
Old, G.H.; Naden, P.S.; Rameshwaran, P.; Acreman, M.C.; Baker, S.; Edwards, F.K.; Sorensen, J.P.R.; Mountford, O.; Gooddy, D.C.; Stratford, C.J.; Scarlett, P.M.; Newman, J.R.; Neal, M.. 2014. **Instream and riparian implications of weed cutting in a chalk river.** *Ecological Engineering*, 71. 290-300. 10.1016/j.ecoleng.2014.07.006

Instream and riparian implications of weed cutting in a chalk river

Old[a], G.H., Naden[a], P.S., Rameshwaran[a], P., Acreman[a], M.C., Baker[a], S., Edwards[a], F.K., Sorensen[b], J.P.R., Mountford[a], O., Gooddy[b], D.C., Stratford[a], C.J., Scarlett[a], P.M., Newman[a], J.R., Neal,[a] M.

[a] Centre for Ecology and Hydrology, Wallingford, Oxfordshire, OX10 8BB

[b] British Geological Survey, Wallingford, Oxfordshire, OX10 8BB

Corresponding author:

Dr Gareth H. Old, Centre for Ecology and Hydrology, Wallingford, Oxfordshire, OX10 8BB. Tel. 00 44 (0) 1491 692486 Email: gho@ceh.ac.uk

Abstract

Macrophyte growth is extensive in the iconic chalk streams that are concentrated in southern and eastern England with a limited global extent. Widespread and frequent weed cutting is undertaken to maintain their key functions (e.g. flood water conveyance and maintenance of viable fisheries). In this study, a multidisciplinary approach was adopted to quantify coincident physio-chemical responses (instream and riparian) that result from weed cutting and to discuss their potential implications. Three weed cuts were monitored at a site on the River Lambourn (The CEH River Lambourn Observatory) and major instream and riparian impacts were observed. Measurements clearly demonstrated how weed cutting enhanced flood flow conveyance, reduced water levels (river and wetland), increased river velocities, and mobilised suspended sediment (with associated chemicals) and reduced the capacity for its retention within the river channel. Potential implications in relation to flood risk, water resources, downstream water quality, instream and riparian ecology, amenity value of the river, and wetland greenhouse gas emissions were considered. Provided the major influence of macrophytes on instream and riparian environments is fully understood then the manipulation of macrophytes represents an effective management tool that demonstrates the great potential of working with nature.

Key words: weed cutting; conveyance; wetland; chalk stream; management; ecology

1. INTRODUCTION

Southern and eastern England hosts the largest chalk river resource in Europe (UK BAP Steering Group for Chalk Rivers 2004). Of the 161 chalk rivers and streams identified, ten are designated for their wildlife interest as river Sites of Special Scientific Interest (SSSI). Four of these are of European interest and designated as candidate Special Areas of Conservation (cSAC) under the Habitats Directive. They represent unique freshwater habitats that are listed in the UK Biodiversity Action Plan as priority habitats for protection.

A pristine chalk river is likely to consist of multiple channels that are largely shaded by trees (alder and willow); supporting patchy macrophyte cover. River water would be characterised by low nutrient and suspended solids concentrations (Mainstone, 1999). However, it is very difficult to accurately define reference conditions for chalk rivers

(Acreman and Ferguson, 2010) although they are needed in the implementation of the European Water Framework Directive (European Commission, 2000).

For more than 2,000 years man has modified these chalk river systems by clearing riparian woodlands, modifying channels (widening, deepening and straightening), elevating nutrient and suspended solids concentrations (from agricultural and urban sources) and reducing flows through abstraction (WWF-UK, 2009). In some chalk rivers low flows, high nutrient concentrations and deep accumulations of fine sediment have resulted in few macrophytes. Likely reasons for this include limited photosynthesis caused by prolific epiphytic algal growth and/or turbid water (e.g. Phillips et al., 1978), limited diffusion of nutrients to leaves owing to low velocity flow (e.g. Madsen et al., 2001) and/or epiphytic algal growth and unsecure rooting in surficial nutrient rich fine sediment (e.g. Spink et al., 1993).

In others rivers, the reduction in natural shade has increased the productivity and coverage of aquatic plants (cf Dawson and Kern-Hansen, 1979). Consequently extensive and frequent weed cutting has been undertaken for many years in many rivers to maintain their key functions, which include flood water conveyance, riparian water level control and viable fisheries (e.g. Baattrup-Pedersen and Riis, 2004; Nikora et al., 2008).

The instream hydraulic and ecological significance of weed is widely accepted and whether or not to cut is a heavily debated subject. It has been suggested that the most satisfactory approach would be to address the causes of excessive growth which include high levels of nutrients and unnaturally low shading of rivers (e.g. Dawson, 1978; Swales, 1982). Without management *Ranunculus* biomass would also naturally be lower (Dawson, 1976) and it would naturally wash out earlier (e.g. Ham et al., 1982). Franklin (2007) also suggests that *Ranunculus* growth would be self regulating owing to the feedbacks between plant growth and velocity. Given that such self-regulation operates over a longer timescale, weed growth may not be adequately controlled in this way and there is likely to be a shorter term need for weed cutting in certain places.

In response the UK Environment Agency only cut weed where it is essential. For example, on the River Avon in Hampshire weed is only cut where there is a real flood risk to multiple properties or damage to infrastructure. To minimise impacts of weed cutting best practice guidance is summarised in several publications (e.g. Mainstone, 1999 and Wheeldon, 1993) and provided by the Environment Agency, Natural England and various angling/wildlife associations.

However, scientific accounts of coincident multiple instream and wider riparian impacts of cutting are limited. Existing accounts include impacts on invertebrate populations (Dawson et al., 1991), transport of fine particulate organic matter (Warren et al., 2009), fish habitat (Swales, 1982) and plant communities (Baattrup-Pedersen and Riis, 2004). None of these accounts consider the ecological impacts on riparian wetlands, which are common in chalk river systems.

In this study a multidisciplinary approach is adopted to quantify key physio-chemical impacts that result from weed cutting and to discuss their potential ecological implications. Specific objectives are to quantify, for the first time, the coincident impacts on river hydraulics (including conveyance capacity), the adjacent wetland, and river water quality.

2. METHODOLOGY

2.1 Study area

The Lambourn catchment is located within the Berkshire Downs, southern England. The ephemeral head of the river is located in Lynch Wood (51.512° N, 1.529° W) at an elevation of approximately 130m above sea level, with the perennial head situated 6-7 km downstream at Maidencourt Farm (51.481° N, 1.464° E). At Shaw, where the catchment area is 234 km^2 it has a mean discharge of 1.73 m^3s^{-1}, a median annual flood of 3.6 m^3s^{-1} and a base flow index of 0.96 (Marsh and Hannaford, 2008) which clearly illustrates its groundwater origin. The whole river is designated as a SSSI as it is a classic example of a lowland chalk river and a SAC owing to its importance for the designated habitat "Water courses of plain to montane levels with *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation" and the individual species brook lamprey and bullhead.

The weed cuts monitored in this paper were undertaken at the CEH River Lambourn Observatory at Boxford (51.447° N, 1.384° E; Figure 1). This site is approximately 14 km from the ephemeral source of the River Lambourn and encompasses approximately 600 m of river and 10 ha of wetland. The Chalk bedrock at the observatory is overlain by river terrace deposits, which nearby have been demonstrated to comprise primarily coarse-grained gravels that are typically 3-4 m thick (Allen *et al.*, 2010). These are in turn overlain by an assortment of alluvial deposits consisting of peat, clay, silt, sand and gravel. Within the wetland, the alluvial deposits are principally peat with interlayered silts giving a total depth of ~0.90 m.

