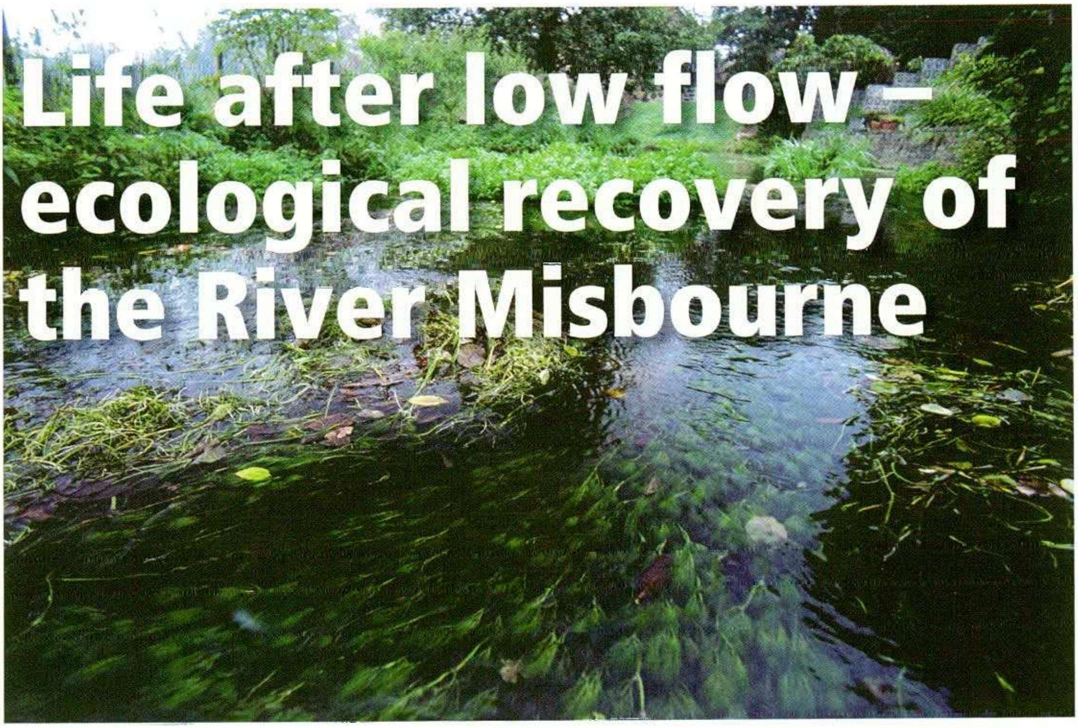
Life after low flow – ecological recovery of the River Misbourne



Martin Perrow, David Leeming, Judy England and Mark Tomlinson

Recolonisation of Stream Water-crowfoot in the River Misbourne, a characteristic species of chalk streams.
Martin Perrow

A succession of drought years in the 1990s led to widespread concern over the effects of low flows in many of the UK's rivers. In response, the National Rivers Authority (now the Environment Agency) published a list of the top 40 low-flow rivers in England and Wales. Amongst them was the Misbourne, a 27km-long treasured chalk stream naturally receiving virtually all of its flow as groundwater from the underlying chalk aquifer on the dip slope of the Chilterns Chalk escarpment in Buckinghamshire. Chalk streams characteristically have stable temperatures (approx. 11°C – relatively cool in summer and warm in winter), clear waters with low levels of suspended solids and little fine sediment on the bed, supporting diverse and productive communities of invertebrates, plants and fish. The value and threatened status of chalk rivers are recognised by their inclusion in UK Biodiversity Action Planning (www.ukbap.org.uk).

Whilst the 92km^2 predominant arable and mixed pastoral catchment, interspersed by relatively small, often picturesque settlements, hardly conjures up an image of a river under extreme anthropogenic pressure, the Misbourne has had a long history of intense modification, with ten mills, three now defunct watercress beds and three large artificial lakes heavily regulating natural flows along its length. Worse still, a long history of abstraction of groundwater for potable supply began at Amersham in 1901, with a further five abstractions added by 1962. The volume of abstraction increased more than ten-fold from the 1930s, reaching greater than 30 million litres per day (Ml per day) by the late 1980s, when it was estimated that as much as 65% of available water could be abstracted from the river. This appeared to be at the root of the Misbourne's low-flow problems.

An early effect of abstraction had been the migration of the perennial headwaters some 5km downstream from above Great Missenden (leaving the lakes there dry) to springs at Little Missenden (Fig. 1). By the early 1990s the river was in a sorry state. Although it flowed over its entire length briefly in 1995, the middle section from Amersham to Chalfont St Peter (c. 6.3km) was porous and habitually dry. The nadir came in autumn 1997, when, exacerbated by a drought

