trout parr data sets from the Castlehill stream and Owengarve tributary.

Mean-Whitney post hoc tests for the salmon parr figures indicate significant ($p<0.001$) increases in the Experimental zones following enhancement. No significant changes are evident in the Control reaches when pre- and post-works data sets are compared (Table 18).

Ranked Trout Fry	**Experimental**	**Control**
Median post-works	27.0	19.0
Median Pre-works	7.0	5.5
Mann-Whitney U	5.0	3.0
z score	-3.347	-2.404
Effect Size r^2	-0.656	-0.642
Sig. (Bonferroni Correction p<0.0125)	<0.001	0.016 ns

Table 18. Results of Mann-Whitney post hoc tests in which the salmon parr denotes in both the Experimental zones pre- and post-works are compared and also in the Control reaches pre- and post-works.

These data are interesting. They suggest, yet again, that the dominant fish species in a stream, pre-works, will be the main beneficiary of an enhancement programme.

3.4.3.2. Moy Experimental and Control Zones for Channel Basewidths of 3m to 6m (Spring Data)

3.4.3.2.1. Background Information

A total of 11 sites (5 experimental and 6 control zones) were monitored in three tributaries – the Deel, Mulaghanoe and Clonlea Rivers. These were relatively high gradient spate channels where enhancement involved the construction of bank revetments (both rip rap and log/xmas), bank fencing and tree planting programmes and the placement of random boulders in the channel. Gradient values in these reaches were relatively high by Moy Catchment standards – max. and min. gradient values of 2.8% and 0.61% were calculated respectively with a mean value of 0.96%. These three channels were regarded by local staff as significant salmon spawning areas. No enhancement works were carried out in the Clonlea stream. All sites here were regarded as control zones.

A minimum of one year's data pre-works was compiled at all locations. Post-works a minimum of two years and a maximum of six years information was compiled for each reach - a mean (x) of three years post-works data per zone.

Two Mann-Whitney post-hoc tests were carried out in which the Experimental pre-works and Control pre-works salmon parr data were compared. No significant difference ($p = 0.400$) was evident for the Experimental pre-works and Control pre-works data sets. A significant difference ($p < 0.0125$) was evident in relation to the post-works data sets reflecting increased salmon parr numbers in enhanced areas post-works (Table 19).

Ranked Salmon Parr	**Post-Works**	**Pre-Works**
Median Experimental	30.0	15.0
Median Control	15.0	32.0
Mann-Whitney U	53.5	1.0
z score	-2.790	-1.155
Effect Size r^2	0.471	-0.516
Sig. (Bonferroni Correction P<0.0125)	<0.0125	0.400 ns

Table 19. Two Mann-Whitney post-hoc tests comparing salmon parr data for both the Experimental and Control zones pre-works and the Experimental and Control zones post-works.

These data reflect the pattern observed in the small (<3m) Moy category streams in that the dominant salmonid present in the reaches pre-works (salmon parr) is the main beneficiary post-enhancement – i.e. the mean (x) minimum density estimate value for all of these sites across the pre – and post – works period was $0.259/m^2$. The trout parr figure, in contrast, was only $0.061/m^2$.

3.4.3.3. Moy Experimental and Control Zones for Channel Basewidths of 3m to 6m (Summer Data)

3.4.3.3.1. Background Information

A small additional data base from the Shanvaus River, a tributary to the Bonet, was added to this Moy data base. This drained stream was in the same size category as these Moy streams. Like the relevant Moy channels it supported both juvenile salmon and trout populations. The Bonet catchment, geographically is adjacent to the Moy system.

Data from a total of ten rivers are included here involving a total of 35 monitored zones – 12 control and 23 experimental reaches. There were, at least, one control and one experimental reach in each river. All reaches were monitored at least once pre-enhancement. Post works monitoring continued annually, for a maximum of six years after works – most reaches were monitored in each of the first three years post-enhancement. The mean (x) stream gradient value for these reaches was 0.64% with individual values ranging from 0.12% up to a maximum of 1.58%.

3.4.3.3.2. The Trout Data

Kruskal Wallis tests for both the ranked trout fry and trout parr data were both significant ($p < 0.05$ in both cases) (Table 20).

	Ranked Trout Fry	Ranked Trout Parr
Chi-square	11.662	8.312
Df	3	3
Asymp Sig.	P<0.05	P<0.05

Table 20. Kruskal Wallis tests for ranked trout fry and trout parr.

Mann-Whitney post hoc tests for trout fry compared the densities in Experimental zones pre- and post works and the densities in the Control reaches pre and post works (Table 21). These data indicate no significant change in the fry densities in either the experimental ($p = 0.414$) or control zones ($p = 0.193$) when comparing the pre- and post-works data sets.

Ranked Trout Fry	Experimental	Control
Median post-works	7.1	43.5
Median pre-works	64.5	31.75
Mann-Whitney U	439.5	166.0
z score	-0.818	-1.302
Effect Size r^2	-0.096	-0.186
Sig. (Bonferroni Correction p<0.0125)	0.414 ns	0.193 ns

Table 21. Two Mann-Whitney post-hoc tests comparing trout fry data in the Experimental zones pre- and post-works and also in the Control reaches pre- and post-works.