The catchment area of the site is approximately 162 km^2 (CEH, 2009). Maps of the site dating back to c.1900 depict a managed water meadow system (Everard, 2005) with a network of channels and sluices that would have been used to artificially flood the site. With a few exceptions (Figure 1) most of these channels have naturally filled in and no longer carry water. There is a flowing channel that leaves the River Lambourn at the northern end of the site and flows southwest to join and supplement flows of the Westbrook stream. The Westbrook is believed to be a natural stream that originally flowed from a spring to the northwest of the site (source area now separated by a road). It currently flows south through the CEH wetland to join the River Lambourn at the southern end of the site. A spring fed channel also flows southwest along the western edge of the site and onto the downstream wetland.

The main vegetation types of this wetland are species-poor sedge (*Carex*) and *Glyceria maxima* swamp with patches of alder and sallow scrub. The meadow is also classed as a SSSI owing to the habitat it provides for *Vertigo moulinsiana* (Desmoulins whorl snail) which is considered rare on a European scale (Killeen, 2003). *V. moulinsiana* was reported in a survey of the site commissioned in October 2011.

The river is typically nine metres wide and on average 0.4 m deep and flows over a substrate comprised mainly of gravel. The macrophyte community is dominated by *Ranunculus penicillatus ssp. pseudofluitans* mixed with smaller quantities of *Ranunculus penicillatus ssp. pseudofluitans x Ranunculus peltatus* hybrid (water crowfoot). Patches of *Callitriche spp.*, *Berula erecta* and *Rorippa nasturtium aquaticum* are also frequent. Overall, macrophyte coverage increases through spring and peaks during summer months.

Two electro fishing campaigns (December 2007 and March 2008) have been undertaken at the site to identify the fish present. Four species of pelagic fish (*salmo trutta* (brown trout), *Thymallus thymallus* (grayling), *Pungitius pungitius* (10-spinned stickleback), and *Gasterosteus acluleatus* (3-spinned stickleback) and two species of benthic fish *Cottus gobio* (bullhead) and *Lampetra planeri* (brook lamprey) were found.

The macroinvertebrate community in the benthos and the hyporheos has been well characterised by CEH's sampling from 2009 to 2013 (C. Mullen et al., in preparation, Muchan, 2012). It is typical of chalks streams and rivers, with a rich assemblage of mayfly nymphs (10 species), gastropods (8 species) and caddis fly larvae (19 species, including the Ranunculus specialist *Brachycentrus subnubilus* Curtis (Brachycentridae)). The community reflects the diversity of habitats presented at the site by shallow riffles, deeper pools and marginal macrophyte stands, with typical rheophylic stream fauna supplemented by standing water specialists such as molluscs, beetles and water bugs. The macroinvertebrate fauna includes species indicative of a deep, well oxygenated, hyporheic zone with good exchange with groundwater (upwelling & downwelling) such as the worm *Haplotaxis gordioides* (Hartmann) (Haplotaxidae) and the groundwater shrimp *Niphargus fontanus* Bate and *Niphargus aquilex* Schiodte (Niphargidae). The assemblage also includes some focal species dear to anglers and nature lovers such as the green drake *Ephemera danica* Müller (Ephemeridae) and the Banded and the Beautiful demoiselles *Calopteryx splendens* (Harris) and *Calopteryx virgo* (Linnaeus) (Calopterygidae). The macroinvertebrate assemblage has several non-native species such as the New Zealand mud snail *Potamopyrgus antipodarum* (J.E.Gray) and the highly invasive signal crayfish *Pacifastacus leniusculus* (Dana).

2.2 The weed cuts

The nature and timing of weed cutting at this site is guided by the advice of a downstream river keeper, whose main motivation is to maintain fish habitat and viable fishing. In addition, CEH must meet its legal obligations with respect to maintaining the conveyance of river water through the site to reduce flood risk. This typically results in 3 weed cuts a year although lower flows in dry years often result in fewer cuts. The weed cuts undertaken on the 9^{th} July 2008, 20^{th} May 2009 and 5^{th} May 2010 were monitored and the results are reported here. In the 2008 and 2009 cuts the *Ranunculus* had started flowering. Weed cutting started soon after sunrise and was complete by mid afternoon. The upstream and downstream limits of the weed cuts are marked on Figure 1. Cutting proceeded in an upstream direction; any remaining cut weed was subsequently cleared from the reach by the cutters moving through the reach in a downstream direction. In 2008, weed was cut to leave a chequer board pattern (Figure 2). Subsequently, in 2009 and 2010, weed was removed leaving a more sinuous flow pattern working in an upstream direction. The aim was to cut approximately 40% of the weed. All cut weed was removed from the river using a downstream weed pit.

2.3 River habitat and macrophyte surveys

River Habitat (RHS) and Mean Trophic Rank (MTR) surveys were undertaken before and then repeated three weeks after the July 2008 weed cut allowing conditions to stabilise. The RHS surveys were undertaken to assess the physical structure of the river (*sensu* Raven *et al*., 1997). The surveys were conducted over a 500m reach with spot checks spaced at 50m intervals. The MTR survey methodology was followed to quantify the coverage of different macrophyte species (*sensu* Holmes *et al*., 1999). Species present within the wetted channel of four reaches (three 100m and one 25m reach; Figure 1) were recorded using a nine point cover scale.

2.4 River hydraulics

Instream vegetation increases flow resistance, which affects hydraulic conditions such as flow depth, velocity and turbulence, and flood conveyance capacity (Yen 2002). Thus, for a particular discharge in spring and summer, the vegetation increases the flow resistance therefore the water depth which in turn decreases the flood conveyance capacity and instream velocity. In such a vegetated case, the vertical profiles of velocity are no longer logarithmic (e.g. Green, 2005; Naden *et al.,* 2006; Wharton *et al*., 2006) and the resistance to the flow is significantly derived from the drag force due to vegetation rather than the bed friction or resistance associated with secondary flow (Rameshwaran and Shiono, 2007). The hydraulic impacts of weed cutting were monitored as described below.

River discharge measurements were made the day before and the day after the weed cuts (8th and 10th July 2008, 19th and 21st of May 2009, 4th and 6th of May 2010). In 2008, water surface level measurements were carried out throughout the site using a Trimble 5600 Total Station, typically at 10-20 m intervals. Continuous water level measurements were also made at an upstream location in the site at Water Quality Station 2 (WQ2; Figure 1) using a Druck (Model PDCR 1830) pressure transducer. During the 2008 cut, detailed measurements of primary velocities were made in a series of vertical profiles spaced at 1 m intervals across the channel (Cross section A-A; Figures 1 and 2) using a electromagnetic flow meter. At each vertical profile, six measurements were taken at bed, 0.8D, 0.6D, 0.4D, 0.2D and water surface where D is water depth and the discharges were computed. In the 2009 and 2010 weed cuts, ADCP (Acoustic Doppler Current Profiler) discharge measurements were carried out.

