Factors Influencing Populations of the Endangered Freshwater Pearl Mussel *Margaritifera Margaritifera* in the River Ehen, UK.

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1. Introduction

The freshwater pearl mussel, *Margaritifera margaritifera* (**Plate 1**), is formally classified as an endangered species. Over the last 100 years, many mussel populations have declined or disappeared completely. A number of factors have been implicated in this decline, including overexploitation by pearl fishermen, poor water quality, 'smothering' of riverbeds by fine sediment and declines in salmonid fish populations (juvenile salmonids are the host of mussels during their glauchidial stage).

In 1995, English Nature commissioned a survey of six rivers in England where substantial pearl mussel populations existed. Subsequently, one of these rivers, the River Ehen in the Lake District, was proposed as a Special Area of Conservation for the species. The flow regime of the Ehen is regulated by Ennerdale Water, with abstractions from the reservoir used for potable supply. A Management Plan developed for the Ehen pearl mussel population highlighted two main issues:

- Poor riparian land management that leads to bank collapse and the entry of fine sediments into the river (**Plate 2**)
- The possible impacts of the reservoir compensation flow regime on instream hydraulic conditions for mussels.

The research summarised here had three specific objectives:

- To determine the age profile, mortality rates and long term viability of the Ehen mussel population
- To determine the suitability of sedimentary and hydraulic habitats for juvenile mussels
- To determine whether populations of salmonid fish may be a factor limiting the recruitment of young mussels

Plate 1. Adult freshwater pearl mussels Margaritifera margaritifera. As shown here, mussels typically lie partly buried in the streambed substrate.

Plate 2. Example to illustrate typical problems in the Ehen. The absence of natural riparian woodland leads to bank erosion, while inadequate fencing allows livestock to enter the channel, contributing to poaching and bank collapse. These factors can result in fine sediments entering the river.

2. Methods

A combination of field surveys and modelling studies were undertaken in 2003 and 2004. The work concentrated in the 13 km stretch of the Ehen between Ennerdale Water and its confluence with the River Keekle (**Figure 1**).

- Field surveys included assessment of the extent and distribution of fine sediment inputs (**Figure 1 b**), streambed sediment size characteristics, assessment of hyporheic water quality and quadrat-based surveys of mussel populations.

- Hydraulic conditions at two sites were modelled using 3-dimensional Computational Fluid Dynamics (CFD) models. Hydraulic conditions were modelled at discharges approximating the compensation flow at sites with medium-high (Site 2) and poor (Site 5) mussel densities. Each site consisted of a 50 m length of the river. The mesh used for prediction consisted of 700,000 cells at site 2 and 1,100,000 cells at site 5. Values of depth, velocity, shear and turbulence intensity were predicted for each cell.

- Juvenile salmonid populations were assessed using pre-existing fishery survey data.

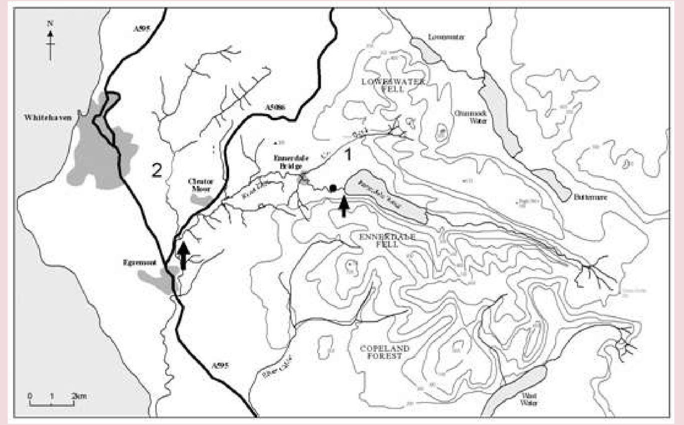

Figure 1a. Location of the River Ehen and study section. The study section is delimited by arrows. The Bleach Green flow gauge is shown as a dot, while the two main Ehen tributaries are numbered 1 (Croasdale Beck) and 2 (River Keekle).

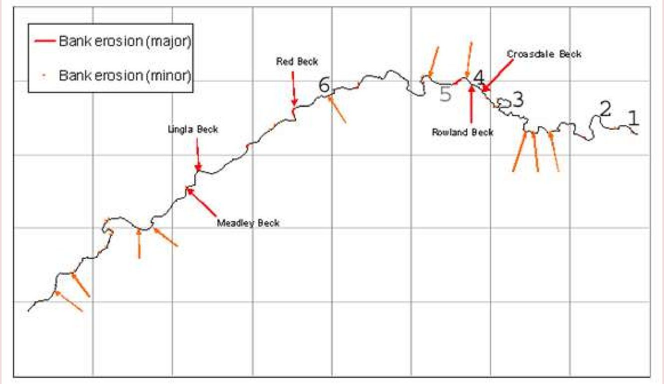

Figure 1b. The study section, showing location of study sites (1-6), areas of bank erosion and sediment inputs (major red, minor orange) from tributary streams.

