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# Recovery of an aquatic ecosystem following treatment of abandoned mine drainage with constructed wetlands

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Abstract

*Seven kilometres of the River Pelenna in South Wales were impacted for approximately 30 years by discharges from abandoned coal mines. Elevated iron and low pH caused significant ochreous staining and had detrimental effects on the river ecology. The River Pelenna Mine water project constructed a series of passive wetland treatment systems to treat these discharges. Monitoring of the performance and environmental benefits of these has been undertaken as part of an Environment Agency R&D project. This project has assessed the changes in water quality as well as monitoring populations of invertebrates, fish and birds between 1993 and 2001.*

*Performance data from the wetlands show that on average the three systems are removing between 82 and 95% of the iron loading from the mine waters. In the rivers downstream, the dissolved iron concentration has dropped to below the Environmental Quality Standard (EQS) of 1 mg/L for the majority of the time. Increases in pH downstream of the discharges have also been demonstrated.*

*Trout (*Salmo trutta*) recovered quickly following mine water treatment, returning the next year to areas that previously had no fish. Intermittent problems with overflows from the treatment systems temporarily depleted the numbers, but the latest data indicate a thriving population. The overflow problems and also background episodes of acidity have affected the recovery of the riverine invertebrates. However, there have been gradual improvements in the catchment, and in the summer of 2001 most sites held faunas which approached those found in unpolluted controls. Recovery of the invertebrate fauna is reflected in marked increases in the breeding success of riverine birds between 1996 and 2001.*

*This study has shown that constructed wetlands can be an effective, low cost and sustainable solution to ecological damage caused by abandoned mine drainage.*

Key words: ecological recovery, environmental benefits, macroinvertebrate diversity, mine water, sustainability, treatment performance

## INTRODUCTION

Former coal industries in South Wales have left an obvious environmental and social legacy. Little is now left in the way of active coal mining operations, but the settlements that developed with the industry still remain. Most mining infrastructure has been demolished, and spoil heaps have been reclaimed, but the environmental impacts of mine drainage are a persistent legacy in many areas.

Tonmawr, a village situated in the Pelenna valley, near the towns of Neath and Port Talbot, developed around the coal industry. The earliest records of coal mining relate to a level opened in 1823 (Reynolds 1985). Over the next 100 or so years many drift mines and one deep mine were opened in the vicinity. By the early 1960s, mining had ceased in the valley.

Following the closure of these mines, the workings flooded and mine drainage discharged into the Gwenf-

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frwd and Blaenpelenna, tributaries of the River Pelenna. These stained the two tributaries and the River Pelenna orange, and caused elevated iron concentrations for approximately 7 km, as far downstream as the confluence with the River Afan (Edwards *et al.* 1997). Assessments of the ecological status of the polluted rivers showed that juvenile trout (*Salmo trutta*) populations and macroinvertebrate assemblages were impoverished both upstream and downstream of the mine water discharges on the Gwenffrwd and Blaenpelenna, and to a lesser extent on the River Pelenna (Edwards 1995). Macroinvertebrate assemblages in the headwaters of the catchment were typical of acidified streams, while communities downstream of the major mine water discharges were even more impoverished. Poor survival rates of trout eggs, alevins and parr were observed in the Blaenpelenna and Gwenffrwd, particularly downstream of the mine water discharges. The toxic effects of metals and acidity in the mine waters and episodic surface-water acidification, coupled with the smothering effects of ochre on the substrate, were thought to be responsible for the impoverishment of the aquatic fauna.

Research elsewhere has investigated the effect that mine water discharges have on invertebrates and fish. A reduction in the invertebrate taxonomic richness at sites impacted by mine waters has been found by Amisah and Cowx (2000), Malmqvist and Hoffsten (1999), Mori *et al.* (1999) and Soucek *et al.* (2000). Restrictions on fish reproduction and egg survival leading to poor juvenile populations have been identified at other sites impacted by mine water in the UK by Amisah and Cowx (2000) and Scullion and Edwards (1980).

