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Hydrological and species-specific responses to water transfers into the River Wear, northeast England

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Abstract The Kielder Water Transfer Scheme in northeast England is designed to transfer water from the River Tyne, supported by Kielder Water, a major regulating reservoir, to the rivers Wear and Tees. The transfer structure is described, with an assessment of the potential influences on transferred water quality. The effect on low flow frequency in the receiving river is assessed, and long-term and short-term impacts of releases on invertebrate fauna are described. Data collected so far suggest that the long-term use of transfers has not disturbed whole invertebrate communities. However, short-term responses to individual releases do occur at the species-specific level. It is not known whether these represent a response to flow changes or water quality.

INTRODUCTION

The Kielder Scheme in northeast England is a regional strategic water resources system with two major components (Fig. 1):

(a) Kielder Water, an impounding reservoir with a capacity of about 200 M m^3, designed to regulate the flow in the Rivers North Tyne and Tyne; and
(b) the Kielder Transfer System, with a 6.2 km rising main and a 31 km gravity tunnel drawing water from the River Tyne at Riding Mill and releasing it when required into the Rivers Wear and Tees to support abstractions and prescribed flows.

The Scheme was designed in the late 1960s and early 1970s to meet a rapidly growing demand for domestic and industrial water supply (Burston & Coats, 1975). However, by the time the Scheme had been officially opened in 1982, growth in industrial demand had ceased and the requirement for a strategic resource to support regional water supply was much diminished.

Public inquiries in 1972 and 1973 (Northumbrian River Authority 1972; 1973) which preceded the authorization for the Kielder Scheme, provided an opportunity for objections to the Scheme to be heard and alternatives to be considered. Most objections focused on the impact of flooding on the North Tyne valley by Kielder Water and the associated disturbance to the local community and the environment. Although over 200 objections and representations were received from environmental organizations and the general public over a nine-week period, none related to the impact of transfers on the flow and ecology of the receiving streams.