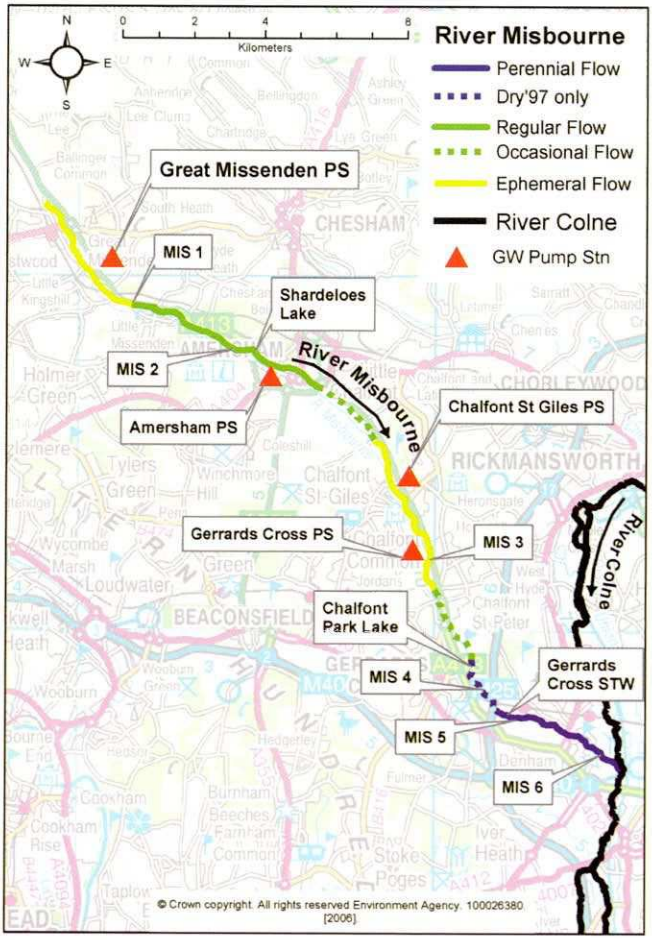


Figure 1 Map of the River Misbourne, illustrating the position of the main abstraction points, the study sections and the extent of particular types of flow.

that saw groundwater levels in the Thames catchment fall to their lowest levels in 20 years, 84% of the Misbourne was dry. The river's source then became the Gerrards Cross sewage-treatment-works (STW) discharge (a downstream migration of almost 23km, leaving just 4.3km of flowing water below this point to the Misbourne's confluence with the River Colne). Something clearly had to be done.

The Misbourne Alleviation of Low Flow scheme (or ALF) was devised and implemented over the winter of 1997 to spring 1998. Thames Water reduced abstraction in the upper river at Wendover Dean and Hampden Bottom by a mean of 7 Ml per day (replacing this with groundwater abstraction at Medmenham, on the Thames), and Three Valleys Water reduced abstraction from Amersham and Great Missenden by a mean of 8 Ml per day (replacing this with groundwater from the Colne Valley). This achieved the target of 15 Ml per day more water available to the river.

The aim of this article is to document the ecological response of the Misbourne over the eight years or so following the implementation of the scheme, as shown by monitoring of invertebrates, fish and vegetation. We discuss the lessons learnt from patterns of colonisation and the continuing human effect, how monitoring is best conducted, and the potential value of such schemes from a conservation perspective.

Monitoring the effects of the ALF scheme

Six study sections (MIS 1 to MIS 6) were selected, each covering about 500m, making a total of 3km (or 11%) of the river. These sections were within strategic reaches with different susceptibilities to drying-out, water quality and proximity to the River Colne (Fig. 1), their location determined by existing Agency biological monitoring stations (MIS 2-5), landowner support and ease of access. Physical structure varied between sections from the artificially widened (c. 8m) and straightened MIS 1 to the more natural MIS 4 and MIS 6, although both of these last two were still influenced by weirs at the end of the reach. Four of the study sections experienced channel-drying during the course of the study. This was either a short-lived event, as at MIS 4 during late summer 1997, or a more extended phase, as at MIS 1 and MIS 2 and, longest of all, at MIS 3, the last representing the middle reaches of the river from Amersham to Chalfont St Giles. The resurrection of the Misbourne from the chalk dust was complete only when flow returned to this section in 2001, creating an important aquatic bridge linking the upper river with the permanently flowing lower river of MIS 5 and MIS 6.

The Agency commissioned an ambitious programme to monitor the physical and ecological structure and character of both the river and its floodplain, using existing standardised techniques such as River Corridor Survey (RCS), River Habitat Survey (RHS), Macrophyte Survey (MS), Aquatic Invertebrate Survey (AIS), Common Bird Census (CBC), Winter Atlas Survey (for birds – WA) and depletion (between stop-nets) electric fishing (for fish). This ran from 1996 until autumn 1999. To allow longer-term change to be better assessed, the monitoring of aquatic invertebrates and fish was continued, in spring or summer and autumn, until 2003, with fish-sampling at three sites in 2004. No sampling of any sort was conducted in summer 2001, when the foot-and-mouth disease (FMD) outbreak prevented all access to the river.

The Ver (above), Pang, Mimram and Gade, as well as the Misbourne, all suffered from low and even non-existent flows in the 1990s. Martin Perrow

Point-abundance sampling by electric fishing (PASE), developed during the initial monitoring, replaced the standard depletion technique. This was partly because this allowed both fish and habitat variables (including surface flow rate, depth, percentage cover of different substrates, woody and detrital material and all functional groups of macrophytes) to be monitored. Sampling at 50 points in each study section (i.e. n=300 per sample occasion for a total n=3,450) also provided a better statistical basis to assess change.