Additional Mann-Whitney tests for trout parr densities suggest significant ($p < 0.0125$) increase in the number of these fish in the enhanced areas post-works – the parr densities in the Experimental and Control zones, pre-works, were not significantly different ($p = 0.071$) while parr figures in the experimental and control reaches, post-works, were significantly different ($p < 0.0125$) with the fish figures being higher in the experimental zones (Table 22).

Ranked Trout Fry	Post-Works	Pre-Works
Median Experimental	71.0	64.5
Median Control	43.5	31.75
Mann-Whitney U	656.0	69.5
Z score	-2.661	-1.806
Effect Size r^2	-0.280	-0.324
Sig. (Bonferroni Correction p<0.0125)	<0.0125	0.071 ns

Table 22. Two Mann-Whitney post hoc tests comparing trout parr densities in the Experimental and Control reaches pre-works and also comparing the parr densities in the Experimental and Control reaches in the post-works data base.

3.4.3.3.3. The Juvenile Salmon Data

Kruskal Wallis tests for the salmon fry and salmon parr data suggest no difference in densities in the Experimental and Control zone data sets (Table 23).

	Ranked Salmon Fry	Ranked Salmon Parr
Chi-squared	3.084	1.314
Df	3	3
Asymp Sig.	0.379 ns	0.726 ns

Table 23. Kruskal Wallis tests for both the ranked salmon fry and salmon parr data.

These data suggest that the enhancement programmes have not, as one might expect, lead to increases in salmon fry stocks. The fact that salmon parr densities in this data set in summer (July to September), have not increased is in contrast to the Spring (March/April) data set compiled for streams of the same size in other parts of the Moy Catchment. In this latter data set significant increases in salmon parr numbers were evident post-enhancement. This apparent anomaly is a consequence of the salmon parr behavioural pattern. The known salmon spawning sites in the Moy Catchment are illustrated in Appendix II, Fig. 8. These data indicate that there are very few spawning locations in the main stem. Yet, a baseline survey of the Moy (O'Grady, 1994) indicated that the upper and middle reaches of the main stem (from Foxford upstream) supported the third highest salmon fry population and the second highest salmon parr population of any subcatchment in the Moy. This reflects a very high mobility in the juvenile salmon stock with both fry and parr emigrating from tributary sub-catchments to the main stem. The migration of parr from the tributaries to the main stem may be a part of their "presmolt behavioural pattern". This is suggested by the fact that trout parr remained in these streams over the summer period in significant numbers.

3.5. The Lough Carra/Mask Data Set

3.5.1. Background Information

Lough Carra and Mask are sub-catchments within the Lough Corrib catchment. They are treated here as a separate data set because brown trout are the only salmonid species present in system – the outfall from Lough Mask to Lough Corrib is partly subterranean in nature and prevents atlantic salmon access upstream to the Carra/Mask subcatchments.

All of the Lough Carra and many of the Lough Mask sub-catchments were arterially drained in the 1980's. The monitoring data presented here relate solely to enhanced drained stream reaches. The nature of the enhancement programme in these streams was similar to that already described for the Lough Ennell stream sub-catchments – excavation of a thalweg, bank revetments and weirs (all stone in these streams), introduction of spawning gravels, and random boulders, extensive bank fencing exercises and some tree planting along larger (> 4m basewidth) channels.

A total of 27 stream reaches were monitored of which 14 were experimental zones and the balance (13) were control reaches. There were a minimum of one experimental and one control zone in all seven tributaries. A minimum of one years pre-works data was available for all monitored reaches. Post-works a majority of sites were monitored annually for two years with data being available for three years post-works.

3.5.2. Monitoring Results

Kruskal Wallis tests for ranked trout fry and trout parr values suggest no change in trout fry denotes ($p = 0.631$) but a significant change ($p < 0.05$) in trout parr values (Table 23). Small numbers of adult trout (≥2+ year old) were noted at some of these locations both pre and post works. A Kruskal Wallis test for ranked adult trout densities suggests no significant change ($p = 0.845$) over the monitoring period. In the authors opinion these channels, even following enhancement, are too small to support a substantial resident stock of adult trout.

	Ranked Trout Fry	Ranked Trout Parr	Ranked Trout Adult
Chi-square	1.727	8.987	0.819
Df	3	3	3
Asymp Sig.	0.631 ns	0.029	0.845 ns

Table 23. Kruskal Wallis tests for ranked trout fry, trout parr and adult trout in the Carra/Mask monitored reaches.

Mann-Whitney post hoc tests compared the trout parr densities in the Experimental and Control zones in the pre-works phase and also the experimental and control zones in the post-works area (Table 24).

Ranked Trout Parr	Post-Works	Pre-Works
Median Experimental	42.5	25.75
Median Control	23.5	20.25
Mann-Whitney U	71.5	44.5
z score	-2.618	-0.416
Effect Size r^2	-0.443	-0.093
Sig. (Bonferroni Correction p<0.0125)	<0.0125	0.677 ns

Table 24. Mann-Whitney post hoc tests comparing trout parr density values for both Experimental and Control reaches in the pre-works phase and also Experimental and Control zones in the post-works era.

Data indicate no significant difference ($p = 0.677$) in the densities in the Experimental and Control densities in the pre-works. A significant difference was evident between these data sets in the post-works phase ($p < 0.0125$) with significantly high values being recorded in the enhanced zones.