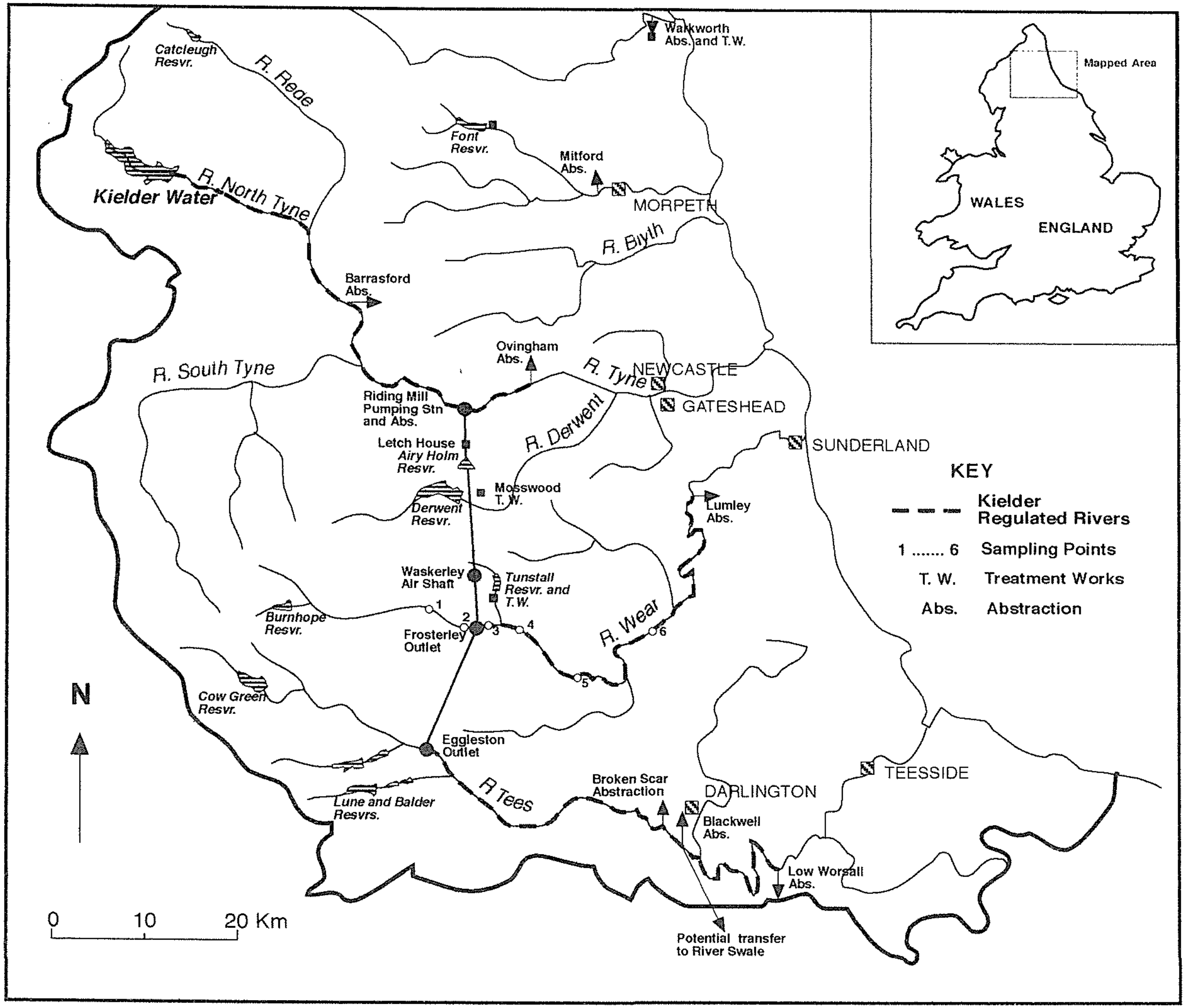


Fig. 1 The Kielder Water Transfer Scheme showing the transfer tunnel and sampling points on the River Wear.

In 1993 the National Rivers Authority (NRA) which has responsibility for ensuring the proper use of water resources in England and Wales, produced a regional water resources strategy, designed to meet demands for water to 2021 over a broader area of northern England (NRA, 1994). Although under the most probable scenarios, there will be no necessity for further major developments of water resources, the NRA listed and reviewed development options in the event that they would be required. One of the options was an extension of the Kielder Scheme by an inter-basin transfer of water from the River Tees southward to regulate the River Swale. Transfers to the River Swale would be supported where necessary by transfers from the River Tyne to the Tees through the Kielder Transfer System. The strategy was opened for public consultation and this option attracted widespread opposition with only four submissions giving qualified support out of 26 referring to this option. Fifteen submissions favoured a direct 69 km pipeline from the Tees to the treatment works adjacent to the demand centre. There was also support for small compensation reservoirs in the Swale headwaters to maintain minimum flows.

Clearly, over a period of two decades there had been a shift in public perception concerning the environmental implications of inter-basin transfers. However, few objectors to recent proposals specified the cause of their concern or supported their assertions from scientifically conducted investigations.

The transfer facility has been used in support of abstractions and prescribed flows on the River Wear during the dry summers of 1984, 1989 to 1992 (Marriott & Archer, 1993), and in 1994. These transfers have provided an opportunity for study and in this paper we outline investigations of impacts on flow and benthic fauna within the context of the transfer system structure and potential influences on chemical and biological quality of transferred water.

THE KIELDER TRANSFER SYSTEM

System structure

The inlet works to the tunnel, consisting of an 80 m long weir on the River Tyne and a pumping station, are situated 56 km downstream from Kielder Water (Fig. 1) and 13 km upstream from the tidal limit (Coats *et al.*, 1982). The gated weir creates a storage pond with an average elevation of about 18 m a.m.s.l. The inlet sill is above bed level and 1 m below the lowest crest of the weir so that debris entrainment is minimized and the maximum intake velocity is 0.3 m s^{-1} with all pumps in operation. The river front intake is protected by trash screen bars with a 65 mm gap and entry to the pumps from the intake forebay is further protected by band screens with 6.35 mm fine mesh screen openings designed to exclude smolts and to ensure again a maximum velocity of 0.3 m s^{-1} through the screens (Banks *et al.*, 1981). Six pump units each with a nominal fixed capacity of 1.05 m^3 s^{-1} are installed in the pumping station.

The 6.2 km pumping main linking the pumping station to the gravity tunnel consists of a steel pipeline of 2 m diameter, lined with cement mortar of 11 mm thickness. It rises to a tank and shaft at a top elevation of 223 m a.m.s.l. at Letch House (Fig. 2).