The species-level aquatic-invertebrate surveys were also adapted. After the initial sampling from a single site in each section, using a standard time-limited kick sampling and netting method, from 1997 onwards effort was increased to five sites located at about 100m intervals in each section in order to improve the detection of scarce species and changes in species abundance and assemblage structure. Around 500 species or taxa (some still await identification) were recorded from the 330 samples. These included about 350 that are conventionally regarded as fully aquatic, with part or all of their life-cycle spent in water. Sampling of non-aquatic species associated with wetlands or exposed riverine sediments (e.g. many rove beetles and some ground beetles), or having aquatic foodplants (e.g. leaf beetles and weevils), was limited to in-stream or river-edge habitats requiring the presence of water or wet mud. Numerous specialists were contracted to enable identification to species within the diverse range of groups encountered.

The 'ponded' nature of MIS 1 immediately after flow returned in May 1998. Martin Perrow

Fisheries sampling among the emergent plants of MIS 2 in 1998 immediately after flow had resumed. Martin Perrow

The response of vegetation

A year after it had dried out, 40 terrestrial species, particularly ruderals such as Common Orache *Atriplex prostrata* and Curled Dock *Rumex crispus*, had colonised MIS 1. The resumption of flow in spring 1998 was so sudden that some of these plants 'functioned' as submerged macrophytes alongside true aquatics such as Various-leaved Water Starwort *Callitriche platycarpa* and filamentous algae (mostly *Cladophora*) and marginal plants such as Water Mint *Mentha aquatica*. But it was the emergent vegetation that dominated the site, and the cover of Reed Sweet-grass *Glyceria maxima* expanded rapidly until the autumn of 1999, its spread across the channel prevented only by the unusual artificial depth of the reach, deeper than anywhere else on the river (mean of 70cm).

Strong flows over subsequent years allowed the development of a central flow path and limited emergent vegetation to the margin in MIS 2. Martin Perrow

Elsewhere in the Misbourne, as at MIS 2, semi-aquatic and emergent vegetation such as Branched Bur-reed *Sparganium erectum* and Fool's Water-cress *Apium nodiflorum*, as well as Reed Sweet-grass, persisted through the drought and continued to dominate the channel after flow returned, which made for interesting sampling. Continuous high flow then appeared to initiate a decline in emergent vegetation, which allowed subsequent colonisation by submerged species. At MIS 2, emergent vegetation decreased from a mean cover of 60% to around 20% by the spring of 2000. Submerged Water Club-moss *Fontinalis antipyretica* became dominant by autumn 2001, with Stream Water-crowfoot *Ranunculus penicillatus* subsp. *pseudofluitans* an important component by spring 2003.

At MIS 4, the recovery of Stream Water-crowfoot, which had surprisingly persisted in small patches through the dry-down, was stimulated by an increase in mean depth (from around 15cm to 25cm) and mean surface flow (to 45cm per sec) sufficient to encourage the transport of sand as well as silt, thereby further exposing gravel and stony substrates (reaching >80% by 2001). *Hildenbrandia rivularis*, a characteristic encrusting red alga of stony substrates in chalk streams, also appeared to be stimulated by strong flows. The experiences of MIS 4 were mirrored at MIS 5, where, after the decline of emergent vegetation, *H. rivularis* colonised and Stream Water-crowfoot expanded.

By autumn 1999, MIS 5 had taken on the character of a classic mini-chalk stream. However, returning to MIS 5 in autumn 2001, after the FMD outbreak, it was clear that a major event had been missed. The crowfoot population had crashed, and by the end of monitoring in autumn 2004 it had not recovered (remaining at <6% cover). This sort of phenomenon was not seen elsewhere in the Misbourne, suggesting a localised event. We suspect wholesale 'removal of weeds' by the riparian landowners. Recovery may then have been suppressed by intense grazing by a pair of Mute Swans *Cygnus olor*, encouraged by hand-outs.

In MIS 6, far greater change was observed than expected. Riffles, runs and pools developed, and these offered a range of ecological niches which were colonised by Stream Water-crowfoot, initially lost in 1997, alongside Various-leaved Water Starwort, the duckweeds *Lemna gibba*, *L. minor* and *L. minuta*, Canadian Pondweed *Elodea canadensis*, Curled Pondweed *Potamogeton crispus* (temporarily) and Common Club-rush *Schoenoplectus lacustris*. Natural changes following flow recovery were of far greater consequence than previous attempts at conservation enhancement through installation of boulders, willow spiling and logs.