In summary the results of the Carra/Mask enhancement programme reflect the findings in relation to all of the other trout data sets – in the post-enhancement phase the enhanced channel zones had an increased capacity to support 1+ year old trout parr.

3.5.3. The Lough Carra Lake Trout Population

A lake fish stock survey series of data are available for Lough Carra, at intervals from 1978 to 2001. Carra, like Lough Ennell has been ecologically stable over this period. These data illustrate an increase in C.P.U.E. value for adult trout numbers in Lough Carra in 2001 which were probably a positive consequence of the stream enhancement programme (Table 25).

Year	Trout C.P.U.E. Values
1978	0.75
1979	1.017
1980	2.117
1981	3.8
1986	2.3
1996	4.425
2001	6.133

Table 25. Trout C.P.U.E. values for a series of Lough Carra surveys from 1978 to 2001. The Carra stream enhancement programme was completed in 1999.

3.6. The Lough Corrib Monitoring Data Set

An analysis of the effectiveness of the Lough Corrib stream enhancement programme has already been published (Gargan et al, 2002). In summary they reported no significant increase in trout fry or adult trout densities post-enhancement. They noted statistically significant increase in both trout and salmon parr densities (1+ year old) post enhancement.

In relation to the salmon parr data it should be noted that a majority of the monitoring sites were sampled in springtime. A significant data base for salmon parr values in enhanced streams in summertime is not available. Gargan (pers comm.) has informed the authors that the Clare river systems, the largest sub-catchment in Lough Corrib has a similar distribution of salmon spawning sites to that already described in this document for the Moy Catchment – i.e. most salmon spawning sites are located in Clare River tributaries with few in the main stem. Yet, the Clare river main stem supports a very large population of 1+ year old salmon parr (P. Gargan, pers. comm.). It is likely therefore that enhancement of the extensive sub-catchments like the Grange and Abert rivers (tributaries to the Clare River) were of benefit to salmon parr up to summer of their second year. Thereafter many of these fish, like their Moy counterparts, probably move downstream into the main stem of the Clare River (Appendix II, Fig. 8).

3.7. Monitoring Fish Stock in Enhanced Channels with Basewidths ≥6m

A limited number of reaches ≥6m were monitored pre- and post-enhancement. Costs dictated the limitations here – for example one 15 m wide channel would require 12 man days just to complete the field work element of monitoring one reach.

Monitoring data on reaches ≥6m are available in relation to channels in the following catchments – the Moy, Boyne and Liffey. Regrettably a significant number of these zones were in channels subject to water quality problems. Data in relation to the latter group are presented first.

3.7.1. Moy Catchment Zones ≥6m

Extensive lengths of the Castlebar and Pollagh Rivers were enhanced as part of the Moy programme. Works involved fencing and tree planning programmes and a variety of instream works to restore the natural morphological form. The latter included re-excavation of the channel bed to restore pre-drainage basewidths at a new lower level, excavation of a thalweg, provision of rubble mats, excavation of pools and the placement of random boulders.

In the case of the Castlebar River the author (O'Grady) was aware that there were water quality problems in the channel. The North Western Regional Fisheries Board Manager requested that the enhancement of the channel proceed on the basis that Castlebar Urban District Council were about to construct a new sewage treatment plant which would resolve the water quality problem. In relation to the Pollagh there was a decline in the water quality in the channel post-enhancement.

A total of ten zones, 5 experiment and 5 control zones were monitored in the Castlebar and Pollagh channels. Kruskal Wallis tests for ranked trout parr, adult trout and salmon parr were not significant (Table 6).

	Trout Parr	Adult Trout	Salmon Parr
Chi squared	5.074	5.057	1.352
df.	3	3	3
Significance	0.166 ns	0.168 ns	0.717 ns

Table 26. Kruskal Wallis tests for trout parr, adult trout and salmon parr for ranked fish numbers in the monitored experimental and control sites in the Castlebar and Pollagh Rivers.

A failure to find significant change in any fish categories can be related to the poor water quality in both channels post-works. During the post-works monitoring period (1997 to 2001) E.P.A. macroinvertebrate quality ratings for both channels in the experimental zones were either Q3 or Q3-4.

Zone	Year	Nos Fish per m^2 Salmon Parr Trout Parr Adult Trout			Enhancement Status
Experimental	1997 1998 1999 2000	0.51 (0.067) 0.54 (0.041) 0.98 (0.11) 0.87 (0.14)	0.019 (0.005) 0.06 * 0.06 * 0.21 (0.04)	0.11 (0.003) 0.06 * 0.053 * 0.12 *	Pre-Works Post-Works Post-Works Post-Works
Control	1997 1998 1999 2000	0.05 (0.04) 0.38 (0.084) 0.47 (0.06) 0.27 (0.05)	0.008 * 0.02 (0.002) 0.023 * 0.07 (0.01)	0.09 * 0.04 * 0.039 * 0.03 *	Not Developed

(-) - 95% Confidence Intervals

- **- Minimum density estimates**

Table 27 . Salmon parr, trout parr, and adult trout stock densities at one Control and Experimental zone in the Owengarve River for one occasion prior to works and each of 3 years post-works.