The Pelenna mine waters are generally net-acidic with iron as the main contaminant, while levels of other metals are generally no higher than background levels in the rivers. Five main discharges were identified as requiring treatment in order to lower the dissolved iron concentration in the rivers to below the Environmental Quality Standard (EQS) of 1 mg/L. The characteristics of each discharge are shown in Table 1.

A project was initiated by Neath Port Talbot County Borough Council (NPTCBC) and The Environment Agency Wales (EAW) to construct a series of passive wetland treatment systems for these discharges. Funding was obtained from the European Union LIFE fund (a European financial instrument for the environment) and the Welsh Development Agency's (WDA) Land Reclamation Programme. The schemes were constructed in three phases from 1995 to 1999. The location of each phase of the treatment system is shown in Figure 3 and Figure 4 in the result section. The design and size of each scheme is outlined below:

- Phase I – Whitworth No 1 wetlands were constructed in 1995 with four cells in parallel covering 900 $m^2$. Bark mulch and mushroom compost were used as substrates and the systems were planted with cat's-tail (*Typha latifolia*) and soft rush (*Juncus effusus*).
- Phase II – Garth Tonmawr wetlands contain five cells covering 6370 $m^2$ and were constructed in 1998/99. There are three aerobic cells and two reducing and alkalinity producing system (RAPS) cells that incorporate downward flow compost substrates with limestone bases for alkalinity generation. This system was left to colonise naturally. There was approximately 70–80% vegetative cover in the systems in 2001. This was made up predominantly of compact rush (*Juncus conglomeratus*), jointed rush (*Juncus articulartus*), bistort (*Polygonum amphibium*) and starwort (*Callitriche stagnalis*) with a small stand of bullrush (*Typha latifolia*).
- Phase III – Whitworth A, Whitworth B and Gwenffrwd wetlands were constructed in 1998. The wetlands operate as two separate systems or legs,

**Table 1. Characteristics of the Pelenna mine waters**

| Mine | Mean flow (L/s) | Mean pH | Mean total iron (mg/L) | Mean iron loading (kg/day) | Mean alkalinity (mg/L $CaCO_3$) |
|---|---|---|---|---|---|
| Whitworth A[a] | 9.3 (8.9)[e] | 6.0 (0.3) | 61.3 (34.0) | 41.9 (26.6) | 31.6 (28.5) |
| Whitworth B[b] | 18.0 (22.1) | 5.9 (0.5) | 5.5 (4.2) | 3.3 (12.6) | 6.8 (17.8) |
| Gwenffrwd[b] | 5.0 (10.0) | 5.3 (0.6) | 1.5 (2.1) | 5.7 (5.9) | 14.4 (16.1) |
| Whitworth No 1[c] | 4.7 (1.4) | 6.3 (0.4) | 24.1 (7.5) | 9.5 (5.3) | 42.0 (32.6) |
| Garth Tonmawr[d] | 20.0 (12.0) | 5.8 (0.5) | 28.6 (11.7) | 47.2 (16.8) | 14.6 (21.0) |

Notes: a Data from 1993 to 2001
b Whitworth B and Gwenffrwd mine water data is post 10/98 only, following an underground diversion of the mine water flow regimes
c Data from 1995 to 2001
d Data from 1991 to 2001
e Standard deviation in brackets.

known as Whitworth A and Gwenffrwd. Each leg takes a separate flow of mine water through the system. The Whitworth A leg has a RAPS of 1825 $m^2$ followed by an aerobic wetland of 4500 $m^2$. The Gwenffrwd leg of the system consists of a RAPS cell of 2425 $m^2$ followed by a settlement pond of 850 $m^2$ and then an aerobic cell of 2000 $m^2$. This leg was modified in 2001 after a natural underground diversion of the mine water in the winter of 1998 resulted in the mine water bypassing the system. It now captures the flow from both the Gwenffrwd and Whitworth B mine waters.

A three-year R&D project funded by the Environment Agency is currently assessing the performance, environmental benefits and sustainability of these treatment systems. The results reported here are the latest assessment of the recovery of the ecology of the River Pelenna and the effectiveness of the constructed wetlands as a method for treating mine water discharges.