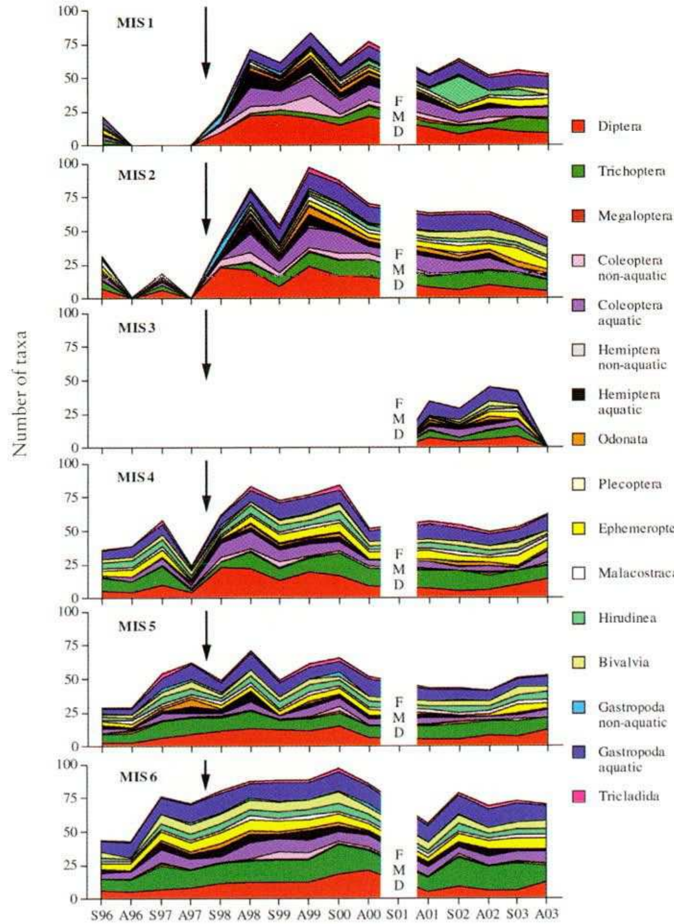


Figure 2 Changes in the invertebrate assemblage (number of taxa in each major taxon) of the six study sections (MIS 1-6) in relation to the implementation of the scheme (arrow). FMD = Foot & Mouth Disease

Invertebrate recolonisation of the upper river (MIS 1-3)

In 1996, prior to the upper river drying out completely, the invertebrate fauna there differed markedly from that found in the lower reaches (MIS 4-6), being a product of incomplete recolonisation after previous drying events (e.g. 1990-92) and the highly modified nature of MIS 1 in particular. Only two species, the freshwater shrimp *Gammarus pulex* and the caddisfly *Athripsodes cinereus*, gave any indication that MIS 1 was ever a riverine waterbody at all, and instead a characteristic pond fauna including the mayfly *Caenis robusta*, water bug *Sigara lateralis*, water beetle *Hydroporus palustris*, and other aquatic invertebrates with broad habitat requirements was present. An unusual find was the leech *Theromyzon tessulatum*, which is a blood-sucking parasite of ducks and other waterbirds, attacking the nasal or buccal cavity, and was most likely to have been introduced by a host. MIS 2 also supported a curious blend of invertebrate species, with particular groups unusually absent or represented by very few species. For example, there were just two aquatic molluscs, the operculate snail *Bithynia tentaculata* and the lake limpet *Acroloxus lacustris*, and no pea mussels, flatworms or leeches.

In spring 1998, within a few weeks of the return of water to MIS 1 and MIS 2, a conspicuous feature of the assemblage was the presence of semi-aquatic or terrestrial invertebrate species, many of which are associated with damp mud or riparian wetland, or the later stages of hydroseral succession. These included molluscs (especially Succineidae, Zonitidae and Helicidae), beetles (Carabidae, Staphylinidae and others) and various fly larvae (particularly Tipuloidea). These groups are frequently disregarded in river surveys as 'tourists', as they tend to occur rather infrequently in-stream, or are overlooked, because the expertise to identify them fully is not widely held amongst river biologists. By autumn, many of these non-aquatic species had indeed declined or disappeared, as their aquatic counterparts colonised.

The colonists of MIS 1 and MIS 2 during 1998 included highly mobile insects such as water beetles, bugs, dragonflies and flies that are well adapted to exploit newly formed or temporary areas of habitat. Within a year, a particularly rich fauna of around 60 taxa was present (Fig. 2) in MIS 1. Not unexpectedly, standing-water species dominated, although they included the scarce diving beetle *Rhantus suturalis* amongst other uncommon species, including those associated with functioning calcareous springs and groundwater seepages, such as the scarce diving beetles *Agabus biguttatus* and *Hydroporus marginatus*. Whilst some non-insect groups were represented, such as the shrimp *Crangonyx pseudogracilis* and seven aquatic snail species, pea mussels and

The caddisfly *Odontocerum albicorne* was recorded during the survey and it is hoped that this species, normally found in torrential streams, will continue to survive in the Misbourne. David Leeming

leeches were absent for several years. However, colonisation by riverine species did begin with the onset of exceptional flows around autumn 2000, when caddis such as *Agapetus fuscipes* and *Hydropsyche* species were present in fairly low numbers. *Gammarus* eventually replaced *Crangonyx* as the dominant shrimp by autumn 2003, when running-water mayflies such as *Ephemera danica*, *Centroptilum luteolum* and *C. pennulatum* had also become established, and another, *Caenis luctuosa*, was particularly abundant by the end of the study period. Populations of many of the opportunist ditch or pond species had declined or disappeared by this time. They included scarce species of conservation interest associated with the spring-line, and it was hoped that these had colonised reawakened springs further up the Misbourne valley.

MIS 2 also benefited from a rapid influx of mobile colonists including a running-water element, with the mayfly *Baetis rhodani*, the caddisfly *Hydropsyche angustipennis* and the beetle *Limnius volckmari* reflecting the restoration of riffle habitat. *Gammarus* quickly replaced an abundant *Crangonyx* population by spring 1999, by which time non-insect species, such as two flatworms, two leeches and two pea mussels, had also arrived. Increased discharge during 2000 and 2001 prompted further bias towards a running-water invertebrate assemblage more similar to that found in the lower river than had been the case previously.