3. Mussel population characteristics and juvenile salmonids

- There was marked variation in mussel densities between the 6 sites (range 0-105 mussels/m^2 **Table 1**). Only 2 sites had high densities (i.e. mussel beds); the remainder had few or no mussels.
- Small numbers of juvenile mussels were found at 3 sites, but in densities well below those expected for a viable population (**Table 2**).
- A consistent pattern was that more empty shells of young mussels were found than live mussels (**Figure 2**). This pattern is indicative of at least one 'event', of unknown duration, sometime within the last 20 years, that has been more damaging for juveniles than adults. This suggests that the mortality of juveniles is related to an aspect of their habitat use that is different to that of adults. Because juveniles are buried within the hyporheic zone whereas adults protrude more into the water column, the high juvenile mortality may indicate poor hyporheic conditions from time to time.
- The paucity of salmonid data for the Ehen, especially at sites where large numbers of mussels are present, make it difficult to draw any firm conclusions about the links between juvenile fish densities and mussel recruitment. Nonetheless, there was general evidence that fish populations in the Ehen are consistently below the optimum densities required for mussel recruitment. Numbers of fish at Ehen sites ranged from 0-50 juveniles per 50 m stream length, compared to an optimum value estimated to be 75(+) fish per 50 m.

Site	Visible / total mussels / m^2 (Quadrat counts)									
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
1	0/0	0/0	0/0	0/0	0/0	0	0	0	0	0
2	30/39	13/24	64/98	45/63	16/25	16	66	66	2	12
3	134/184	24/29	40/53	164/388	1/1	160	0	0	57	2
4	0/0	1/1	0/0	0/0	0/0	0	0	0	0	0
5	0/0	0/0	0/0	0/0	0/0	0	0	0	0	0
6	4/6	1/2	3/5	2/3	1/1	0	0	0	0	0

Table 1. Numbers of live mussels found in 1 m^2 quadrats at sites on the River Ehen. Visible mussels are those recorded during quadrat surveys; total numbers are calculated from the ratio of visible to total (visible plus buried) mussels established from previous work.

Site	Mussels / 50m^2	Mussels / m^2	Shells / 50m^2	% Juveniles (<65mm)
1	1	0.02	0	0.0
2	2320	46.40	33	3.1
3	5291	105.82	32	5.9
4	2	0.04	22	0.0
5	0	0.00	0	-
6	90	1.80	39	1.7

Table 2. Estimated overall numbers of live mussels, empty shells and relative numbers of juveniles recorded at study sites on the River Ehen.

4. Sediments and hyporheic water quality

- The surface sedimentary characteristics of 5 of the 6 study sites were very similar and broadly suitable for adult mussels (**Figure 3**). One of the sites (the site closest to Ennerdale Water) had a much greater proportion of fine material. There was a large variation in mussel density between sites with broadly similar sediment characteristics, while some sites with very different mussel densities had similar sediments. Thus, there is no evidence of any simple link between the *overall size distribution* of sediments and mussel densities. However, the 3 sites with relatively high mussel densities had the largest sized D84 sediment clasts.

- Excavations during mussel surveys indicated that there was much fine (silt/clay sized) material below the streambed armoured layer. This may be problematic for juvenile mussels.

- The chemistry of water in the hyporheic zone during the two periods sampled was extremely similar to streamwater (**Figure 4**). Thus, during these periods there was no evidence of the intrusion of poor quality groundwater into the hyporheos. However, sampling was undertaken at only two sites and restricted to two time periods. Hyporheic water quality may differ at other sites or at these sites at different times. Further work is necessary to fully assess hyporheic conditions and their impact on juvenile mussels.