## METHODS

### Water quality monitoring

Water quality samples were taken from the mine waters and the outlet from each cell of each treatment system. River water quality was monitored at a number of sites including up and downstream of each discharge (Figure 1). Monitoring has been undertaken by the EAW at all sites from 1993 to 2001 and at the wetland sites since construction. Samples were taken using standard Environment Agency (EA) methods (Environment Agency 1998*a*). Field measurements for pH were taken on a YSI 600XL multi-parameter meter, and alkalinity was measured using a Palintest photometer 5000. The Environment Agency National Laboratory Service in Llanelli analysed the samples. EAW Hydrometric Field Officers monitored wetland and river flows using standard EA techniques (Environment Agency 1998*b*).

River water quality data was analysed for any significant step changes following mine water treatment. Two software packages were used (TAPIR and BADGER) to assess temporal trends. These were developed by the Water Research Council (WRc), specifically for improved environmental monitoring by the Environment Agency (Wyatt *et al.* 1998).

### Ecological studies

Invertebrate populations were monitored yearly from 1993 until 2001. Sampling was undertaken in spring and autumn using a three-minute kick sample, followed by identification to species level in the laboratory. Standard EA methodology was followed (Environment Agency 1999). The accuracy of sorting and identification was subject to in-house and external quality control. Data generated were analysed using a number of biotic indices, including the Biological Monitoring Working Party (BMWP) Score, Average Score Per Taxon (ASPT) and total abundance. The BMWP score was designed to give a general indication of the biological conditions of rivers. Each macroinvertebrate family is given a score between one and ten, based upon its susceptibility to organic pollution (Metcalfe 1989). The ASPT is calculated by dividing the BMWP score by the number of taxa.

The multivariate classification technique TWINSPAN (Two-Way INdicator SPecies ANalysis) was also employed. TWINSPAN splits sites into groups that are essentially similar in taxonomic composition (Gauch 1982). Indicator species that show a preference for each split or group are identified and the relationships between the site groupings and environmental variables can be explored.

Fish population data were gathered in the summers of 1993, 1994, 1996 and 1999 to 2001. Stretches of 50 m were electrofished using a quantitative method. The stretches were isolated up and downstream using nets, and then fished a minimum of three times. Standard EA methodology was observed (Environment Agency 1998*c*). Results were converted into fish densities per 100 $m^2$ using the method of Carle and Strub (1978) for both fry (<1 year old) and parr (>1 year old). National Fisheries Classification Scores (NFCS) were calculated for the data (Mainstone *et al*. 1994). This system categorises the fish densities observed against a national dataset of fisheries of a similar type. The observed densities are then expressed as being within a certain percentage of sites for a given species group within the database. The system is classified in six parts as below:

- Grade A Excellent within top 20% of database
- Grade B Good 60–80%
- Grade C Fair 40–60%
- Grade D Fair 20–40%
- Grade E Poor lower than 20%
- Grade F Fishless

Predicted densities of fish were calculated using a habitat assessment scheme (HABSCORE) that measures and evaluates habitat features which influence salmonid distribution (WRc 1999). Characteristics of each field site are input into the system, which then returns a predicted fish density for such a habitat, assuming pristine water quality.

Riverine bird populations were assessed using the British Trust for Ornithology (BTO) Waterways Bird Survey (WBS) methodology (Taylor and Murray

**Table 2. Summary performance data for the Pelenna wetlands**

| Wetland[a] | pH in | pH out | Fe inlet[b] | Fe outlet[b] | Fe loading inlet[c] | Fe loading outlet | Percent removal[d] | Removal per $m^2$ [e] |
|---|---|---|---|---|---|---|---|---|
| Whitworth No.1 | 6.30 | 6.87 (0.5)[f] | 24.1 | 4.3 (2.29) | 9.5 | 1.6 (1.6) | 82.0 (13.8) | 8.1 (4.4) |
| Garth Tonmawr | 5.80 | 6.85 (0.4) | 28.6 | 1.9 (1.8) | 47.2 | 3.0 (3.8) | 94.7 (6.4) | 7.8 (2.3) |
| Whitworth A | 6.00 | 7.36 (0.3) | 61.3 | 2.2 (4.2) | 41.9 | 1.2 (1.7) | 95.7 (9.0) | 6.1 (3.9) |

Notes: a Wetland data averaged over the following timescales: Whitworth No.1: 1995 to 2001; Garth Tonmawr: 1999 to 2001; Whitworth A: 1998 to 2001.
b Fe as total iron in mg/L.
c Fe loading in kg/day
d Percent removal of incoming iron loading
e as $g/m^2/day$
f standard deviation (S.D.) in brackets, mine water S.D. data in Table 1.