Using these data flow resistance was calculated to assess the impact of weed cutting on the conveyance capacity of the channel. To define each component of flow resistance, detailed flow field measurements, vegetation attributes and biomechanical characteristics, and boundary roughness characteristics are required (Nikora, 2009) which were not possible in this field study. An alternative approach was adopted which represents all roughness effects including vegetation in a single equivalent roughness value as proposed in the Conveyance and Afflux Estimation System (CES/AES), which is a software tool for estimating flood and drainage water levels in rivers, watercourses and drainage channels (McGahey and Samuels, 2003). In river engineering, the most frequently used resistance coefficients are Manning coefficient n, Chezy coefficient C

and Darcy-Weisbach friction factor *f* (Yen 2002). Among them, the Manning coefficient *n* is commonly used in CES/AES.

Here the flow resistance is calculated from the Manning equation:

$$n = \frac{R^{2/3} S^{1/2}}{U} \qquad (1)$$

where *R* is the hydraulic radius, *S* is the energy slope and *U* is the cross-sectional mean velocity. The single value Manning coefficient was calculated using the cross-sectional mean velocity calculated from measured data, hydraulic radius of the measured cross-section and measured water surface slope assumed equal to the energy slope. The distribution of the Manning coefficient across the cross-section was also calculated using the measured depth-averaged velocity, local water depth *h* (assuming a wide channel where $h \approx R$) and measured water surface slope.

2.5 Groundwater levels

Groundwater levels in the wetland were monitored before and after the 2009 and 2010 weed cuts using an array of peat and gravel piezometers installed in a transect between the River Lambourn and the Westbrook (see Figure 1). In 2009, levels were monitored manually with a dip tape, the day before and six days after the week cut. In 2010, continuous higher resolution data (1 hr) were obtained over four days following the weed cut by installing logging pressure transducers within five peat and four gravel piezometers, and stilling wells in the River Lambourn (at WQ2) and the Westbrook (Figure 1). Regular manual dip measurements were also taken on the day of the weed cut to validate the logger data (*sensu* Sorensen and Butcher, 2011).

2.6 River water quality

Suspended sediment concentration was monitored throughout the 2008 and 2009 weed cuts while chemical analysis of river water and suspended sediment were only possible during the 2008 weed cut. Suspended sediment concentration samples were taken downstream of the weed cut at Water Quality Station 3 (WQ3 on Figure 1) both manually using a USGS DH48 sampler (Edwards and Glysson, 1999) and automatically using a Xian 1000 sampler (Hach Lange Ltd, Salford). Throughout the May 2009 weed cut an Analite turbidity probe (McVan, Australia) was deployed at this site and connected to a Campbell data logger (recording 15 minute resolution data). Turbidity data were calibrated to suspended sediment concentrations.

For detailed chemical analysis of river water and suspended sediment during the July 2008 weed cut 5 manual samples were taken (mid channel from bridges) upstream at Water Quality Station 1 (WQ1; Figure 1) and 5 downstream of the weed cut at Water Quality Station 4 (WQ4; Figure 1). Phosphorus concentration was monitored given its potential impact on rivers through eutrophication. Total phosphorus concentrations were determined by spectroscopy using a Varian Cary 50 spectrophotometer. As an indicator of algal abundance Chlorophyll concentrations were determined spectrophotometrically. Two trace elements were monitored (Pb and Cd) that are known to pose a significant risk to or via the aquatic environment (Priority Substances Directive 2008/105/EC) using Inductively Coupled Plasma-Mass Spectrometry.

2.7 River discharge

To enable flux calculations, river discharge was estimated for the reach using a regression developed between 38 ADCP flow gaugings, immediately downstream of WQ2, and 15 minute discharge data from the downstream Environment Agency gauging station at Shaw (51.411° N, 1.326° W) for the period May 2009 to December 2011.

3. RESULTS

3.1 Macrophyte coverage in July 2008

The objective of the weed cuts was to remove approximately 40% of the instream macrophyte coverage comprised mainly of *Ranunculus*. The observed reduction in coverage after the weed cut was evident in the MTR surveys. At three of the four surveyed reaches the recorded coverage reduced from >75% to 25-50% whereas at the other reach it reduced from 50-75% to 10-25%. The coverage of floating plant species (*Azolla filiculoides, Lemna minor and Lemna minuta*) showed less obvious changes in cover. They generally either remained unchanged or reduced only slightly with the exception of one site where cover reduced from 5-10% to 1-2.5% (Table 1).

3.2 River water levels

The water level dropped by ~22% (0.232 m) in 2008, ~28% (0.293 m) in 2009 and ~17% (0.155 m) in 2010 mainly due to removal of weed as the discharge only changed by -3%, -7% and +9% between measurements, respectively (Table 2). In July 2008, the water surface slope (m/m) was about 1:450 for both pre and post weed cut measurements except near the end of the reach (Figure 3). Here, after the weed cut, it gradually recovered back to its original downstream level where the weed was not cut or where the mill controls the level.

3.3 River flow velocity

Mean cross-sectional velocities increased by >40% after each weed cut (Table 2). For the July 2008 weed cut the vertical profiles of primary velocity are presented in Figure 4 from the true left to the true right bank. It is clear that vegetation is a dominant influence on flow velocity where these profiles depart from a logarithmic profile. The pattern of this weed cut was a checkerboard (Figure 2) and the profiles 1 to 4 show increased velocity due to weed removal in the zone upstream of remaining vegetation where the flow is accelerated. On other hand, in profiles 5 to 8, the difference between before and after weed cut velocity profile patterns are relatively minor due to non-removal of weed in the upstream zone (Figure 2).

The calculated depth-averaged velocity $U_d \left[= 0.1\left(u_{bed} + 2u_{0.8} + 2u_{0.6} + 2u_{0.4} + 2u_{0.2} + u_{surface}\right)\right]$ (British Standards Institution, 1980) is also shown in Figure 5. The effect of weed removal in the upstream region of the measurement section can be clearly seen where the depth-averaged velocity in the left bank region increases by up to ~158% whereas in the right bank region, the velocity is almost the same.

3.4 Flow Resistance and Conveyance capacity

Table 2 lists the calculated flow resistance (Manning's n coefficients: single channel approach; Chow, 1959) for each of the three weed cuts. Although the discharges were similar (within 10%) before and after each cut, there were corresponding large reductions in water depth which reflect the increased cross-sectional mean velocities produced by the reduced roughness (Table 2). Thus removal of ~40% in-stream vegetation decreased the single channel Manning coefficient by >40%. The dominant influence of weed on the distribution of the Manning's coefficient across the channel can be clearly seen in Figure 6 where single location estimates are presented for before and after the July 2008 weed cut. In the left side of the channel, the Manning coefficient dropped by >62% owing to a considerable increase in depth-averaged velocity compared to the right side where it remained similar (Figure 5).

Conveyance capacity was calculated before and after each weed cut for a bankfull level as approximated by the level prior to the July 2008 weed cut. The increase in conveyance capacity produced by weed cutting ranged from 89% to 141% (Table 2).

3.5 Wetland groundwater levels

During 2009, groundwater levels closely followed the 0.29 m decline in river levels. Six days after the cut groundwater levels in the peat and gravels had declined from means of 0.08 to 0.23 m bgl (below ground level) and 0.09 to 0.27 m bgl, respectively (Table 3). Within the peat this represents a reduction in saturation in the order of 15 %.

In 2010, the response within Westbrook was almost instantaneous and of similar magnitude to the Lambourn (Figure 7). The drop in river stage on both these boundaries of the piezometer transect invoked a rapid response within the wetland, with gravel levels declining most rapidly within the first 24 hours (Figure 7). Thereafter, peat levels lowered at a greater rate than gravel levels, with groundwater levels in both units stabilising at a similar total change after 72 hours. Overall mean ground water levels in the peat dropped from 0.08 to 0.17 m bgl over 4 days (Table 3), which is equivalent to a ~10% reduction in saturation. Groundwater levels in the gravels reduced from 0.03 to 0.12 m bgl over the same period.