The gravity tunnel from Letch House to the River Tees was drilled predominantly through sandstones and mudstones and, with a minimum concrete lining of 200 mm the

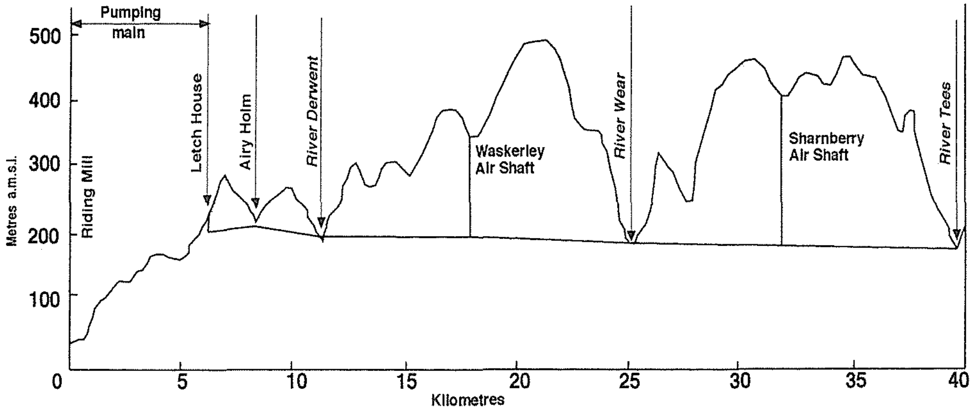


Fig. 2 Cross section of the Kielder transfer tunnel from the River Tyne at Riding Mill to the rivers Wear and Tees.

tunnel diameter is 2.91 m. The outlet portal at Frosterley on the River Wear is at 180.0 m a.m.s.l. and at Eggleston on the River Tees at 177.75 m a.m.s.l.. Their respective maximum discharge capacities are 2.0 $m^3 s^{-1}$ and 10.5 $m^3 s^{-1}$.

Airy Holm dam forms a head pond on the tunnel system to correct any imbalance between rates of pumping and outlet discharge. It has a surface area of 8.5 ha and a capacity below crest level of 220 000 m^3. Inflow to and draw-off from the tunnel is by means of a 5 m diameter shaft connected to the reservoir floor. It is unclear what level of screening is received by water passing from the reservoir to the tunnel. However, the reservoir can be by-passed by drawing down the water level below the shaft entry level.

The tunnel is designed to remain charged and has a capacity of 230 000 m^3 (approximately 30 000 m^3 for the rising main and 100 000 m^3 each for Letch House to Wear and Wear to Tees).

Impact of flow on the River Wear

Releases are made into the River Wear at Frosterley to support a public water supply abstraction at Lumley 70 km downstream, and a prescribed minimum flow of 2.0 $m^3 s^{-1}$ below the abstraction. Volumes and rates of transfer shown in Table 1 illustrate that during periods of low flow, transfers may be prolonged and may form a significant proportion of the flow. At the point of transfer, they sometimes exceed the natural receiving flow.

However, not all low flows in the River Wear at the outlet are equally supported by releases. The controlling abstraction rates vary, and prescribed flows are at a point where the basin area is 1008 km^2 compared with an area of 211 km^2 at the outlet. There are significant and variable natural inflows to the intervening reach and pumped mine waters also contribute. The impact of releases on the flow duration curve for the River Wear at the outlet is shown in Fig. 3. Minimum flow for the period 1984 to 1993 is increased by only 0.15 $m^3 s^{-1}$ but flow augmentation is spread over a range up to 1.5 $m^3 s^{-1}$ (exceedence probability 65%).

Table 1 Volumes and rates of transfer from the Kielder tunnel to the River Wear.

		1984	1985-1988	1989	1990	1991	1992
Total seasonal volume	Mm^3	0.50	Nil	7.83	5.27	1.04	1.20
Number of transfer days		35	Nil	145	105	46	38
Average transfer flow	$m^3 s^{-1}$	0.17	-	0.62	0.58	0.26	0.36
Max. transfer flow	$m^3 s^{-1}$	0.42	-	0.87	0.84	0.37	0.87
Min. receiving flow	$m^3 s^{-1}$	0.43	-	0.48	0.35	0.36	0.50
Mean river flow at transfer point			4.17 $m^3 s^{-1}$				
Mean river flow at Lumley (prescribed flow point)			14.60 $m^3 s^{-1}$				

Influences on transferred water quality

The biological and chemical properties of water released into the River Wear depend essentially on six factors:

(a) the quality of water stored in Kielder Water, its transformation in transit in the River Tyne and its proportional contribution to pumped water at Riding Mill (Dyson, 1971);