1982). Three river stretches were surveyed on six occasions with no three sequential visits spanning less than ten days. Species were identified and as much extra information as possible was noted; including sex, juvenile birds and nest sites. The location of each siting was made using a handheld Global Positioning System (GPS). Analysis of territories was done using the BTO WBS guidelines (Marchant 1994). This identifies areas of the river that are occupied by separate specific groups of birds over a number of visits.

## RESULTS AND DISCUSSION

### Wetland treatment performance

Iron is the only metal found in highly elevated concentrations in the Pelenna mine waters. The sizing of the schemes was designed around the iron loading of each mine water. Alkalinity-producing cells were utilised where mine water within the treatment systems was net-acidic. Use of alkalinity producing cells at Garth Tonmawr and Whitworth A resulted in significant pH increases (Table 2). At the Whitworth No. 1 site there has been a smaller pH rise during treatment; this system has no cells designed to specifically increase alkalinity. The change in pH in Whitworth No.1 is therefore presumably due to bacterially generated alkalinity.

The mean total iron concentration and iron loading of the mine water and wetland outlets is shown in Table 2. From this the percent removal of the iron loading has been calculated. Whitworth No. 1 wetland has the least loading and of this only 82% is being removed. This is the lowest performance of the three systems. The mean outlet iron concentration of 4.26 mg/L is still causing some staining downstream in the Gwenffrwd. This was the first system constructed and consisted of four cells in parallel. It frequently had flow distribution problems resulting in reduced residence time and lowered treatment efficiency. The Garth Tonmawr and Whitworth A wetlands received a much higher iron loading and have both removed approximately 95% of the incoming iron since their construction.

### River water quality

A stated objective of the mine water treatment project was to reduce the mean dissolved iron content in all the receiving watercourses to below the Environmental Quality Standard (EQS) limit of 1 mg/L. Using TAPIR analysis, significant ($p < 0.01$) step changes in the dissolved iron and pH concentrations have been found at most river sample points. These correspond to the dates of mine water treatment. The most significant changes have been seen at the sites immediately below the mine waters. The dissolved iron concentration in all the river sample points has been <1 mg/L during normal wetland operation.

Figure 1 demonstrates the changes in pH and dissolved iron at two of these sites (G4 and G5) following the construction of the treatment schemes. It can be seen that the dissolved iron level has been generally less than 1 mg/L. However, the two peaks in late 1998 and spring 2000 when the iron level was continuously above 1 mg/L were caused by ochre blocking the inlet pipes to the Whitworth A system. The mine water then discharged untreated into the Gwenffrwd at the original discharge point upstream of site G4. As it took a few months for the inlet pipes to be cleared, this had an obvious detrimental effect on the watercourse. Iron peaks can be seen in the data as far downstream as site P2 at Efail Fach, approximately 3 km downstream. Once these overflows were cleared, the water quality has been almost consistently below 1 mg/L dissolved iron.