Contiguous flow over the whole river was achieved by 2001. As at the other sites, recolonisation of MIS 3 was rapid, although by only about half the number of taxa compared with the situation at MIS 1 or MIS 2. This was probably a reflection of the prolonged time over which the site had been dry, with no remnant populations and no immediate source of colonists. Consequently, it was remarkable that amongst the colonists in autumn 2001 were individual specimens of the mayfly *Heptagenia sulphurea*, previously known only from the neighbouring River Chess, and the caddisfly *Brachycentrus subnubilis*, which was previously unknown in the wider Colne catchment. These mirrored the strange occurrence of minnows in this reach (see below), and neither species has been recorded since. These promising signs were promptly cut short as the water disappeared beneath the chalk by autumn 2003.

Wane and wax of the invertebrate assemblage in the lower river (MIS 4-6)

It was known that the lower river below Chalfont Park as far as Denham Country Park contained an important aquatic-invertebrate community into the early 1990s, with many pollution-sensitive mayflies, caddisflies and other groups present that are characteristic of 'classic' southern chalk streams. Upstream of the Gerrards Cross sewage-treatment-works discharge at MIS 4, the river also supported White-clawed Crayfish *Austropotamobius pallipes*, even though this species had been lost to outbreaks of 'crayfish plague' from nearly all other known locations in the wider Colne catchment as early as the mid-1980s. Sadly, the brief dry-down of MIS 4 in the late summer/autumn of 1997 seems to have been the final straw for the White-clawed Crayfish, which has not been found since. Fortunately, the same is not true of the caddisfly *Odontocerum albicorne*, which is normally a species of torrential streams or rivers and is virtually unknown in the Home Counties or eastern England. A population of this species had re-established in MIS 4 by the end of the study period, and it was hoped that its long-term decline and range contraction in the Misbourne noted since the 1980s could ultimately be reversed.

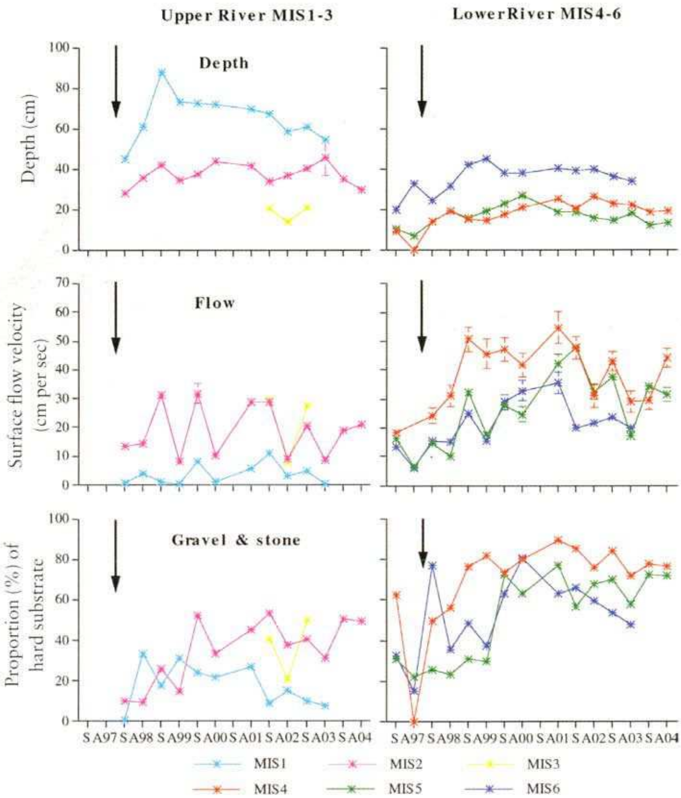


Figure 3 Changes in mean depth, mean surface flow and the proportion of hard substrate in the upper and lower Misbourne in relation to the implementation of the scheme (arrow).

Remarkably, the temporary dry-down did not lead to the elimination of all invertebrates (Fig. 2). A sample from a puddle of water in an otherwise dry channel in autumn 1997 contained many of the characteristic pollution-sensitive caddisflies, mayflies and crustaceans, illustrating that this may have been an important refuge that allowed for subsequent rapid recovery. Within a year, the maximum number of taxa recorded in MIS 4 had been reached.

Whilst MIS 5 and MIS 6 retained permanent flow, the substantial improvement in flow, depth and the proportion of hard gravelly substrate (Fig. 3) showed how pervasive the effects of chronic low flows had been on the invertebrate assemblage. Invasion of the channel by opportunist ditch or pond species produced unusual communities, as illustrated by a sample collected from MIS 6 during autumn 1997 which contained the caseless caddis *Rhyacophila dorsalis* and the screech beetle *Hygrobia hermanni*; two species that are generally most unlikely to occur together as their habitat requirements are poles apart. Moreover, whilst some riffle-dwelling species such as *Gammarus* and *Elmis* had been severely reduced, others appear to have been lost, albeit temporarily. Following the restoration of flows during 1998 and the shift back towards habitats that are more fluvial in character (Fig. 3), the richness of insect taxa increased steadily from around 50 species to more than 70 by spring 2000 (Fig. 2). Coupled with the highest number of non-insect taxa (and thus less readily dispersive groups such as bivalve molluscs) than anywhere else in the Misbourne, the total number of taxa in MIS 6 reached more than 100. This contrasted with MIS 5, where the substantially lower peak of about 70 taxa was

Three-spined Stickleback were one of the first fishes to recolonise, following resumption of water flow. Paul Sterry/Nature Photographers

upstream migration of potentially native Browns from below MIS 4, and MIS 3 remained dry until 2001, preventing dispersal of any survivors from remnant pools (if these existed), it was strongly suspected that all trout originated from illegal introductions for angling purposes at a number of sites.