Zones	Year	Salmonid Stock Densities as No./m^2 & 95% C.I. Salmon Parr Trout		Period Post-Works (Months)
Experimental 1	1987	0	$0.5 \times 10^{-3} \pm 0$	Pre-Works
	1988	0.02 ± 0.001	0.006 ± 0.002	5
	1989	0.06 ± 0.002	0.04 ± 0.003	17
	1990	0.04 ± 0.01	0.06 ± 0.006	29
Experimental 2	1987	0	$0.2 \times 10^{-3} \pm 0$	Pre-Works
	1988	0.02 ± 0.002	0.01 ± 0.002	12
	1989	0.03 ± 0.004	0.01 ± 0.005	24
	1990	0.01 ± 0.003	0.01 ± 0.002	36
Control (An unaltered deep uniform glide)	1987	0	$0.2 \times 10^{-3} \pm 0$	Not Developed
	1988	0	0	
	1989	0	0	
	1990	0	0	
Unaltered Shallow Productive Glide	1988	0.09 ± 0.04	0.03 ± 0.003	A productive zone which recovered post-drainage

Table 28. Data from O'Grady *et al* (1991) illustrating the increases in juvenile salmon and trout numbers in "two new" rubble mat areas relative to an unproductive and a productive reach in the main Boyne Channel. The trout data include all parr and adult trout in significant numbers up to 35cms with a few larger trout (≤ 41cms).

A current study of the relationship between Q values and salmonid stocks (Kelly and Champ, Central Fisheries Board, in prep) shows that once Q values fall to a 3-4 category salmon parr stock may decline. They (Kelly and Champ) have also shown that trout stocks can decline significantly at Q3 or lower values. This is the most likely reason why salmonid stocks did not benefit from the morphological improvements to these channels. A review of the physical works carried out in these zones, four years post-works, indicated that all structures were still functioning as designed. Significant improvements were also evident in the riparian zone once stock were excluded – tree planting programmes had been successful and the semi-aquatic plant communities in the riparian zones had recovered.

3.7.2. Rye River (Liffey Catchment)

An extensive physical enhancement programme for the lower reaches (2.4 km) of the Rye River was designed by the author (O'Grady) and implemented in 1994. This involved an extensive desilting programme, the construction of stone weirs and deflectors, stone bank revetments and tossing of existing gravel beds. The new owners of the property, at that time, excluded all farm stock, undertook a riparian tree planting programme and subsequently planted a deciduous forest alongside a one kilometre reach of the left bank.

This enhancement programme was monitored comprehensively pre- and post-works (1993 to 1999) as part of two successive Ph.D. studies in University College Dublin (Kelly, 1996 and McCreesh, 2000). Data indicate that the programme was unsuccessful in relation to enhancing either juvenile salmon, juvenile trout or adult trout stocks. The Ph.D. studies indicate that structurally the morphological changes were, as built, at the end of the study period. (Major improvements in the riparian zone were evident once all farm stock were removed). Q values were Q3-4 over the entire study period (1993 to 1999). The authors of these studies (Kelly & McCreesh) conclude that poor water quality was prohibiting a recovery in salmonid stocks. The more recent detailed study of Q-value impacts by Kelly & Champ (In prep.) concur with this view.

3.7.3. Owengarve and Boyne Channels

Limited monitoring data are available for enhanced sites in two unpolluted rivers, the Owengarve (Moy Catchment) and Boyne main channels. The reaches involved in both channels had basewidths of between 13.0m and 17.0m in the case of the Boyne and 9-11m in the case of the Owengarve. The nature of the enhancement works were quite different in each channel. Data are provided here in relation to the nature of the works at each site and the subsequent changes evident in salmonid stocks over a three year post-works period. The small size of these data sets presented one from applying the same statistical analysis to these data as were used in the larger data set analysis in this report.

3.7.3.1. Owengarve Project

The Owengarve river was drained in the course of the overall Moy Catchment arterial drainage scheme in the 1960's. The enhancement programme here involved constructing a two stage channel – all of the summer volume discharge could be accommodated within the lower of the two stages (see O'Grady, 2006, p.94). Additional physical features were incorporated into this lower stage channel which had the same basewidth as the Owengarve prior to drainage – vortex stone weirs at gradient breakpoints and random boulders (0.5 tonne stones at 3m centres).

Electro-fishing data for one experimental and one control reach were compiled in 1997 prior to enhancement and thereafter for each of three years, post-enhancement (Table 27). The data suggest significant increases in 1+ year-old trout and salmon parr and adult trout (≥2+ year-old) numbers in the experimental zone (enhanced area) relative to the control (undeveloped) reach following enhancement. These monitoring data were compiled in springtime.

3.7.3.2. Boyne Project

A baseline physical / ecological survey of the Boyne Catchment in late 1980's post-drainage, indicated that many main stem reaches with gradient values in the range 0.2% to 0.25% which had an uneven substrate composed of broken bedrock and/or cobble/gravel were the most productive zones in terms of their salmonid standing crops (for salmon parr and 1+ and older trout). In contrast uniform glides with little hydraulic diversity, post-drainage, supported few salmonids even when they were sufficiently shallow (0.5-1.0m) to allow a degree of macrophytic colonisation on the bed.