3.6 River water quality

3.6.1 Suspended sediments: concentration and flux

Downstream suspended sediment concentrations at WQ3 rose to high levels during the 2008 and 2009 weed cuts (Figure 8). During July 2008 it increased almost 10-fold from a pre cut level of 6 mg/l (average of 4 pre cut samples) to a peak concentration of 57 mg/l. During the May 2009 it rose almost 16-fold from a pre cut level of 7 mg/l (average of 3 samples pre cut) to a peak concentration of 113 mg/l. These peak concentrations are significant given the maximum concentration sampled in three years of monitoring (April 2008 to March 2011) of natural flow events upstream at WQ2 was 74 mg/l. During the weed cuts the highest concentrations were sampled as the weed cutters were in closest proximity to the sampling location. Interestingly sediment concentration reached a double peak during each weed cut (Figure 8). The first peak was produced as the cutters cut the weed in an upstream direction while the second peak occurred as the cutters moved back downstream moving the cut weed through the reach.

To assess the impact of the July 2008 and May 2009 weed cuts on the flux of sediment, periods of disturbance were defined from the time of cut initiation to the time that suspended sediment concentrations at WQ3 dropped below 10 mg/l. Disturbance durations were similar for the 2008 and 2009 cuts (27 hours in July 2008 and 25 hours in May 2009). Over both periods of disturbance, discharge volume was 16% (2008) and 0.5% (2009) above that which would have occurred with an assumed constant initial discharge. The background flux was estimated using the mean suspended sediment concentration of several pre-cut samples (see above). Estimates of the total background sediment flux of the July 2008 and May 2009 cuts were similar at 1173 kg and 975 kg respectively. Monitored fluxes were high (July 2008 = 4882 kg and May 2009 = 3189 kg) when compared to these background values and represent a 3- or 4-fold increase.

After both weed cuts the sediment concentration recovery time at WQ3 was short. Following the July 2008 cut, after ~3 hours concentrations dropped to <25 mg/l and after ~18 hours they dropped to <10 mg/l. Following the May 2009 cut, after 1 hour concentrations were <25 mg/l and after ~16 hrs they dropped to <10 mg/l.

3.6.2 Suspended sediments: composition

Approximately one third (29% in 2008 and 35% in 2009) of the mobilised sediment flux at WQ3 was composed of volatile organic matter. This is comparable to the 40% organic content of suspended sediment in the Bere stream, Dorset (UK) reported by Westlake *et al*. (1972). Sediments accumulating in summer may have high organic contents and thus high Biological Oxygen Demand as they are likely to be largely produced in the channel (Mainstone, 1999) through biogenic processes (Wharton *et al*., 2006).

On comparing average water quality indices from 5 samples upstream (at WQ1) and downstream (at WQ4) of the July 2008 weed cut, enhanced concentrations of several pollutant species were identified (Table 4). Based on these samples suspended sediment concentration increased almost 7 fold. The coincident 5 fold increase in chlorophyll illustrates that part of this increase is due to disturbed benthic and epiphytic algae. Increases in total (dissolved and particulate) phosphorus, lead and cadmium concentrations demonstrate their presence in the mobilised sediment.

4. **DISCUSSION**

4.1 Conveyance of flood flows versus maintenance of low flow water levels

While observations of the hydraulic impact of vegetation growth have been reported previously (Wharton et al., 2006) quantification of hydraulic impacts of weed cutting, primarily undertaken to mitigate flood risk, is rare.

The consequent increase in the conveyance capacity of the River Lambourn (89 to 141%) monitored here in response to reduced flow resistance from vegetation demonstrates the effectiveness, at least in the short term, of weed management over the spring and summer period. Increased conveyance was associated with higher water velocities and lower depths.

Reach-scale changes in water level following a weed cut can be dramatic, however, smaller changes downstream (Figure 3) may illustrate that there is a need for coordinated upstream and downstream weed management to successfully reduce the flood risk. However, in this instance it is possible that the smaller downstream change in level may reflect a backwater effect from the downstream Mill and not the backwater effect of uncut *Ranunculus*. Co-ordinated summer weed cutting currently takes place along the River Test, Hampshire, between specific dates that are agreed with the Environment Agency.

Although increased conveyance is desirable to mitigate flood risk it may result in low water levels where abstractions are high (Hearne and Armitage, 1993) or where drought conditions prevail. Therefore, the presence of macrophytes may be important in maintaining acceptable water levels. If macrophytes are removed then it may be necessary to reduce abstractions to safeguard ecological habitat (see below).

4.2 Retention and mobilisation of fine sediment and associated chemicals

The enhanced transport (concentration and flux) of fine sediment and associated chemicals that was observed during weed cutting reflected the direct disturbance of accumulated sediment and its exposure to higher river flow velocities. The short duration of high sediment concentration and flux at the monitoring site (WQ3) reflects both the short period (<10 hours) and close proximity of disturbance (<1 km), the rapid flushing of exposed sediment and, perhaps, limited mobilisation and transport of fine sediment during the prevailing summer vegetated low flow conditions. The observation that highest sediment concentrations occurred as weed cutters were in closest proximity to WQ3 is consistent with the river having limited transport capacity at this time. This is likely to contrast to winter conditions where higher velocity conditions may prevail in a sparsely vegetated channel in response to a rainfall event.

It is significant that even in this relatively clean river system, with low intensity urban and agricultural landuse, mobilised sediment elevated total concentrations by 50 - 400% (Table 4) of several species (P, Pb and Cd) that are known to have significant impacts on or via the aquatic environment. However, note that the concentrations of Pb and Cd recorded here are low (cf. Council Directive 98/83/EC). Effective trapping of fine sediment and chemicals below and within macrophytes has been reported by several researchers. Sand-Jensen (1998) states that macrophytes in Danish eutrophic streams may retain up to 80% of the transported sediment. Schulz *et al*. (2003) used field measurements from the River Spree in Germany to estimate that sediment deposition associated with macrophytes contributed up to 25% of the total monthly phosphorus retention. Sedimentation occurs in response to low flow velocities within plants, filtration by sand sized material in the river bed (Warren et al., 2009), production of dense faecal pellets by suspension feeders (e.g. blackfly larvae Diptera:Simuliidae), trapping of organic particles in biofilms (Cotton *et al*., 2006) and accumulation in the hyporheic zone in response to plant induced downwelling (Warren et al., 2009). The resultant sediment deposits represent important stores of organic material, nutrients and other pollutants (e.g. Walling *et al*., 2003, Clarke and Wharton, 2001).

In addition to its immediate impact, the weed cut is likely to elevate sediment transport during future flow events by exposing deposits to higher discharges in a comparable way to autumn mobilisation that occurs in response to vegetation dieback (e.g. Wharton *et al*., 2006). Warren et al. (2009) observed how sediment deposits may remain following a weed cut owing to the stabilising effect of biofilms. Thus, it is important that weed cover is sufficiently low in winter/spring to allow higher flows to clean fine sediment deposits from the river system.

A key implication is that the instream summer retention of sediment and associated chemicals is reduced in headwater streams after weed cutting which may have important downstream water quality impacts. Background summer concentrations are likely to be higher and event driven inputs will be attenuated less as they travel downstream. Sediment retention may be more significant in more polluted systems where sediments with very high nutrient and/or trace element concentrations are input to the river from agricultural, urban or industrial sources (e.g. Old et al., 2002). Desorption of pollutants from such deposits when disturbed may be a particular hazard.