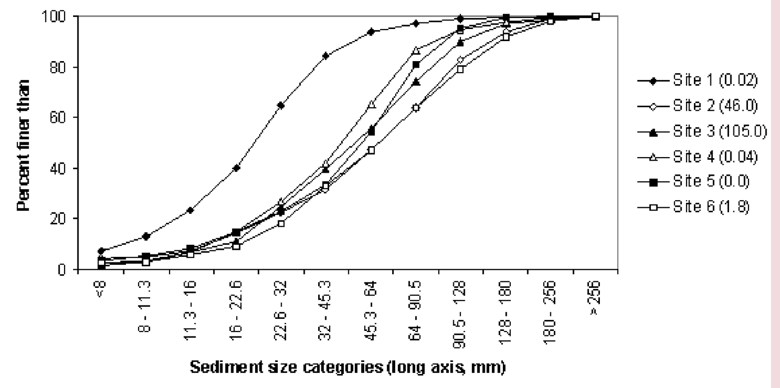

Figure 3. Sediment size characteristics of study sites. Characteristics were determined from the Wolman-walk sampling method. Values in parentheses are densities of mussels (number/m^2 **Box 3**).

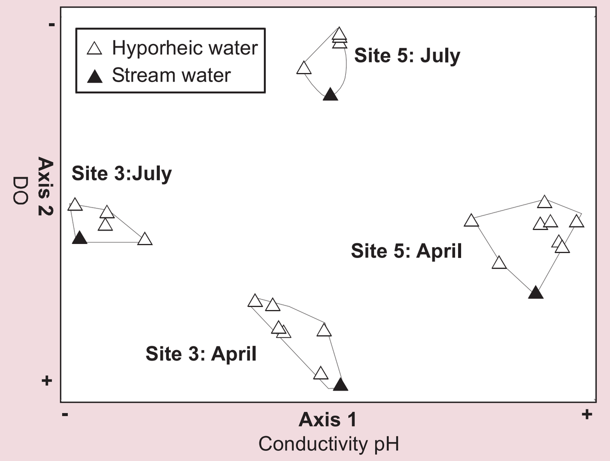

Figure 4. Principal Components Analysis of Ehen hyporheic and streamwater chemistry. Each symbol represents a sample. On each date, a number of samples from the hyporheos were taken from each site (20 cm depth within riffles), along with a single sample from the water column. There are clear differences between sites and dates. However, differences between hyporheic and streamwater chemistries at respective sites are relatively small; differences occur along axis 2, an axis that reflects DO (slightly lower in hyporheic samples).

5. Hydraulic conditions at compensation flow

- Previous work by the authors, together with other published studies, has indicated an optimum range of water velocities for mussels of 0.28-1.14 m s^{-1} (at the water surface). Outwith this range, velocities are considered sub-optimum. These broad tolerance profiles were used to give an indication of thavailability of suitable hydraulic conditions for mussels during periods of compensation flow.

- Figure 5 shows the cumulative empirical frequencies of surface velocities at compensation flow (0.4 m^3 s^{-1}) for the two sites modelled. At site 2 around 0.95 (i.e. 95%) of points had velocities below the optimum range for pearl mussels. Approximately 55% of points had velocities between 0.15 and 0.28 m s $^{-1}$, a range that defines usable but not optimum mussel habitat. At site 5, no velocities were within the optimum range and only around 20% were within the usable range.

Figure 5. Cumulative empirical frequencies of surface velocities for sites 2 (stippled line) and 5 (bold line). Values represent estimates of the probability that a surface velocity at any point along a site is less than v. Values are for a discharge of 0.4 m^3

Plate 3. Ad-hoc bank protection measures on the Ehen; here a landowner has dumped waste building material in an attempt to stop bank erosion.

6. Conclusions

- Surveys indicated ageing mussel populations in the Ehen, with little or no recent recruitment of juveniles.
- Overall, there was no clear evidence to link inter-site differences in mussel densities or age profiles to flow regulation: indeed the highest densities occurred at sites close to Ennerdale Water.
- In broad terms, the compensation flow results in water velocities predominantly below those considered most suitable for mussels. Nonetheless, the absence of high flows below the impoundment may help limit bed movement in what would otherwise be a flashy, unstable upland river system.
- The main sedimentary difference between the study sites appears to be the size of the D84 sediment, which is consistently larger at sites with high mussel densities. It may be that these larger clasts help stabilise the substrate, so providing more suitable conditions for mussels.
- The Ehen suffers from extensive, small scale/local bank modification designed to limit bank erosion (**Plate 3**). Where there is no or limited riparian tree cover, the river also suffers from local bank erosion brought about by poor land management (inadequate fencing, poaching by cattle etc). Although individually small, the cumulative effects of bank modification and erosion on the river are significant.
- The limited data on salmonids suggests that numbers may be sub-optimum for mussel recruitment.
- Mussel densities decrease with distance downstream from Ennerdale Water. It seems most likely that this pattern results from the combination of a number of factors.