The enhancement programme in this channel involved the construction of rubble mats in uniform glide areas to provide more complex hydraulic conditions and increase macroinvertebrate production thereby improving salmonid standing crops (O'Grady *et al* 1991). Monitoring data, pre- and post-works are provided in Table 28. This table also includes stock densities estimated for a shallow productive glide area, unaltered since this channel zone had been drained 20 years prior to this programme. The two experimental and one control zone were monitored once pre-works and three occasions post-works (Table 28).

This data set indicated very significant increases in both salmon parr and trout (≥1+ year-old) stock densities in the two experimental zones in a short period post-works – from zero or, virtually, zero pre-works. Three years post-works the substantial adult trout stock included many trout >30cm in length and a few individual fish up to 41cm (O'Grady *et al*, 1991). No such change was evident in the control zone where stock densities of both salmonid species remained at, or close to, zero over the entire four year period. The stock density values for unaltered shallow productive glide were higher than those recorded in the experimental zone three years post-enhancement. This suggests that, in this instance, further increases in the salmonid standing crops might be expected in the course of time.

3.8. Additional Aspects of the Enhancement Programmes

There are a number of other aspects of these drained riverine enhancement programmes which are important. These data, by their nature, could not be subject to rigorous statistical analysis. However, the author would still regard them as very important considerations in the context of designing future national programmes to enhance the morphology of drained systems.

3.8.1. Restoring Spawning Opportunities

Increasing channel basewidths, to prevent flooding, is one of the primary objectives of any drainage scheme. Increased channel basewidths inevitably lead to a reduction in flow velocities during low flow regimes. This will lead to changes in channel morphology – reduced flows will result in changes in bed sediment movement patterns. There will be less movement of the bigger particles (gravel and cobble). Post-drainage, in Irish rivers, this change has been accelerated in circumstances where landowners do not fence out stock – bank trampling and poaching can lead to further increases in basewidth and additional quantities of fine material (sand/silt) on the channel bed. From a salmonid perspective this can become critical in relation to spawning opportunities – a layer of fine material can cover spawning gravel deposits virtually eliminating spawning opportunities over long channel reaches.

Two examples are provided here to illustrate how bank stabilisation and exclusion of stock can restore the natural morphology of the channel bed (from sand to gravel) thereby providing spawning opportunities. A third excessively broad reach, with a cobbled gravel bed, provides an example of another channel type where the restoration of stream natural morphology (provision of pools) indirectly provided additional spawning opportunities (Currerevagh stream).

3.8.1.1. Shanvaus River (Bonet Catchment)

Accurate salmon redd counts were available for a 1.04 km reach of this stream for two years immediately post drainage (Table 29). Post-drainage cattle poaching along the banks further increased the silt load to the channel. The increased basewidths post-drainage, in combination with bank poaching, meant that gravel deposits on the bed were largely covered in sand. Salmon redd counts, post-drainage, virtually collapsed (Table 29).

The enhancement of this reach of the Shanvaus involved a stabilisation of eroding bank sections with timber revetments and the exclusion of farm stock with a fencing programme. No instream physical works were carried out as part of this programme. This allowed the channel to scour out the finer bed material exposing gravel deposits – essentially during the first winter, post-enhancement a thalweg had re-established itself in this sinuous channel. Once the gravels were exposed substantial salmon spawning activity resumed (Table 29).

Winter	Drainage Status	Enhanced Status	Salmon Redd Count
1991/92	Just Drained	Not Enhanced	2
1992/93	Drained	Not Enhanced	3
1993/94	Drained	Enhanced (Oct '03)	24
1994/95	Drained	Enhanced	29

Table 29. Salmon redd counts for a 1.04 km reach in the Shanvaus River (immediately post-drainage and following enhancement).

3.8.1.2. Tobergall Stream

The Tobergall stream is a small sub-catchment in the Moy system which discharges to Lough Cullin. It is an important spawning and nursery stream for the adult trout population in Lough Cullin. A 1.0 km long section in the upper reaches of this stream was drained by a landowner in 1995. Post-drainage the stream had the same suite of morphological problems as those already described for the Shanvaus River. Log/Xmas tree revetments were built to stabilise the banks and encourage aggradation of sand suspended during flood flows. Stock were fenced out. No instream morphological works were carried out. Once the excess sand deposits on the bed were either scoured out, or entrapped in the revetments, a gravelled bed with a well-defined thalweg was reformed.

Redd count figures are available for this reach for two spawning seasons post-drainage and 5 years post-enhancement. The increase in redd count figures, post-enhancement, is obvious (Table 30).

Winter	No. of Trout Redds	Comment
1995/96	2	Drained in July, 1995
1996/97	3	Enhanced in July, 1997
1997/98	23	
1998/99	60	
1999/00	53	
2000/01	62	
2001/02	59	

Table 30. Trout redd count figures pre- and post-enhancement in a 1.04 km reach of the Tobergall Streams (from O'Grady, 2006(b)).

3.8.1.3. Currerevagh Stream (Lough Corrib)

The lower reaches of this stream had been artificially widened by land owners to relieve flooding in the past (possibly 50 to 60 years ago). Since then this relatively high gradient reach (1.2%), 500m in length, had a broad shallow compacted cobble / gravel bed without a well-defined thalweg and with no significant pool areas.