4.3 Ecological perspectives

4.3.1 Wetland vegetation

In wetlands, particular plant species have characteristic tolerances both to the water supply mechanism and to the timing, duration and degree of any waterlogging or drought event (Wheeler et al., 2004). These species in turn make up wetland plant communities and they may be affected by the falls in groundwater levels that were observed here (to ~0.3 m bgl; Table 3). The particular ecohydrological requirements of each community will be determined by the attributes of the component species.

On the Lambourn floodplain the main herbaceous wetland communities are the *Glycerietum maxima* (S5 *Glyceria maxima* swamp of the National Vegetation Classification (NVC), Rodwell, 1995) and the *Caricetum acutiformis* (S7 *Carex acutiformis* swamp of the NVC). The *Glyceria* swamp is known to withstand frequent marked changes in water-table depth of the type caused by the weed cuts (Mountford in Wheeler et al., 2004), and the response of *Carex acutiformis* is thought to be similar though data are limited. All these drawdown events on the Lambourn floodplain are within the growing season for the wetland vegetation, when the component communities are most vulnerable to stresses through reduced aeration or prolonged drought. However, Mountford advises that desirable conditions for S5 *(Glyceria maxima)* swamp include water table levels down to 0.6 m below ground level in the period March to May and 0.8 m in June to August. Thus even the drop in water level from 0.08 to 0.23 m recorded in 2009 still provide acceptable conditions for this wetland plant community. Work on floodplain grasslands has shown that the spring period may be especially critical (Gowing in Wheeler et al., 2004). The duration and magnitude of drops in groundwater levels will affect both the performance of the individual plant species and the competitive interactions between them. It is probable that the occurrence of these species-poor swamps on the Lambourn floodplain partly reflects the wide tolerances of the dominant species (C. acutiformis and G. maxima) to such hydrological perturbations, though the lack of management (grazing or cutting) over recent decades has also favoured these vegetation types.

4.3.2 Instream macrophyte growth and diversity

During the three weed cuts mean cross sectional velocity increased by 43 to 55% (Table 2). This is likely to have revitalised existing plants and initiated new growth by reducing the areas of low flow velocity within stands where growth may have been limited by diffusion (Westlake, 1967) or growth of epiphytic algae (Franklin, 2007; Wade et al., 2002) and exposing the remaining plant edges to higher desirable velocities (Franklin, 2007; Riis and Biggs, 2003).

Following the weed cuts increased river flow velocities and reduced extents of floating *Ranunculus* also increased the washout of the free-floating invasive alien species *Azolla filiculoides* (Table 1). Out of the four MTR surveys conducted in 2008 coverage in two decreased while in two it remained unchanged. The possibility of other species being unintentionally removed during weed cutting is reduced as *Ranunculus* usually grows in dense stands, out-competing other species.

Ranunculus growth may also be affected by the intensity and frequency of weed cutting. The removal of ~40% of the *Ranunculus* biomass in each of the weed cuts reported here ensures a sufficient source of vegetative propagules remained for recovery. However, Franklin (2007) observed a period of retarded recovery (2003 to 2005; exacerbated by low flows) following a ~70% weed cut on the River Lambourn at Boxford. Furthermore, regular weed cutting, typically three times per year at this site, may significantly reduce species diversity and result in a shift towards those more able to cope with disturbance (Baattrup-Pedersen *et al.,* 2003 and Baattrup-Pedersen and Riis, 2004).

4.3.3 Invertebrate populations

Removing ~40% of the macrophyte biomass will have resulted in the direct loss of invertebrates (e.g. Wright, 1992, Dawson *et al*., 1991, Kaenel and Uehlinger 1999) with highest loses for those animals most strongly attached to the macrophytes (e.g. Pearson and Jones, 1978) or at key stages in their life cycle (e.g. Gunn, 1985).

Weed cutting was also observed to increase depth averaged river flow velocity by up to 158% during the July 2008 weed cut. These higher velocities favour rheophylic taxa, and may flush out the invertebrates that prefer weaker flow, further depleting the standing stock biomass of invertebrates at the reach scale.

During the three monitored weed cuts water level drops of up to ~28% caused marginal habitats to dry out with likely negative impacts on a number of popular species, in particular the Banded Demoiselle *C. splendens,* and the juvenile invasive crayfish *P. leniusculus* (Blake *et al*., 1994), both observed at the site.

The short term mobilisation of fine sediment from river bed gravels through weed cutting is critical to many invertebrate species which score highly in bioassessment metrics (e.g. BMWP) and conservation indices (e.g. CCI) and favour clean well oxygenated gravels (burrowing mayflies are an exception). However, downstream deposition of mobilised material may smother benthic surfaces and have negative impacts.

Furthermore, given the specific hydrological requirements of *V. moulinsiana* (Killeen, 2003) their populations may be negatively impacted by weed cutting. High populations occur where mean annual water levels are >0.25m above ground level (range 0 to 0.6m). Prior to the 2009 weed cut peat water levels along the monitored transect (Figure 1) were within the proposed range for medium populations (i.e. -0.2m to 0.2m; Table 3). However, 5 of the 6 post weed cut measurements along this transect indicated that the water levels had dropped to a level only thought to support low populations. Furthermore, given that *V. moulinsiana* is thought to disperse via waterborne transport the significant reductions in water levels and flows within the wetland waterways may have a negative impact on its success.

4.3.4 Fish populations

During all three weed cuts river water levels drops of up to ~28% were measured with corresponding increases in velocity. Given that most aquatic species have specific requirements for physical habitat conditions, defined by hydraulic variables, such as water depth and velocity (Waters, 1976) these changes are likely to have important consequences. The impact of changes in mean column velocity on *S. trutta* and *T. thymallus*, both regularly recorded at the site, was evaluated using graphs of the suitability of physical habitat metrics (scored from 0 to 1). These were originally developed as part of the Physical Habitat Simulation (PHABSIM; Bovee, 1982) system. Habitat suitability indices (HSIs) are available in the literature for *S. trutta* 0-7 cm (Elliott et al., 2002) and *T. thymallus* fry (Bullock et al., 1991; Ibbotson et al., 2000) from which Weighted Useable Width (WUW) was calculated for velocity habitat before and after weed cuts in 2008, 2009 and 2010 (Table 5). It can be seen that in July 2008 WUW for young *S. trutta* was reduced by the weed cut by 29% but by only 0.5% in May 2009, whereas for *T. thymallus* fry the reductions were 4% and 41% respectively. This was a result of increases in velocity. The weed cut in May 2010 resulted in an increase in WUW of 19% for young *S. trutta* but a decrease for *T. thymallus* of 92% again as a result of significant increases in velocity particularly in the channel centre. It is evident that changes in habitat depend on the pattern and extent of weed cutting and the impacts vary between species.

The weed cutting will have also benefitted rheophylic species by maintaining their spawning habitat. Resultant higher flow velocities ensure gravels are clean, with necessary interstitial space and water flow (Soulsby et al., 2001, Crisp, 1996). However, localised patches of soft sediment deposits are necessary to provide habitat and food for burrowing juvenile Lamprey (Clemens et al., 2010).

Additional key negative impacts on fish, of the 40% reduction in macrophyte coverage observed here, are likely to include enhanced pressure from predators by removal of refuge (Swales, 1982), reduced invertebrate food source (Dawson *et al.* 1991) and damage to the nests of Bullheads and Sticklebacks during their most sensitive breeding period (spring-early summer).