Remarkably, the capture of young-of-the-year Brown Trout in MIS 4 in both 2003 and 2004 suggested that stocked fish had 'naturalised' and begun to spawn successfully, using the abundant (>75% cover) hard gravel/stone substrate as a spawning medium. Likewise, three years of good flows exposing gravel and stone in MIS 2 seemed to lead to spawning and the development of a self-sustaining population. Despite suitable habitat and at least some adult stock – large individuals were present in the mill pool upstream of MIS 5 until at least 1996 and two large (to 385mm) individuals were caught at MIS 6 in 1997 – there was no sign of a recovery of a trout population in the lower river.

Recolonisation by Three-spined Sticklebacks *Gasterosteus aculeatus*, typically the pioneer fish colonist of new waterbodies, began in autumn 1999 in MIS 4, where they had dominated the fish community prior to ALF. Both Three-spined and Ten-spined Sticklebacks *Pungitius pungitius* reached MIS 2 in 2000, the former eventually reaching the remote outpost of MIS 1 in spring 2003. Whilst the purported 'eggs on birds' feet' route may have been used to reach MIS 1, the large inoculum of sticklebacks in MIS 2 suggested an origin from a forgotten puddle in Shardeloes Lake. Just a year after colonising, Three-spined Sticklebacks had reached the huge density of 3.7 individuals (ind.) per m^2 in MIS 2, probably the result of a protracted breeding season and the potential production of several broods a year by each protective male. Competitive exclusion by this massive density of Three-spined Sticklebacks may have been responsible for the demise of their less aggressive Ten-spined relatives. Incredibly, Three-spined Sticklebacks themselves suffered a catastrophic decline to just 0.01 ind. per m^2 by the summer of 2002 (Fig. 4). If not the root cause, the huge (>70g per m^2) biomass of predatory large trout was thought likely to have exacerbated

reached rather quickly in 1998, followed by fluctuation until 2000. The difference between the two sites may be due to the difference in habitat diversity. At MIS 5, the dominance of the channel by macrophytes, be they emergent or submerged (see above), appeared to buffer potential remodelling of the channel by increased flows (also enabling sticklebacks to persist, see below). In contrast, at MIS 6, a steady increase in both flow rate and hard substrate (Fig. 3), but with retention of silt in pools and edges, simply increased habitat for all.

The decline in richness in the entire lower river, which began in autumn 2000, was thought to be caused by the eradication of opportunistic species (and their preferred habitats) by the winter spates and sustained high flows until spring 2002, initiating catastrophic drift of many invertebrates. For example, within MIS 6 *Elmis* had greatly reduced populations in spring 2002, and a small population of Fine-lined Pea Mussel *Pisidium tenulineatum* had disappeared from a hitherto silted site in the section by autumn 2001. By 2003, there was some evidence that ameliorating conditions were once again allowing the return of species associated more with still waters.

Natural and not so natural recolonisation by fish

Recolonisation by fish proved to be rapid as, within 1-2 years of the resumption of flow, Brown Trout *Salmo trutta* and Rainbow Trout *Oncorhynchus mykiss* appeared in surveys in MIS 1, MIS 2 and MIS 4 (Fig. 4). However, as these events involved non-native Rainbows, there seemed to be an impassable barrier to any the speed and depth of this decline.

Even in the absence of trout in the perennially flowing MIS 5, a similar decline in sticklebacks was observed from autumn 2000 to 2001. Sticklebacks had persisted through the shift from emergent to submerged vegetation, with either vegetation type seemingly supplying nest sites and refuges from the stronger flows for these relatively poor swimmers. However, the switch to open conditions through invasive management (see above) appeared to precipitate the decline in sticklebacks and, rather perversely, to promote significant and desirable change in the fish community. A dense (to nearly 2 ind. per m^2) population of Bullheads *Cottus gobio*, a characteristic component of the chalk-stream fish assemblage, rapidly developed (Fig. 4). Bullheads are physically adapted to faster flows and gravelly substrates, typically nesting under large stones (Perrow *et al.* 2006), and were thus likely to have responded to the peak surface flow velocities (>40cm per sec) and cover of hard substrate (>75%) observed in 2001 and 2002 (Fig. 3).