Redd counts had been recorded by the same fishery officer on the Currerevagh stream over a thirty year period. He had never observed any spawning activity in the aforementioned reach prior to the implementation of an enhancement programme (D. Goldrick, pers. comm.). This zone, pre-enhancement, supported salmon and trout fry in summertime which had been spawned elsewhere and subsequently moved into this area.

A series of five vortex stone weirs were constructed at gradient breakpoints in this reach. These have been successful in scouring and maintaining pool areas post-construction now for eight years. Since their construction significant numbers of salmon and trout have spawned in the gravel shoals which have accumulated at the tail of these pool areas – this is a morphological reorganisation of existing bed materials following weir construction. No additional gravels were introduced to the stream bed. Accurate redd counts are not possible here because of the very spaty nature of the stream.

These observations in the Currerevagh stream were evident at many other locations in many enhanced channels. This broadening of spawning opportunities in drained channels is likely to lead to increased fry production. A heavy spawning effort in limited areas of a stream is likely to lead to a significant loss of fry production.

3.9. Links between Morphological Change, Fish Food Production and Fish Densities

One particular study in this data set (main Boyne channel) indicates that the restoration of riffle areas in long uniform drained glide areas can significantly increase salmonid stocks. This data set shows that the uniform hydrology in the drained glide areas was not the sole factor in limiting salmonid standing crops. Macro-invertebrate faunal populations in the drained glide areas were virtually non-existent – only an occasional Gammarid or trichopteran larva could be found following extensive qualitative sampling with a pond net. Following the construction of rubble mats substantial and diverse macroinvertebrate populations become established in these new riffle zones. A very substantial biomass of invertebrates was evident in these new shallow reaches only two years after their construction (Lynch and Murray, 1992). Clearly the re-establishment of a food supply, following the morphological enhancement played a significant role in the re-establishment of a significant salmonid fish stock.

In Ireland many of the main stem channels in drained systems are extensive uniform glides 1-2m deep at summer water levels. In the author's opinion the above findings indicate very considerable scope to enhance these zones in future programmes where their introduction will not impede flood flows.

3.10. Creation of Salmon Angling Pools in Larger Channels

An extensive series of salmon angling pools were reconstructed in the middle reaches of the Moy main channel - Fifty years after drainage only 7 pools had reformed over a 12 km length of channel. An additional 60 pools were excavated as part of an enhancement project to restore the morphology of this relatively large channel (basewidth 25-30m). It

Mean and Standard Deviations of Trout and Salmon parr for Moy Category 3-6m basewidth, streams plotted against gradient values.