4.3.5 Ecological processes

The removal, redistribution or increased vulnerability (to prey) of invertebrate fauna can potentially lead to changes in fundamental ecological processes. Though the net effects on trophic flows through the food web are hard to establish, it is clear that weed cutting can disrupt both top-down processes, through the abundance and behaviour of prey, and bottom-up processes, through the flushing of organic detritus and a shift from epiphytic to epilithic algal assemblages as the weed cover is removed and light penetration increases. Strong shifts in community structure can also be associated with changes to ecosystem functioning when a particular functional group or guild of organisms is disproportionately affected. Here, because filter feeding invertebrates dominate the assemblage of invertebrates attached to the plants, the removal of weed may have deleterious effects on a key ecosystem function, the removal of fine organic detritus from the water, at the reach scale at least.

4.4 Perspective on amenity value of the river

The clarity of chalk stream water gives them their high recreational value in terms of angling and aesthetics (e.g. Smith and Davies-Colley, 1992). Fly fishing in chalk streams is an exclusive activity for anglers who pay significant sums of money for the privilege. The high sediment concentrations and floating debris that were observed here produced during the weed cuts can have an adverse impact on this activity by rendering downstream reaches unfishable. Furthermore, the low water depth and fast velocities immediately upstream and through the cut reach may be unsuitable for angling. River managers often manipulate macrophyte growth to maintain suitable upstream water levels. This usually involves weed cutting but it is usually done in co-ordination with angling activity.

4.5 Perspective on mitigating green house gas emissions

Wetlands can be significant sources of green house gases and their emissions may be mediated by weed cutting through its effect on groundwater levels. It has been estimated that wetlands contribute 40-50% of global methane (CH_4) emissions (Whiting and Chanton, 1993). This is due to the persistence of anaerobic conditions within saturated ground, which are highly favourable for the production of both CH_4 and relatively smaller quantities of nitrous oxide (N_2O) (Audet *et al*., 2013).

A number of studies have shown that changes in wetland hydrology can have a significant impact upon green house gas production (Moore and Knowles, 1989; Sha *et al*., 2011), whereby a fall in water level can decrease CH_4 production but increase CO_2 and N_2O. There is some evidence however that as water levels rise again, although both CO_2 and N_2O concentrations decline rapidly, CH_4 concentrations do not respond at the same rate (Freeman et al., 1993) and remain lower for longer. This is either due to the longer acclimation periods that methanogenesis requires or suppression of methanogenesis from the mobilisation of sulphate during the more aerobic conditions present when the water level fell (Gauci et al., 2004). In fact, periodic lowering of the water table to 0.15-0.20 m below the surface (within the range observed here; table 3) has been demonstrated to completely inhibit CH_4 generation (Shannon and White, 1994; Altor and Mitsch, 2006). Therefore, weed cutting may have potential as a management tool to mitigate greenhouse gas emissions from riparian wetlands.

5. CONCLUSION

This paper has quantified, for the first time, a wide range of coincident physical and chemical impacts of weed cutting and both instream and riparian environments were shown to be affected. Thus, when deciding on whether, when and how much weed to cut a wide range of potential implications should be evaluated. Measurements clearly demonstrated how weed cutting enhanced flood flow conveyance, reduced water levels (river and wetland) and increased velocities, and mobilised fine sediment with its associated chemicals and reduced the capacity for its retention within the river channel. Potential implications in relation to flood risk, water resources, downstream water quality, instream/riparian ecology and amenity value of the river were considered. Importantly, riparian wetland groundwater levels were shown to be sensitive to changes in river levels. Thus, the impacts of the weed cut may be translated into the floodplain with implications for wetland ecology and greenhouse gas emissions.

Provided the major influence of macrophytes on instream and riparian environments is fully understood then their manipulation clearly represents a rapid and effective management tool that demonstrates the potential value of working with nature to enhance resilience of river systems. However, for the longer term the most sustainable macrophyte management requires a strategy that addresses environmental factors that promote prolific growth and prescribes optimal timings, extents and patterns of cutting. The findings presented in this paper may be of wider international relevance given that river water discharges are artificially reduced in systems worldwide through abstraction for water supply or hydro electric power generation.

Acknowledgements

This study represents CEH core science that is funded by the Natural Environment Research Council. The authors would like to thank Ms Luff for granting access to Water Quality station 3 and Mr. B. Wheeler and his colleagues for conducting the weed cuts. Comments on drafts of this paper from CEH and BGS colleagues were much appreciated.

References

Acreman, M.C., Ferguson, A., 2010. Environmental flows and European Water Framework Directive. Freshwater Biology, 55, 32-48

Allen, D.J.; Darling, W.G.; Gooddy, D.C.; Lapworth, D.J.; Newell, A.J.; Williams, A.T.; Allen, D.; Abesser, C., 2010. Interaction between groundwater, the hyporheic zone and a Chalk stream : a case study from the River Lambourn, UK. Hydrogeology Journal, 18 (5), 1125-1141. 10.1007/s10040-010-0592-2.

Altor, A. E., Mitsch, W. J., 2006. Methane flux from created riparian marshes: relationship to intermittent versus continuous inundation and emergent macrophytes. Ecological Engineering, 28(3), 224-234.

Audet, J., Elsgaard, L., Kjærgaard, C., Larsen, S. E., Hoffmann, C. C., 2013. Greenhouse gas emissions from a Danish riparian wetland before and after restoration. Ecological Engineering, 57, 170-182.

Baattrup-Pedersen, A., Larsen, S. E., Riis, T., 2003. Composition and richness of macrophye communities in small Danish streams - influence of environmental factors and weed cutting. Hydrobiologia, 495, 171-179.

Baattrup-Pedersen, A., Riis, T., 2004. Impacts of Different Weed Cutting Practices on Macrophyte Species Diversity and Composition in a Danish Stream, River Research and Applications, 20, 103-114.

Blake, M., Nystrom, P., Hart, P. 1994. The effect of weed cover on juvenile signal crayfish (pacifastacus-leniusculus dana) exposed to adult crayfish and nonpredatory fish. Annales Zoologici Fennici, 31, 297-306.

Bovee, K.D., 1982. A guide to stream habitat analysis using the IFIM. – US Fish and Wildlife Service Report FWS/OBS-82/26. Fort Collins, USA

British Standards Institution 1980. BS 3680:Part 3A:1980 *Methods of measurement of liquid flow in open channels, Part 3. Stream flow measurement, Part 3A. Velocity-area methods.* London, BSI.

Bullock, A., Gustard, A., Grainger, E.S., 1991. Instream flow requirements for aquatic ecology in two British rivers. Institute of Hydrology report no 115, Institute of Hydrology, Wallingford, 138 pp

CEH 2009. Flood Estimation Handbook CD-ROM, Version 3, Centre for Ecology and Hydrology, UK.

Chow, V.T., 1959. Open-channel hydraulics: New York, McGraw-Hill.

Clarke, S. J., Wharton, G., 2001. Sediment nutrient characteristics and aquatic macrophytes in lowland English rivers. Science of the Total Environment, 266, 103-112.

Clemens, B. J., Binder, T. R., Docker, M. F., Moser, M. L., Sower, S. A., 2010. Similarities, Differences, and Unknowns in Biology and Management of Three Parasitic Lampreys of North America. Fisheries, 35**,** 580-594.