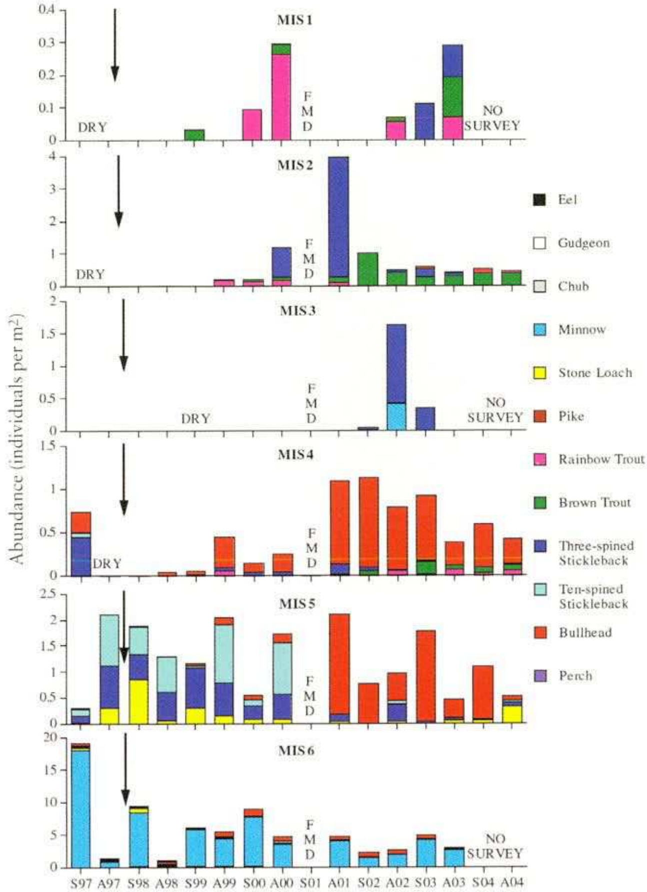


Figure 4 Changes in the fish assemblage of the six study sections (MIS 1-6) in relation to the implementation of the scheme (arrow). Each species in each section is represented by its mean density (individuals per m^2) as sampled by PASE.

After recolonising, just a few months after the resumption of flow, Bullheads also dominated the fish assemblage of MIS 4 at high density under similar habitat conditions of high flow and hard substrate. The source of Bullheads remains difficult to explain, since the large weir downstream of MIS 4 near the M25 would have prevented upstream migration from the lower river. One explanation is that some individuals survived in small pools, which may have persisted in this impounded section, as has been suggested to occur in the River Till, a chalk winterbourne with seasonal flows (Perrow *et al.* 2006). Bullheads also colonised MIS 2 in spring 2003, two years after flow returned, during the brief period of contiguous flow over the entire river. The only known source of colonists was MIS 4, some 7.5km downstream. This may be a further example of the surprising colonisation ability of what was once thought to be a sedentary small benthic fish (Perrow *et al.* 2006).

But perhaps the most surprising colonisation of all was the occurrence of Minnows at MIS 3 in the autumn of 2002. Prior to this, Minnows had been reported only from MIS 6. Short of a hitherto unrecorded ability to fly or to remain dormant in mud (as attributed to Swallows *Hirundo rustica* in the time of Gilbert White), it seems most likely that Minnows were introduced, perhaps accidentally with trout, which had been also recorded in the spring. Perhaps a bucket or two of fish and substrate helps to explain the unusual invertebrates recorded in this area (see above)?

The permanent residence of shoals of Minnows throughout the year, rather than this being a spring spawning phenomenon, was the only clear change in the fish assemblage in MIS 6. This contrasted with the species shifts in MIS 5, despite both sections retaining perennial flow. In truth, greater

Section MIS 6 of the Misbourne, showing a diverse structure of clean gravels and silty margins dominated by Fool's Water-cress. Martin Perrow

depth (apart from that in MIS 1), more stable and diverse habitat structure and the proximity of the Colne, with which fish may interact, ensured that MIS 6 always retained a rather different and more diverse fish assemblage (15 species) compared with the rest of the Misbourne. This included species not recorded elsewhere, such as Chub *Leuciscus cephalus*, Roach *Rutilus rutilus*, Perch *Perca fluviatilis*, Eel *Anguilla anguilla* and Pike *Esox lucius*. The capture of large fish (to 600mm in the case of Pike) also meant that biomass estimates remained high (>20g per m^2).

Lessons learnt

Experiences from the Misbourne illustrate that monitoring is most appropriate and cost-effective if it is both quantitative and specifically designed for the purpose. With hindsight, RCS, RHS, CBC, MS and WA (see page 337) were all of little value. Further, even though colonisation by many groups proved to be very rapid, the before-after design was constrained by the insufficient duration of monitoring to compensate for the lag response of river flow. Substantial change was thus still being recorded more than five years after the scheme. Monitoring would ideally have been extended further into 2006, when the recurrence of drought conditions tested the resilience of biological communities (see below). Whilst it could be argued that the timescale for monitoring of flow recovery could be as long as the proverbial piece of string, it does seem that at least five and probably ten years would be most beneficial. Focusing on specific aspects in a programme could be the best way of coping with limited budgets, and setting clear targets could be a good way of ensuring that monitoring is focused.

If more thought had been given to the target for the fish assemblage and individual species, it may have become obvious that for one of the most important species, Brown Trout, neither the origin of the previous stock (i.e. whether it was native, naturalised or introduced) nor whether it could recolonise naturally was known. A clear Agency-led proactive policy of reintroduction, if not of native stock then at least of fish of local provenance, would clearly have been preferable to unregulated and thus illegal introduction, which also led to the introduction of Rainbow Trout. Fortunately, the latter have not been the ecological disaster that they first appeared to be, as they seem to migrate rapidly through the system and there is no evidence that they can recruit. Without further introduction they should decline to extinction.

However, the same may not be said of Signal Crayfish *Pacifastacus leniusculus*. Unauthorised stocking and farming of these was undertaken between 1992 and 1996 in Shardloes Lake, with some inevitably finding their way into MIS 2. Following dry-down in 1996, Signal Crayfish were still being found alive under large stones after the riverbed had been dry for at least several weeks. Whilst it was assumed that Signal Crayfish had been naturally eliminated by drought, one was seen during a fish survey in spring 2003 after the recovery of flow. Whether this was a survivor or a more recent introduction was unknown. But, as there is evidence that the previous introduction of non-native crayfish had been perpetrated by the same possibly well-intentioned, but misinformed, landowners as were responsible for the recent stocking of trout, further introduction of crayfish seems distinctly possible.