(b) the quality of water originating from the natural Tyne basin below Kielder Water as mixed with the release water (Northumbrian River Authority, 1972) including the risks of episodic pollution (North East Water, 1994);

(c) the effectiveness of pollution monitoring on the River Tyne and of the biological screening at Riding Mill;

(d) the transformation of water quality in the tunnel especially the reaction with tunnel lining when the water remains static in the tunnel for a prolonged period (Pomfret *et al.*, 1978; Garlick *et al.*, 1979);

(e) the quality of water in Airy Holm and especially the potential for algal blooms in hot dry summers when transfers may become necessary (Northumbrian Water, 1980); and

(f) retention time in the tunnel in relation to discharge rates and the volume stored in the tunnel and Airy Holm.

The greatest concerns prior to tunnel construction were for the deoxygenation of standing water in the tunnel and for a sequence of reactions leading to the release of ammonia and sulphides. Intense monitoring by Northumbrian Water Authority (1984) following construction revealed that these fears were unfounded and that regular or continuous flushing was unnecessary.

Influences on water quality are integrated in the water released to the receiving river and, although it is essential to consider the nature of these influences and associated risks, it may be more revealing to study the biological consequences in the receiving river.

THE RESPONSE OF BENTHIC INVERTEBRATES

The sequence of dry years from 1989 onwards, when significant releases were made,

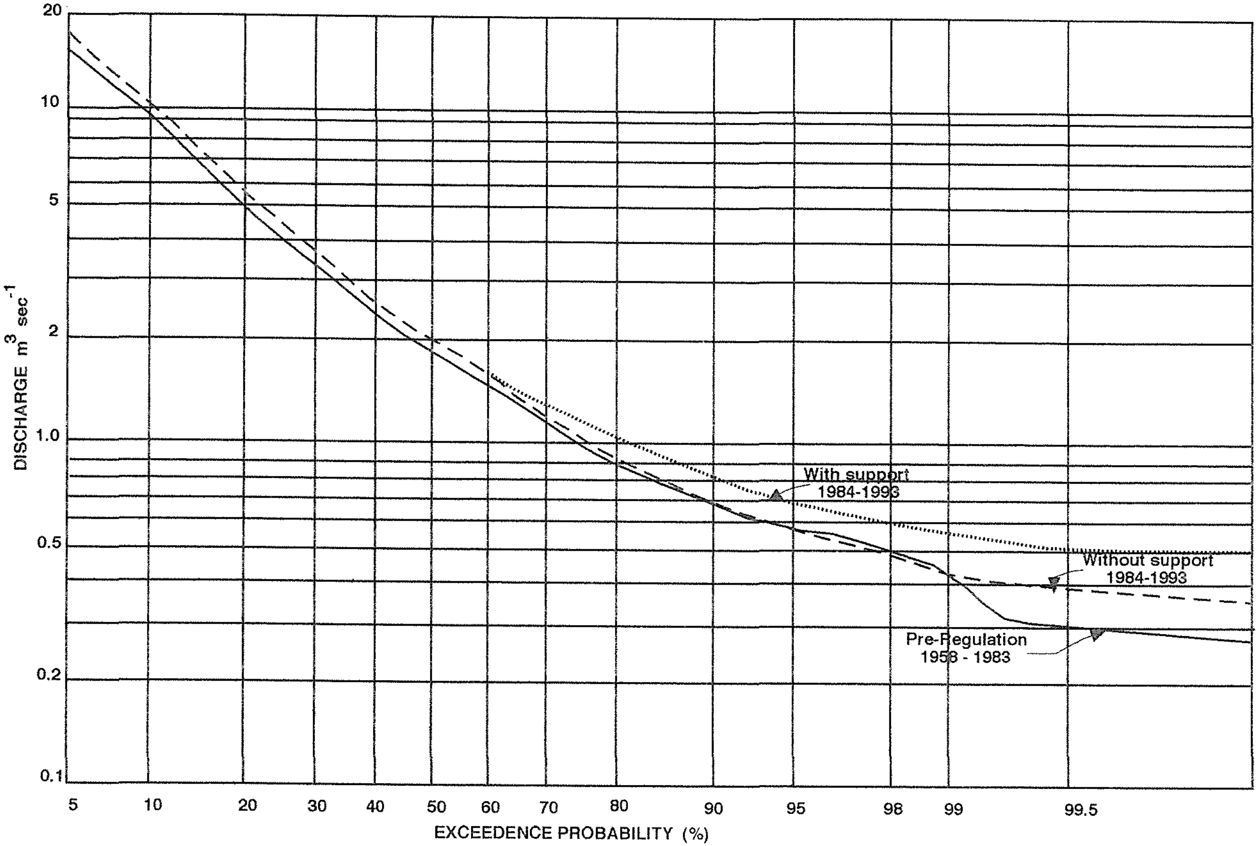


Fig. 3 Flow duration curves for the River Wear at the tunnel outlet at Frosterley, comparing flows with and without regulation support.