Site G4 shows a slight increase in pH once the mine water discharges were prevented from entering the Gwenffrwd without treatment (Figure 1). This was expected, as there is no longer the acidity production created by the oxidation of iron in the watercourse. Site

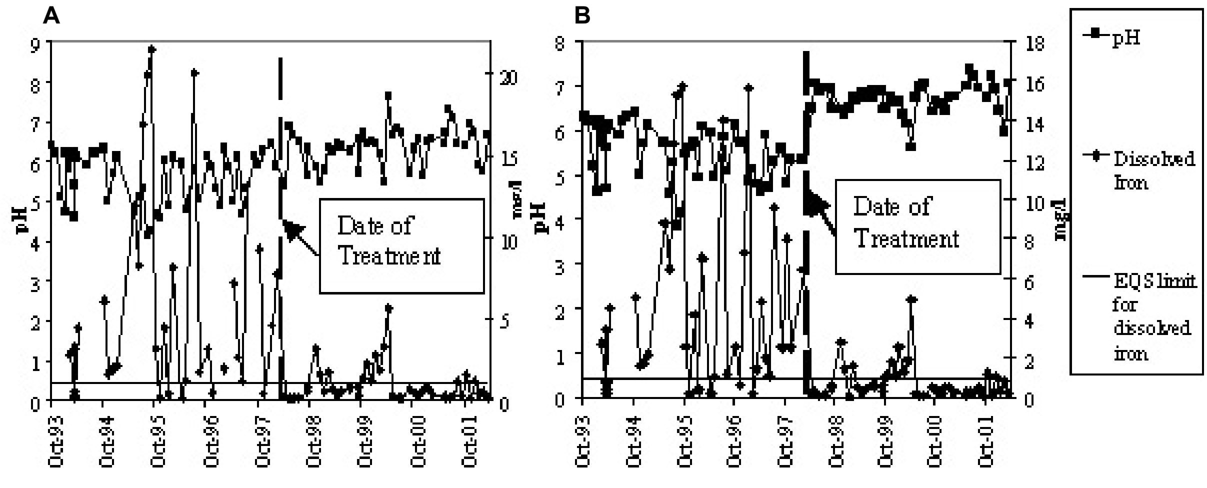


*Figure 1. pH and dissolved iron at G4 (IA; original discharge and current overflow) and G5 (B; downstream of phase III treatment system)*

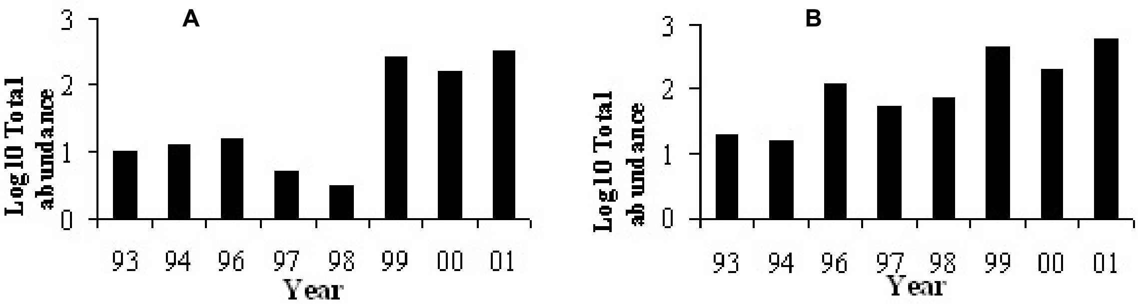


*Figure 2. Summer total abundance data for site BP5 (A) and G4 (B)*

G5 shows a much greater increase in pH following treatment. This site is downstream of the discharges from the Phase III wetlands which contain two RAPS cells. The alkalinity generated from these RAPS cells raises the pH sufficiently to have a much greater buffering effect in the receiving water.

### Macroinvertebrate populations

Macroinvertebrate assemblages were assessed in the spring and summer of each year. The total abundance of individuals at each site was used as a simple method of assessing the recovery of the population as a whole. The results from this method are similar to those shown by BMWP score and number of taxa. Variations in abundance over time, and specifically following treatment, were not obvious at some sites. Sites BP5 and G4 are immediately downstream of the two main mine waters on the Blaenpelenna and Gwenffrwd. They respectively demonstrate the improvement in total abundance following mine water treatment (Figure 2).

The TWINSPAN classification was used to assign the sites into groups that are essentially similar in taxonomic composition. The groups identified can then be related to environmental variables, while specific indicator organisms are identified that govern membership of each group. Using this statistical tool, improvements over time can be assessed as the sites move from the high number groups to lower number. Table 3 shows the average values for the BMWP and ASPT scores, number of taxa and total abundance for the four groups (Von Reibnitz 2001).