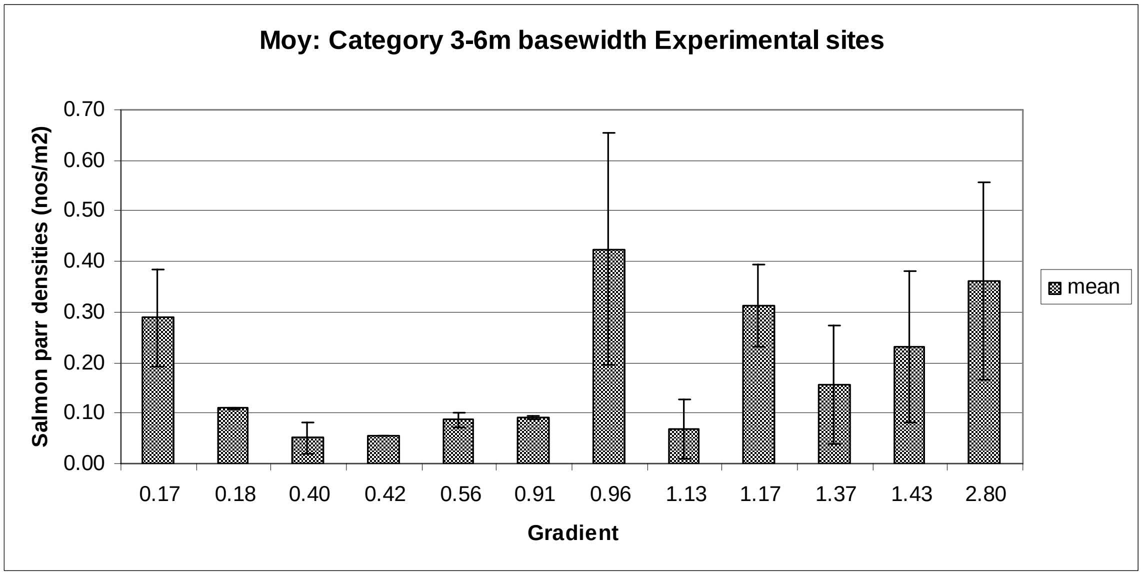

Table 30a Salmon parr densities and gradients

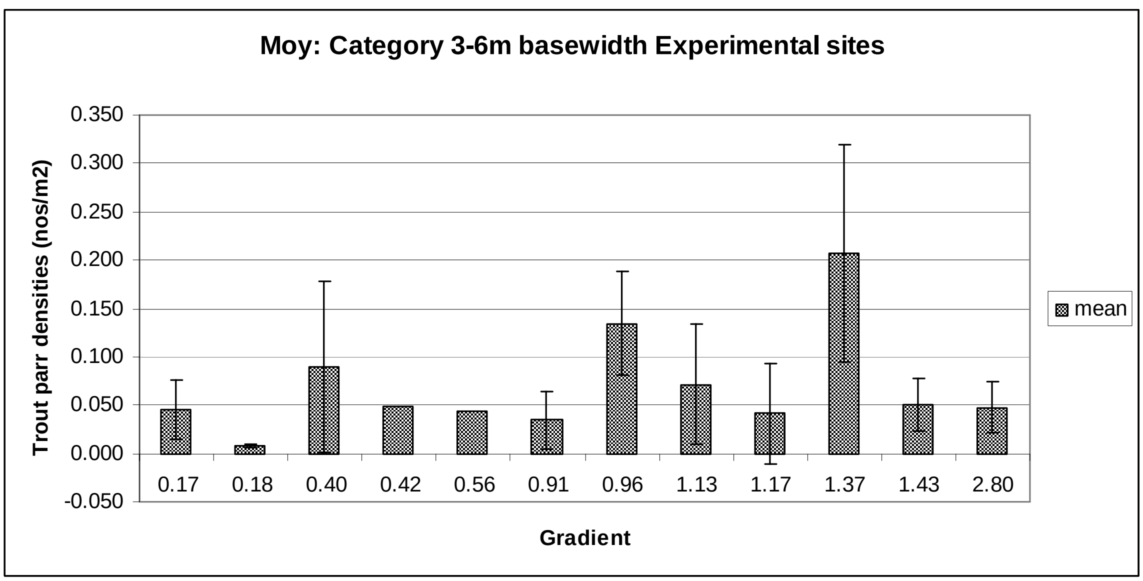

Table 30b trout parr densities and gradients.

is impossible to quantify the effectiveness of this new angling resource because adult salmon movements in the Moy are ephemeral, being dictated by the hydrological conditions in the river when they return from the ocean – in dry periods adult salmon tend to congregate in the lower reaches of the main stem. With persistent high flows the adult salmon (both spring fish and grilse) move upstream and use these new pools as resting areas. Anglers have reported catching salmon in all of these new pools. They can therefore be regarded as a successful morphological adjustment procedure.

3.11. Links between Morphology and a Rivers Ecology

The completion of a physical / ecological baseline survey of drained river catchments is an essential pre-requisite to planning an enhancement programme. Variation in the physical and ecological features of individual catchments means that a particular suite of morphological enhancement programmes may be productive in one circumstance and counter productive in others. The redevelopment of angling pools in the middle reaches of the Moy main stem provide a good example of where morphological restoration had to be tailored to accommodate local ecological conditions.

A baseline survey of the Moy main stem indicated that the dominant aquatic plants (mosses) had a very limited distribution – no plant colonisation of the river bed was evident in reaches ≥0.5m deep. This is unusual by Irish standards – plants, including mosses will normally colonise deeper areas (<0.5m) reaches. Electro-fishing data indicated the presence of any substantial salmon parr stocks in the shallow reaches of this channel. The creation and subsequent maintenance of new pool areas in any channel necessitates the creation of an energy source (head of water) to create scour. This can only be achieved by either impeding or constricting flows to create this effect. In the Moy the use of paired deflectors to scour pool areas was used in order to minimise back-watering effects. If standard weirs or rubble mats had been used instead then a significant wetted area of productive salmon parr habitat would have been lost.

3.12. The Influence of Stream Gradient on Juvenile (1+ year-old) Salmon and Trout Densities in Drained Channels

The largest data set, across the broadest range of stream gradient values, available to the authors for streams supporting both juvenile (1+) salmon and trout was the Moy 3-6m basewidth monitoring series. Data are presented here in graphic form relating minimum fish densities recorded to gradient values for Experimental zones, post-enhancement.

The data suggest that, within the range of gradient values for these stream reaches (0.17% up to 2.8%), the stream gradient alone did not dictate that one or other salmonid species would be dominant. Significant stocks of both species were evident across the spectrum of gradient values (Tables 30a and 30b).

4. Impacts of Drainage on Salmonid Stocks

It is not possible to assign a precise level of stock reduction, caused specifically by arterial drainage, to the channels in this study for a number of reasons:-

I. A majority of the channels in the study were drained long before the enhancement programmes were carried out – the Corrib in the 1950's, the Moy in the 1960's, Ennell and Sheelin in the 1970's and the Boyne in the 1980's. Only the Tobergall stream (Moy Catchment) and the Shanvaus River had been drained two years prior to enhancement. The fact that most channels in question had been drained long before the implementation of enhancement programmes had both advantages and disadvantages from an ecological perspective.

   The advantages, in relation to this time lag would include the fact that, in the period after drainage but prior to enhancement, there would have been a partial ecological recovery in the channel from an aquatic floral, macroinvertebrate and fish stock viewpoint. Where farm stock was fenced out, post-drainage, significant riparian zone recovery was evident. This, in part, explains why there were significant increases in 1+ year old salmonid numbers only one year after the completion of enhancement programmes – i.e morphological imbalances, not the food supply, were primarily responsible for the depression of 1+ year old fish numbers.