Cotton, J. A., Wharton, G., Bass, J. A. B., Heppell, C. M. and Wotton, R. S., 2006. The effects of seasonal changes to in-stream vegetation cover on patterns of flow and accumulation of sediment. Geomorphology, 77, 320-334.

Crisp, D.T., 1996. Environmental requirements of common riverine European salmonid fish species in freshwater with particular reference to physical and chemical aspects. Hydrobiologia, 323, 201-221.

Dawson, F. H., 1976. The annual production of the aquatic macrophyte *Ranunculus penicillatus* var. *calcareus* (R.W. Butcher) C.D.K. Cook. *Aquatic Botany* 2, 51-73.

Dawson, F. H., 1978. Aquatic plant management in semi natural streams: the role of marginal vegetation. Journal of Environmental Management, 6, 213-221.

Dawson, F.H., Clinton, E.M.F., Ladle, M., 1991. Invertebrates on cut weed removed during weed-cutting operations along an English river, the River Frome, Dorset. Aquaculture and Fisheries Management, 22, 113-121

Dawson, F.H., Kern-Hansen, U., 1979. The effect of natural and artificial shade on the macrophytes of lowland streams and the use of shade as a management technique, Int. Revue ges. Hydrobiol., 64,437-455.

Edwards, T.K., Glysson, G.D., 1999. *Field Measurements of Fluvial Sediment: U.S. Geological Survey Techniques of water resources Investigations*, Book 3, Chapter C2, 89 p. http://pubs.usgs.gov/twri/twri3-c2/

European Commission, 2000. *Directive 2000/60/EC of the European Parliament and of the Council of 23rd October 2000 establishing a framework for Community action in the field of water policy*, Official Journal 22nd December 2000 L 327/1, Brussels: European Commission.

Everard, M. (Ed) 2005. Water meadows. Forest Text, Cardigan, UK.

Franklin, P.A., 2007. *Dynamic analysis and modelling of hydroecology in two chalk streams.* University of Reading, Unpublished PhD thesis.

Freeman C., Lock M.A., Reynolds B., 1993. Fluxes of CO_2, CH_4 and N_2O from a Welsh Peatland Following Simulation of Water Table Drawdown: Potential Feedback to Climatic Change. Biogeochemistry, 19, 1 51-60.

Gauci V., Fowler D., Chapman S.J., Dise N.B. 2004. Controls on suppression of methane flux from a peat bog subjected to simulated acid rain sulphate deposition. Biogeochemistry 71, 2, 141-162.

Green J.C., 2005. Velocity and turbulence distribution around lotic macrophytes. *Aquatic Ecology*, 39, 1–10.

Gunn, R. J. M., 1985. The biology of Brachycentrus-Subnubilus Curtis (Trichoptera) in the River Frome, Dorset. Hydrobiologia, 120, 133-140.

Ham, S.F., Wright, J.F., Berrie, A.D., 1982. The Effect of Cutting on the Growth and recession of the Freshwater Macrophyte Ranunculus penicillatus (Dumort.) Bab. Var. calcareous (R.W. Butcher) C.D.K. Cook, Journal of Environmental Management, 15, 263-271.

Hearne, J.W., Armitage, P.D., 1993. Implications of the annual macrophyte growth cycle on habitat in river, Regulated Rivers Research and Management, 8, 313-322.

Holmes, N.T.H., Newman, J.R., Chadd, S., Rouen, K.J., Saint, L., Dawson, F.H., 1999. Mean Trophic Rank: A User's Manual. Environment Agency R&D Technical Report E38, 134pp.

Ibbotson, A.T., Ingram, A., Cove, R.J., Gallagher, M., Hornby, D.D., Furse, M., Williams, C., 2000. A review of grayling ecology, status and management practice; recommendations for future mamagement. Environment Agency (WRC Dissemination Centre), Swindon. 114 pp.

Kaenel, B., Uehlinger, U., 1999. Aquatic plant management: ecological effects in two streams of the Swiss Plateau, Hydrobiologia, 415, 257-263.

Killeen, I.J., 2003. Ecology of Desmoulin's Whorl Snail. Conserving Natura 2000 Rivers Ecology Series No.6 English Nature, Peterborough.

Madsen, J.D., Chambers, P.A., James, W.F., Koch, E.W., Westlake, D.F., 2001. The interaction between water movement, sediment dynamics and submerged macrophytes, Hydrobiologia, 444, 71-84.

Mainstone, C. 1999. Chalk rivers: nature conservation and management. WRc, Medmenham.

Marsh, T. J., Hannaford, J. (Eds). 2008. UK Hydrometric Register. Hydrological data UK series. Centre for Ecology & Hydrology. 210 pp.

McGahey, C., Samuels, P.G., 2003. Methodology for Conveyance Estimation in Two-Stage Straight, Skewed and Meandering Channels. Proceedings of the XXX Congress of the International Association for Hydraulic Research, Vol. **C1**, Thessaloniki, Greece.

Moore T.R., Knowles R., 1989. The influence of water table levels on methane and carbon dioxide emissions from peatland soils. Canadian Journal of Soil Science 69, 33-38.

Muchan K., 2012. Hyporheic invertebrate community response to flow permanence in a chalk stream, MSc Thesis (unpublished), University of Birmingham.

Naden, P.S., Rameshwaran, P. Mountford, O., Robertson, C., 2006. The influence of macrophyte growth, typical of eutrophic conditions, on river flow velocities and turbulence production. Hydrological Processes, 20, 3915–3938.

Nikora, V., 2009. Hydrodynamics of aquatic ecosystems: an interface between ecology, biomechanics and environmental fluid mechanics. River Research and Applications, DOI: 10.1002/rra.1291.

Nikora, V., Larned, S., Nikora, N., Debnath, K., Cooper, G., Reid, M., 2008. Hydraulic resistance due to aquatic vegetation in small streams: a field study. Journal of Hydraulic Engineering, 134, 1326-1332.

Old, G.H., Leeks, G.J.L., Packman, J.C., Stokes, N., Williams, N.D., Smith, B.P.G., Hewitt, E.J. and Lewis, S. 2002. Dynamics of sediment-associated metals in a highly urbanised catchment: Bradford, west Yorkshire. J. CIWEM, 18, 11-16.

Pearson, R. G., Jones, N. V., 1978. Effects of weed-cutting on macro invertebrate fauna of a canalized section of the River Hull, a northern English chalk stream. Journal of Environmental Management, 7, 91-97.

Phillips, G.L., Eminson, D., Moss, B., 1978. A mechanism to account for macrophyte decline in progressively eutrophicated waters. Aquatic Botany, 4, 103-126.

Rameshwaran, P., Shiono, K., 2007. Quasi two-dimensional model for straight overbank flows through emergent vegetation on floodplains. Journal of Hydraulic Research, 45, 302–315.

Raven, P.J., Fox, P., Everard, M., Holmes, N.T.H., Dawson, F.H. 1997. River Habitat Survey: a new system for classifying rivers according to their habitat quality in: Boon, P.J. and Howell, D.L. (Eds), Freshwater Quality: Defining the Indefinable?, The Stationery Office, Edinburgh, 215–234.

Riis, T., Biggs, B.J.F. 2003. Hydrologic and hydraulic control of macrophyte establishment and performance in streams. Limnol Oceanogr, 48, 1488-97.

Rodwell, J.S. (ed), 1995. British Plant Communities Volume 4. Aquatic communities, swamps and tall-herb fens. Cambridge: Cambridge University press.