A map of the changes in TWINSPAN groups in summer is shown in Figure 3. At the control sites FD3, A1 and A3 there have been few changes in group membership across the years. On the Blaenpelenna there has been a change from Group 4 to Group 3 at the upstream

**Table 3. Biotic indices data for the summer TWINSPAN classification groups**

| | TWINSPAN group | BMWP[a] | ASPT[b] | Number of taxa[c] | Total abundance[d] |
|---|---|---|---|---|---|
| Summer | 1 | 86.7 | 5.9 | 14.6 | 887 |
| | 2 | 82.0 | 6.0 | 13.5 | 810 |
| | 3 | 53.4 | 5.5 | 9.7 | 142 |
| | 4 | 24.5 | 4.7 | 5.1 | 16 |

Notes: a Mean Biological Monitoring Working Party (BMWP) score
b Mean average score per taxon (ASPT)
c Mean number of taxa
d Mean total abundance

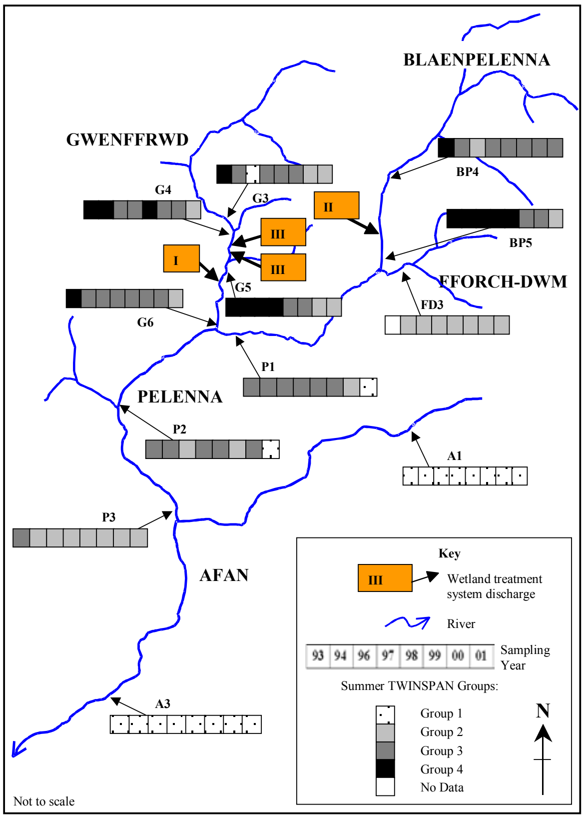


*Figure 3. Summer TWINSPAN results*

site. Downstream of the mine water, the improvements following treatment are obvious from 1999 onwards. However, the spring data (Wiseman *et al.* 2002) do not show an improvement until 2001, possibly due to the increased environmental stress in spring caused by the more frequent acidic episodes. Furthermore, certain species that appear to return quickly in this catchment once the mine water pollution has been removed were abundant only in summer samples. This is due to the annual life cycle of these species, and it is likely to account for the more pronounced recovery seen in summer.

*Ephemerella ignita*, a species of mayfly, was the main species that characterised the recovery of this catchment. It exists in the control sites in fairly stable numbers but was not evident at any of the mine water impacted sites. Following treatment of the mine waters, *Ephemerella ignita* were the first species to obviously recover. Nelson and Roline (1996) also found that the number of taxa in the Ephemeroptera order increased following mine water treatment along with Plecoptera and Trichoptera. Ephemeroptera were identified as being intolerant to elevated metal concentrations by Malmqvist and Hoffsten (1999) and Soucek *et al.* (2000). *Leuctra spp.* (stonefly) were also identified as indicators of the recovery of the Pelenna catchment, but the improvements were not as marked as those of *Ephemerella ignita.*

On the Gwenffrwd, a similar pattern emerges from the TWINSPAN analysis. Some recovery is seen upstream over the entire time period. A greater recovery is seen during both spring and summer below the mine water discharges following the main treatment in 1998. In spring 2000 the Whitworth A system, treating the most polluting mine water, became blocked with ochre for a period of a few months, discharging untreated mine water. This blockage, combined with the impacts of the natural underground diversion of the Gwenffrwd, caused a number of environmental stresses in the catchment. The iron levels in the watercourse, which were well above 1 mg/L during this period (Figure 1), especially affected the invertebrates in spring. At all the Gwenffrwd sites during this period, the invertebrate population soon reverted to the pre-treatment polluted conditions. In 2001, once these problems had been resolved, the invertebrates recovered quickly, demonstrating the best improvements to date.