provided the opportunity for such study. The drought severity was of the order of 40 years return period and, given the nearly static forecast water demand, the degree and effect of this regulation is likely to be as great as can expected over the next several decades.

There had been no investigation of invertebrate communities prior to the main transfer years of 1989 and 1990 with which to make temporal comparisons. The study therefore concentrated on spatial comparisons, upstream and downstream from the release point. Six sampling sites were selected (Fig. 1) with sites 2 and 3 immediately upstream and downstream respectively from the outlet.

Firstly, the long term impact of transfers was investigated in 1993 and is reported in detail in Gibbins *et al.*, (1994) and Soulsby *et al.*, (1994). The structure of invertebrate communities at each site was examined in order to look for changes in stream fauna which could be attributed to releases in previous years. Using multivariate ordination and classification techniques, no discontinuities in invertebrate community structure were apparent at the transfer release point. Techniques for predicting the probability of species occurrence using environmental variables (Wright *et al.*, 1989) were also used to compare observed to predicted faunas. In general, invertebrate communities conformed to predictions, again with no anomalies associated with the transfer outlet.

Secondly, the short term impacts were studied in more detail around a five-day release from 26 to 31 August 1993. A 0.5 $m^3\ s^{-1}$ transfer was made into a receiving flow averaging 1.05 $m^3\ s^{-1}$. At each site three sets of kick samples were taken, one immediately before the release, another during the first 24 h and the third within 24 h of the end of the release. Five replicate samples, one from each of five discrete riffle habitats were collected at each sampling site. For both total invertebrate abundance and species richness, no significant differences (Analysis of Variance (AOV) $P < 0.05$) between samples taken before, during and after the release were found. The apparent lack of community level impact is supported by an ordination diagram of samples from site 2 and 3 over the three sampling occasions (Fig. 4). The plots show the total area covered by an ordination of all six sites together, although, for clarity, samples from sites 1, 4, 5 and 6 are omitted. The polygons enclosing sample replicates from before, during and after the release remain at a similar position on the ordination, with a large degree of overlap. If invertebrate communities were impacted, polygons from site 3 would be expected to move across the plot in response to the transfer input, whereas those from site 2 would remain relatively constant. This is not the case.

Four species of mayfly (*Ephemeroptera*) showed a significant numerical response (AOV, $P < 0.05$) at downstream locations associated with the timing of Frosterley releases (Fig. 5):

Baetis rhodani (Pictet)	($P = 0.023, F = 4.09, df\,2, 47$)
Baetis muticus (L.)	($P = 0.045, F = 3.31, df\,2, 48$)
Rhithrogena semicolorata (Curtis)	($P = 0.044, F = 3.34, df\,2, 47$)
Heptagenia sulphurea (Muller)	($P = 0.001, F = 7.89, df\,2, 47$)

Upstream of Frosterley (sites 1 and 2) their numbers remained unchanged. However, none of these significant changes in abundance occurred at site 3 where the Frosterley release enters the river. *B. muticus* decreased at site 5 and showed concomitant increase at site 6; *R. semicolorata* and *H. sulphurea* increased at sites 4 and 6 respectively following releases. *B. rhodani* increased at two sites downstream of the

Frosterley outlet (Duncan's Multiple Range Test, $P < 0.05$) (Fig 5). Changes in the abundance of each of these four species occurred between sampling occasions 1 and 2, suggesting an immediate response to the transfer.

The reason for these changes at present remains unexplained but the data illustrate the immediate impact of a relatively low intensity, short duration release on the species-specific level in a river regulated by transfers since 1984.