Signal Crayfish. Richard Revels

With hindsight, there was a clear need to engage local stakeholders more thoroughly and effectively and, if education could not prevent introduction of non-native species, then perhaps the threat of prosecution could have done. Whatever the case, further introduction needs to be stopped and, armed with further evidence of the current distribution and population size of non-native crayfish, there is a good case for a programme of eradication.

In the case of the landowners at MIS 5, it may also have been possible to stop wholesale 'gardening', which seemed to lead to the loss of valuable plant communities and resulted in a number of unnatural species being introduced to the channel. These included Galingale *Cyperus longus*, a species of *Iris*, Bogbean *Menyanthes trifoliata* and even Australian Swamp Stonecrop *Crassula helmsii*. Fortunately, the last-mentioned highly invasive species was in a pot and one of the surveyors persuaded its owner to remove it. Greater public awareness in general may also have prevented the damage to the streambed of MIS 4 as a result of the activity of off-road vehicles, which is rumoured to have been during an episode of *Top Gear*. As this did not cause lasting damage, perhaps it is best to forgive Jeremy Clarkson on this occasion!

Despite these issues, the Misbourne has provided invaluable insight into the patterns of recolonisation should a more natural flow regime be established in a river affected by chronic low flows. In simple terms, even large impacts upon the invertebrate, macrophyte and fish assemblages are reversible and a more or less characteristic fauna and flora may be attained very quickly, provided that species are not lost in the meantime before suitable habitat is fully restored. This, in turn, points to the restoration of habitat types that are naturally expected within the corridor of chalk streams, such as riparian wetlands, to act as refuges for a number of often scarce, rapidly colonising species. Selected deep pools in the channel may also provide refuges for fish and several species of invertebrates, perhaps including native crayfish. Sadly, though, this is a lesson for the future, as it looks as if a reintroduction programme will be required for White-clawed Crayfish to re-establish in the Misbourne.

With recovery of flow, the extent of past channel modification and the way in which this hinders future geomorphological development have also become glaringly obvious. For example, MIS 1 is ultimately limited by its artificial channel morphology, although it still proved to be a valuable aquatic floodplain habitat for a variety of invertebrates (beetles especially). To maximise its conservation value, perhaps the best scenario is to scrape and lower the floodplain and restore the shallower natural sinuous channel, whilst retaining the current channel and wetland as a linear mimic of an 'oxbow' lake. At MIS 2 and MIS 5, narrowing the channel with flow-deflectors to encourage deposition near the bank without compromising channel capacity may now build on the success of the scheme. This sort of work would not have been so worthwhile before.

More importantly, the recovery of flow has clearly illustrated that the Misbourne is broken into ecological sub-units by mills and other structures. Establishing connectivity between sections is essential for groups incapable of aerial colonisation (from snails to crayfish to fish). Future habitat restoration should therefore focus also on bypass or even removal of such structures. But, for non-flying species to colonise the entire river, flow must obviously be contiguous, including through the (still) ephemeral middle reaches. Whilst this may be eminently desirable on one hand, an alternative view may be that the river has its highest conservation potential in the longer term if the middle reaches still flow only periodically, as this may limit colonisation by fish, which are hugely important in structuring the food-web, perhaps even eliminating favoured prey species and competitors such as large predatory invertebrates (e.g. some caddis, beetles and dragonflies). Low flows in the upper reaches may also naturally restrict fish from time to time, and continual resetting of the 'recolonisation clock' in some sections may ultimately maximise biodiversity as this favours 'pioneer' habitat specialists, which are naturally rare. But whether such species are available to colonise will depend on the existence of population refugia within the floodplain or wider catchment.

The future

In the past, it was difficult to state just what sort of ecological benefits may accrue from restoring flows. The wealth of nationally 'scarce' or RDB (14 species) and 'local' (67 species) invertebrates, characteristic macrophytes and a thriving population of Bullhead (a species listed under Annex II of the Species & Habitats Directive and thus of conservation value) in the Misbourne has provided a much clearer picture of how worthwhile it may be. However, whilst it is certain that flows have generally increased since 1998, the winter of 2000/01 was the wettest on record, prompting the nearby 'River' Kyme to flow for the first time since the 16th century. The Agency's view is that further monitoring of river flows in more 'normal' weather conditions will enable a more definitive view about how successful the ALF scheme has been, which will determine whether further expenditure on the Misbourne and perhaps other schemes can be justified.

In truth, perhaps the first test and answer to this question have already come and gone, as 18 of the first 23 months since November 2004 had rainfall totals below the long-term average. This resulted in a drought during 2006 even more severe than that of 1996 before the ALF was implemented, and the most severe drought since 1976. Whilst the Misbourne was affected and MIS 2 (along with MIS 3) dried down between August and October, neither MIS 1 nor MIS 4 suffered anything more than 'low flows' and both are thus expected to recover rapidly.

In conclusion, even if humans can halt the rate of global warming, there is clearly a lot more uncertainty to come, with increasing pressure upon our aquatic habitats in particular. Perhaps never before has the urgency to tackle what *is* within our control, including abstraction, been so clear.

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