The TWINSPAN analysis also identified improvements in the macroinvertebrate populations further downstream, on the Pelenna. During both spring and summer improvement has been gradual over a number of years, as each mine water has been treated.

It has taken a couple of years for the impacted sites to move up through the groups to match those represented by the control sites. However, it was noted earlier that the abundance of species appears to recover quickly. The most likely reason for this is that when water quality improves, the numbers of species can increase, but for new species to colonise the area they need to migrate in from elsewhere. The easiest method is by downstream drift from a healthy upstream population. Nelson and Roline (1996) found that invertebrate populations recovered to comparable levels of upstream sites within two years. They suggested that aquatic communities impacted by metals, in the absence of degraded habitat and with nearby colonist pools, will recover quickly if low instream concentrations of toxicants are achieved. The limited upstream populations on the Pelenna are likely to slow down the recovery of the invertebrates, as the sites have to rely on recolonisation from downstream.

*Fish populations*

Figure 4 contains the observed and expected trout fry densities in the catchment over the period of monitoring. Table 4 contains the National Fisheries Classification Scheme (NFCS) scores for 1993 and 2001, along with the expected score.

The Fforch Dwm (FD3) (the control site for the catchment) has had a fairly stable fry and parr population, except in 2000. This was most likely to have been caused by habitat loss due to erosion of a spoil tip. The site was ranked as grade A in the NFCS score throughout most of the years of sampling.

**Table 4. Observed National Fisheries Classification Scores (NFCS)**

| Site | 1993 | 2001 | Predicted |
|---|---|---|---|
| P1 | E | B | C |
| P2 | D | A | D |
| P3 | D | C | D |
| BP4 | E | D | C |
| BP5 | E | B | B |
| G3 | F | F[b] | C |
| G4 | F | B | B |
| G5 | F | A | C |
| G6 | F | B | C |
| FD3 | A[a] | A | A |

Notes: a Data for the Fforch Dwm (FD3) from 1994, as it was not sampled in 1993
b Site G3 is inaccessible for fish, due to a migratory barrier

The Gwenffrwd and Blaenpelenna sites have all demonstrated significant improvements in the populations of fry. Many sites have improved from having no fish or very few fish to having populations that meet or exceed the expected fish densities, in some cases within a year following mine water treatment. This improvement is also seen in the sites upstream of the mine water discharges, although the upstream Blaenpelenna site (BP4) is still below its expected NFCS population density. It has been noted that fish annually returned to the Pelenna and attempted to spawn (M. Brett, Fisheries Enforcement Officer, pers. comm.) but the water quality impacts on the eggs and fry meant that few survived. Following the treatment of the mine waters, the recovery of the fish has been quick, as many more eggs and fry survive. As a result of the overflows on the Gwenffrwd in 2000, the fry population was severely reduced, especially at site G4. Once the blockages were cleared, the population recovered again the following year.