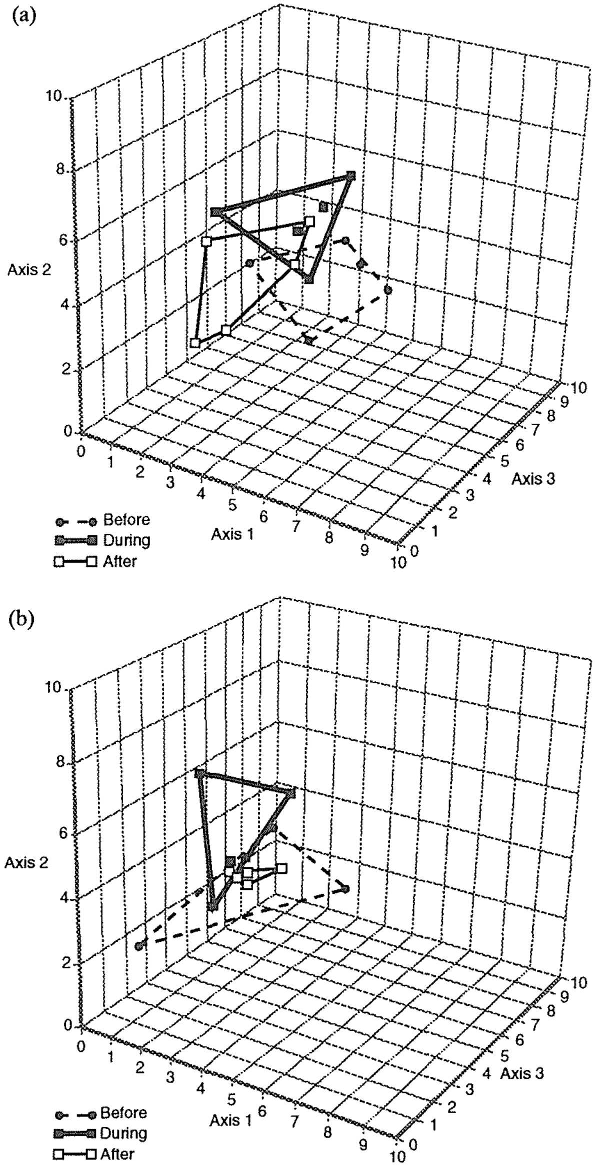
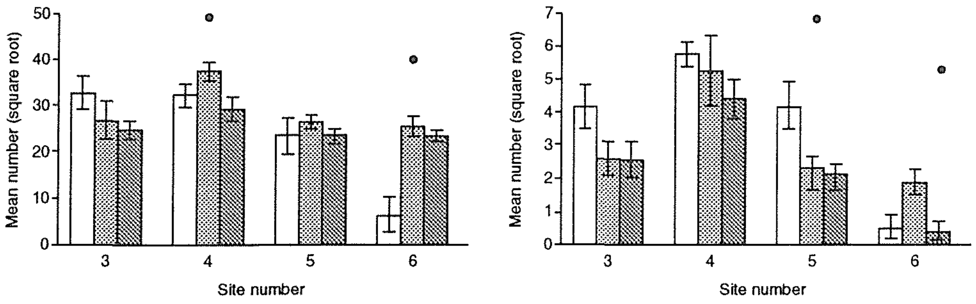
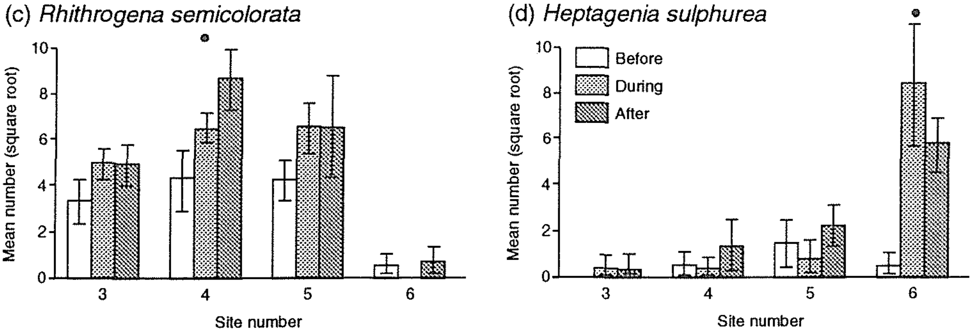


Fig. 4 Detrended Correspondence Analysis (DECORANA) of invertebrate sample data, before, during and after a transfer release for (a) Site 2, upstream; and (b) Site 3, downstream from the release point.