   The time lag between drainage and enhancement, in contrast, also had very negative effects in some cases. In many channels which were not fenced, post-drainage, subsequent bank trampling by stock lead to further significant increases in channel basewidths. Numerous examples were evident in this study of channel reaches where the drained design channel basewidth had increased by 30% to 40% in the time span between the completion of the drainage programme and the implementation of the enhancement scheme. These increases were usually a consequence of bank trampling by farm stock (not bank erosion) following the drainage programme. The reader should also note that a number of channels in the Moy and Corrib Catchments had been drained and significantly canalised prior to the implementation of the O.P.W. drainage schemes – possibly in the 1840's to 1880's.

II. Two studies (O'Grady, 1991 and O'Grady & King, 1992) indicate that drained channel reaches in Ireland can sometimes recover both floristically and faunistically (including fish). – the natural morphology of these channels was restored post-drainage at a lower bed level and fencing excluded farm stock allowing riparian zone recovery.

III. Sometimes "so called" drainage programmes in Irish rivers have substantially improved salmonid production – the prime example being the Boyne main channel from Trim to Navan (O'Grady, 2006, 2006(a)). However, this exercise removed a series of large stone built weirs and silt islands accumulated upstream of these structures over several hundred years. In essence the channel, "post-drainage", was much closer to its natural morphological form than it had been since the weirs were built.

In summary, the author would conclude that any land management practice or, combination of practices, which lead to a significant alteration in the natural morphology of a channel and/or its riparian zone will inevitably have negative consequences for fish stocks. It is simply not possible to quantify the negative impact of drainage itself as a factor. In general terms it is fair to say that in smaller (<6m) channels drainage will usually result in a significant loss in the standing crop of 1+ year-old salmonids. In larger (>6m) channels the standing crops of larger trout (2+ to 5+ year-old) will decline significantly and there will also be a reduction in the number of resting pools for adult salmon.

5. Recovery Rates in Salmonid Stocks Post Enhancement

The positive impact of most of these morphological / ecological enhancement programmes provides one with the opportunity to look at fish stock recovery rates post-enhancement. Changes in salmon parr minimum density values are provided in graphic form for 5 reaches over the monitoring period. A similar data set in relation to 1+ year-old trout is also provided (Appendix I). These data sets illustrate two points:-

I. There is generally a very significant increase in the numbers of 1+ year old salmon or trout one year after the completion of the enhancement programme.
II. Over a period of years, post-enhancement, considerable fluctuation is evident in the annually recorded fish densities for both the control and experimental reaches.

The fact there is a significant increase in fish numbers in enhanced areas, relative to control zones, in the first year post-works is a reflection of the morphological changes – i.e. thalweg restoration and presence of lateral scour pools and/or plunge pools, post-works, have reintroduced the physical habitat requirements of 1+ year old fish. The author (O'Grady) is also satisfied that, in larger channels where pool areas are lost adult trout stocks decline and lies for adult salmon are reduced in value or lost.

The variation in minimum density values recorded annually at all sites over a period of years is to be expected and is probably independent of geomorphic change. A number of long-term studies in relation to juvenile salmonids in other countries have noted wide fluctuations in annual standing crops (Elliot, 1987; Crisp, 1993 and Niemla et al, 1999). In the authors opinion annual fluctuations in the hydrology of these streams are the most likely cause of these fluctuations in circumstances where there are no pollution problems.

The Boyne monitoring data set (Section 3.7.3.2.) suggests that adult trout stocks had possibly not peaked in enhanced areas some three years post enhancement. Hunter (1991) expressed the view that brown trout populations in enhanced channels will reach optimum levels for a five to six year post-enhancement period.

Occasionally, in particular circumstances, substantial adult trout numbers will colonise a channel only one year post-works. The author (O'Grady) observed this trend in the Grange River (Corrib Catchment), where pre-enhancement, fish stocks were limited to 0+ and 1+ year-old trout. One year post-works some individual trout, up to 1.5kgs in weight, occupied the new pool areas – these were obviously trout which had returned from Lough Corrib to spawn the previous winter and, thereafter, became residents in the river.

Most trout in Irish rivers have a lifespan of 5 years. In the author opinion channels which have a capacity to support adult fish will, post-enhancement, probably reach peak carrying capacity 5 years post-works. Thereafter hydrological fluctuations will obviously influence the standing crop values significantly.

A majority (>90%) of Irish salmon smoltify as two year-old fish. It is likely therefore that juvenile salmon stocks, post-enhancement, can peak in as little as one year post-works – assuming that moderate fry densities were colonising the channel pre-works.

6. Effectiveness of Individual Enhancement Measures

When the author (O'Grady) reflected on the final part of this brief he realised that it is not possible to put a rating value on any one structure in one or more enhancement schemes.

The success of any scheme will be guaranteed by following a set of agenda:-

i - Carry out a physical / ecological baseline survey on a catchment or large sub-catchment basis to establish the status quo and identify the imbalances. Where relevant a review of OPW physical records are an essential part of this critique.

ii - Design the enhancement programme from first principals i.e. – use timber and stone structures to restore the natural morphology of the channel at a lower bed level if necessary.

iii - Reintroduce gravels and boulders where the natural recruitment of these materials has been lost.

iv - Fence out stock and allow the riparian zone to recover.

O'Grady (2006)(a)) summarises the relative value of particular weir structures and bank revetment options in different channel types enhanced in Ireland. In summary there are various options available to restoring the morphology of channels. The final choice will usually come down to the availability and cost of materials locally and the difficulties associated with transporting materials to the site.

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