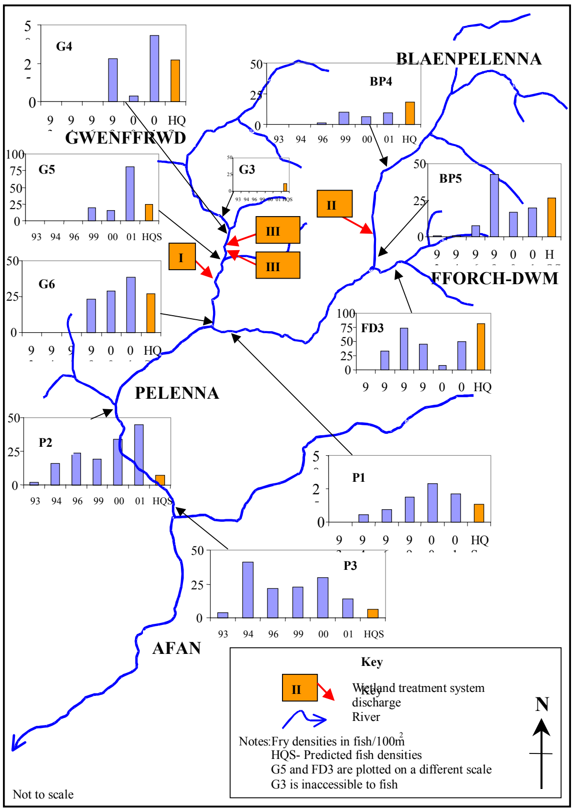


*Figure 4. Observed and expected trout fry densities*

At site P2 on the Pelenna there was a large increase in the population of fry, again exceeding the expected densities. Further downstream at site P3, increases are again evident, but these are not so great, as the existing populations were healthier due to the better water quality at this distance from the mine water discharges.

*Riverine birds*

The riverine bird survey was undertaken in 1996 and 2001 to assess the effects higher up in the food chain, resulting from the improvements in water quality following mine water treatment. The total number of sightings has markedly increased from 1996 to 2001. This is especially evident for the populations of dippers and grey wagtails. A territorial analysis was undertaken on the data and used to assess how many individual territories were held by each species. Grey wagtails (*Motacilla cinerea*) held 17 territories in 2001 compared to five in 1996. Five dipper (*Cinclus cinclus*) territories were identified in 2001 compared to none in 1996 (Wiseman 2001). Due to their feeding habits, dippers are very good indicators of water quality, as they feed exclusively within the watercourse on the invertebrate populations and occasional fish fry. Roberts (1996) estimated that the catchment could support five dipper territories if the water quality was improved. It now has this number of territories, indicating significant improvements in water quality.

## CONCLUSIONS

The passive treatment of the mine water discharges on the Pelenna has been demonstrated to be very effective. The three phases of wetlands are removing the vast majority of the iron loading that they receive. The later two phases that treat the most polluting discharges are generally performing at a removal rate of around 95%. Significant increases in the pH of the discharges have also been achieved.

The river water quality changes observed as a result of this treatment performance are considerable. A stated objective of the treatment project was to lower the mean dissolved iron concentration in the watercourses to below the EQS level of 1 mg/L. This has been achieved at all the monitoring points on the rivers.

Macroinvertebrate populations have started to recover, with increased total abundance and species diversity being observed at a number of the sites. The abundance of the mayfly *Ephemerella ignita* in particular has increased. Various biological indices have shown that this recovery is most obvious immediately below the mine water discharges. The recovery of invertebrates appears to be slower than that observed in studies elsewhere; this could be due to episodic surface-water acidification impoverishing upstream populations and therefore limiting recovery by downstream drift.

The trout populations have recovered more quickly. At some sites the numbers of fry and parr reached predicted densities within one or two years after mine water treatment. Prior to remediation, adult sea trout had attempted to spawn in the river, but the ochre smothered gravels and poor water quality meant that few eggs or fry survived. Once the water and gravel quality improved, the populations were able to recover quickly.

With the increase in invertebrate populations a 'knock-on' effect up the food chain to the riverine birds has been observed. Numbers and territories of grey wagtails and dippers have increased dramatically in the catchment. The dipper is especially important as an indicator species, as it feeds exclusively in the aquatic environment and therefore requires clean water conditions.

The overflow problems experienced on the Gwenffrwd demonstrate how quickly the river water quality, macroinvertebrates and fish could be impacted again by mine water. This indicates the need for the systems to be maintained in appropriate operating conditions.

The monitoring of the performance and environmental benefits of these passive constructed wetlands have demonstrated that they can be an effective, low-cost, low-maintenance and sustainable solution to ecological damage caused by abandoned mine drainage.

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