(a) *Baetis rhodani* (b) *Baetis muticus*



(c) *Rhithrogena semicolorata* (d) *Heptagenia sulphurea*

Fig. 5 Changes in abundance of selected invertebrate species over three sampling occasions on the River Wear, Aug-Sept 1993. Sites with significant changes (AOV, $P < 0.05$) are indicated (*).

DISCUSSION

The results presented here, although preliminary, raise a series of questions concerning hydrological disturbance of invertebrate communities and the general management of regulated rivers.

There was no discernible impact of transfers on invertebrate communities but, species level analysis revealed changes up to 39 km downstream from the release point. It is possible that similar changes occur in response to natural flow and associated depth and velocity variations generated within the catchment. In this case, such ecological adjustments may not be uncommon given that the release slightly altered the natural flow magnitude from 75% exceedence to 62% exceedence (Fig. 3). If changes are purely the result of discharge variation, then methods such as those illustrated by Archer & Williams (in press), must be sought to define more precisely the pre- and post-regulation disturbance of the hydrological regime which may then be linked to changes in the fauna.

The absence of species response at site 3, immediately below the outlet, is puzzling. One possible explanation is that although changes in species abundance are occurring at site 3, they are masked by the variability of site replicates.

One of the reported concerns over inter-basin water transfers is the possible introduction of "alien species" into the receiving system (Petitjean & Davies, 1988). As part of the present study, three drift nets (306 mm diameter, mesh size 250 mm) were placed simultaneously over the outlet pipe at Frosterley for two hours on 16 July 1994, to test whether invertebrates were being transferred into the Wear. Despite the inlet screening, described above, a number of invertebrates were found alive: *Chironomus longistylus* Goetghebuer, *Ephemerella ignita* (Poda), *Daphnia longispina* Muller and the Copepod *Cyclops* spp. All were single specimens except for *D. longispina* which occurred in large numbers; both moribund individuals and a variety of body parts were found. *D. longispina* are a still-water species and are most likely to have originated from Airy Holm reservoir rather than the River Tyne. Whatever their origin, *D. longispina* represent a substantial biomass or energy input to the Wear, potentially affecting the abundance of predatory species which collect their food from the water column. A more quantitative assessment of such species transfer is planned for 1995.

Many published accounts of disturbance effects have focused on whole communities (Voelz & Ward, 1989; Weatherley & Ormerod, 1992). However, for Kielder transfers to the Wear, the only responses so far detected are at the species-specific level and, as a result, any impact assessment based solely on community level analysis would be misleading. In a discussion of heavy metal contamination in English streams, Gower *et al.* (1994) stressed the importance of species level identification in determining sensitivity sequences. Systems such as the Biological Monitoring Working Party (BMWP) score and other general community measures are likely to overlook the type of changes reported here. For river managers, the question is whether to target effort at whole communities or individual species.

The development of an indicator species approach for assessing low flow problems could be of value to organizations such as the NRA. Species which are sensitive to flow change could be used to indicate possible community-level impacts. Future routine monitoring effort could be focused on a small number of sensitive species in a similar way to that advocated for assessing pollution problems (van Hassel & Gaulke, 1986). However, on the River Wear, subtle species-specific changes have not been translated to discernible community-level impacts and the species likely to prove useful as indicators are still unclear.

CONCLUSIONS

The primary purpose of the Kielder Transfer Scheme is to augment water resources for public water supply throughout northeast England and it has been used effectively for this purpose over the last six years. The associated provision of support to the River Wear at times of low flow was seen as a benefit at the time of the Scheme proposal. However, the present policy for water transfers is not viewed with universal favour by river users.

A questionnaire survey by the NRA in 1994 showed that concern was divided between those who advocate greater releases in dry weather to limit the impact of natural drought on river ecology and fisheries, and those who believe that rivers should be left to adjust naturally to extremes of weather and climate. The latter group believe that the risks of harmful transferred water quality outweigh the benefits.

The present study suggests that there are no patterns within invertebrate communities at the study sites on the River Wear which could be attributed to the long-term use of transfers. Although no immediate community responses to a short-term release were apparent, certain species do seem to be affected. It is unclear whether these species-level changes reflect flow related responses or are the result of changes in water quality resulting from the transfer.

These studies may help to allay the worst fears of river users. Nevertheless, the impacts to date may not yet reflect the full range of possible impacts. Further monitoring and analysis are required, both of biological impact in the receiving river, and risk assessment of the component influences on transferred water quality.

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