Sand-Jensen, K., 1998. Influence of Submerged Macrophytes on Sediment Composition and near-Bed Flow in Lowland Streams. Freshwater Biology, 39, 663-679.

Schulz, M., Kozerski, H.P., Pluntke, T., Rinke, T., 2003. The influence of macrophytes on sedimentation and nutrient retention in the lower River Spree (Germany). Water Research, 37(3), 569-78.

Sha, C., Mitsch, W. J., Mander, Ü., Lu, J., Batson, J., Zhang, L., & He, W., 2011. Methane emissions from freshwater riverine wetlands. Ecological Engineering, 37(1), 16-24.

Shannon, R. D., White, J. R., 1994. A three-year study of controls on methane emissions from two Michigan peatlands. Biogeochemistry, 27(1), 35-60.

Smith, D. G. and R. J. Davies-Colley, 1992. Perception of Water Clarity and Colour in Terms of Suitability for Recreational Use. Journal of Environmental Management 36:225-235.

Sorensen, J.P.R.; Butcher, A.S., 2011. Water level monitoring pressure transducers : a need for industry-wide standards. Ground Water Monitoring & Remediation, 31 (4). 56-62. 10.1111/j.1745-6592.2011.01346.x

Soulsby, C., Youngson, A. F., Moir, H. J., Malcolm, I. A., 2001. Fine sediment influence on salmonid spawning habitat in a lowland agricultural stream: a preliminary assessment. Science of the Total Environment, 265**,** 295-307.

Spink, A.J., Murphy, K.J., Smith, S.M., Westlake, D.F., 1993. Effects of eutrophication on *Ranunculus* and *Potamogeton*. J. Aquatic Plant Manage, 31, 113-7.

Swales, S., 1982. Impacts of Weed-cutting on Fisheries: an Experimental
Study in a Small Lowland River., Fisheries. Management. 13 (4), 125-137.

UK BAP Steering Group for Chalk rivers, 2004. The state of England's Chalk rivers. Bristol, Environment Agency.

Wade, A.J., Whitehead, P.G., Hornberger, G.M., Snook, D.L., 2002. On modelling the flow controls on macrophyte and epiphyte dynamics in a lowland permeable catchment:

the River Kennet, southern England. The Science of the Total Environment 282-283, 375-393.

Walling, D.E., Collins, A.L., McMellin, G.K., 2003. A reconnaissance survey of the source of interstitial fine sediment recovered from salmonid spawning gravels in England and Wales, Hydrobiologia, 497, 91-108.

Warren, L.L., Wotton, R.S., Wharton, G., Bass, J.A.B. and Cotton. J.A., 2009. The transport of fine particulate organic matter in vegetaeted chalk streams. Ecohydrol. 2, 480-491.

Waters, B. F., 1976. A methodology for evaluating the effects of different stream flows on salmonid habitat, in: J.F.Orsborn and C.H.Allman (Eds.) Instream Flow Needs, 254-266

Westlake, D.F., 1967. Some effects of low-velocity currents on the metabolism of aquatic macrophytes. J. Exp Bot, 18, 187-205.

Westlake, D.F., Casey, H., Dawson, F.H., Ladle, M., Mann, R.H.K., Marker, A.F.H.M., 1972. The chalk stream ecosystem, in: Kajak, Z. and Hillbright-Illkowska, A. (eds) Productivity problems of freshwaters. 615-635. Warsawa, Krakow.

Wharton, G., Cotton, J. A., Wotton, R. S., Bass, J. A. B., Heppell, C. M., Trimmer, M., Sanders, I. A., Warren, L. L., 2006. Macrophytes and suspension-feeding invertebrates modify flows and fine sediments in the Frome and Piddle catchments, Dorset (UK). Journal of Hydrology, 330, 171-184.

Wheeldon J., 2003. The River Avon cSAC Conservation Strategy. English Nature, Peterborough.

Wheeler, B.D., Gowing, D.J.G., Shaw, S.C., Mountford, J.O., Money, R.P. 2004. *Ecohydrological Guidelines for Lowland Wetland Plant Communities, in:* Brooks, A.W., José, P.V., Whiteman, M.I. (Eds) Peterborough: Environment Agency (Anglian Region).

Whiting, G.J.; Chanton, J.P., 1993. Primary production control of methane emission from wetlands. Nature, 364, 794-795.

Wright, J. F., 1992. Spatial and temporal occurrence of invertebrates in a chalk stream, Berkshire, England. Hydrobiologia, 248**,** 11-30.

WWF-UK, 2009 Rivers on the edge, WWF-UK, London.

Yen, B.C., 2002. Open channel flow resistance. Journal of Hydraulic Engineering. 128, 20-39.

Figure Captions

Figure 1: River Lambourn Observatory, Berkshire, southern England (© NERC (CEH) © Crown copyright and database rights 2009 Ordnance Survey 100017572)

Figure 2 Illustration of sinuous flow weed cutting pattern and location of measured cross-section (A-A)

Figure 3 Water level measurements along ~500m of the River Lambourn at Boxford before and after the weed cut in July 2008

Figure 4 Vertical profiles of velocity across Cross Section A-A before and after the July 2008 weed cut at Boxford, River Lambourn.

Figure 5 Depth averaged velocity (U_d), Water level (WL) and Bed shape at Cross Section A-A before and after the 2008 weed cut.

Figure 6 Manning coefficient across Cross-Section A-A before and after the July 2008 weed cut.

Figure 7 Water level responses following the 2010 weed cut in wetland peat (black) and gravel piezometers (grey) (data from paired piezometers 1, 6 and 13) as well as in the River Lambourn (at WQ2) and the Westbrook (at SW).

Figure 8 Suspended sediment concentration time series throughout the 2008 and 2009 weed cuts at Water Quality Station 3 on the River Lambourn at Boxford.

Weed cutting increased flood conveyance by reducing levels and increasing velocities.

Instream and riparian ecology is likely to be impacted by weed cutting.

Weed cutting affected riparian groundwater levels.

Weed cutting mobilised instream fine sediment and associated chemicals.

Manipulation of macrophytes represents an effective management tool.

Table 1. Changes in macrophyte coverage identified by comparing the four MTR surveys pre and post the July 2008 weed cut.

Species	Number of surveys		
	No change	Increase	Decrease
Azolla filiculoides	**2**	**0**	**2**
Lemna minor	**3**	**0**	**1**
Lemna minuta	**1**	**1**	**2**
Ranunculus spp.	**0**	**0**	**4**

Table 2. Flow conditions before and after the 2008, 2009 and 2010 weed cuts with the % change given in parentheses.

Event	Discharge (m^3/s)	Stage (m)	Cross-sectional mean velocity (m/s)	Manning Coefficient (n)	Conveyance Capacity (m^3/s)
8th July 2008 (BC)	2.08	1.07	0.30	0.13	2.08
10th July 2008 (AC)	2.03 (-3%)	0.84 (-22%)	0.43 (+43%)	0.08 (-43%)	3.82 (+89%)
19th May 2009 (BC)	1.57	1.06	0.22	0.18	1.68
21st May 2009 (AC)	1.46 (-7%)	0.77 (-28%)	0.35 (+55%)	0.08 (-54%)	3.52 (+141%)
4th May 2010 (BC)	2.04	0.92	0.36	0.10	3.03
6th May 2010 (AC)	2.22 (+9%)	0.77 (-17%)	0.52 (+45%)	0.05 (-45%)	5.21 (+135%)

Table 3 Wetland groundwater levels (m bgl) pre- and post- 2009 and 2010 weed cuts.

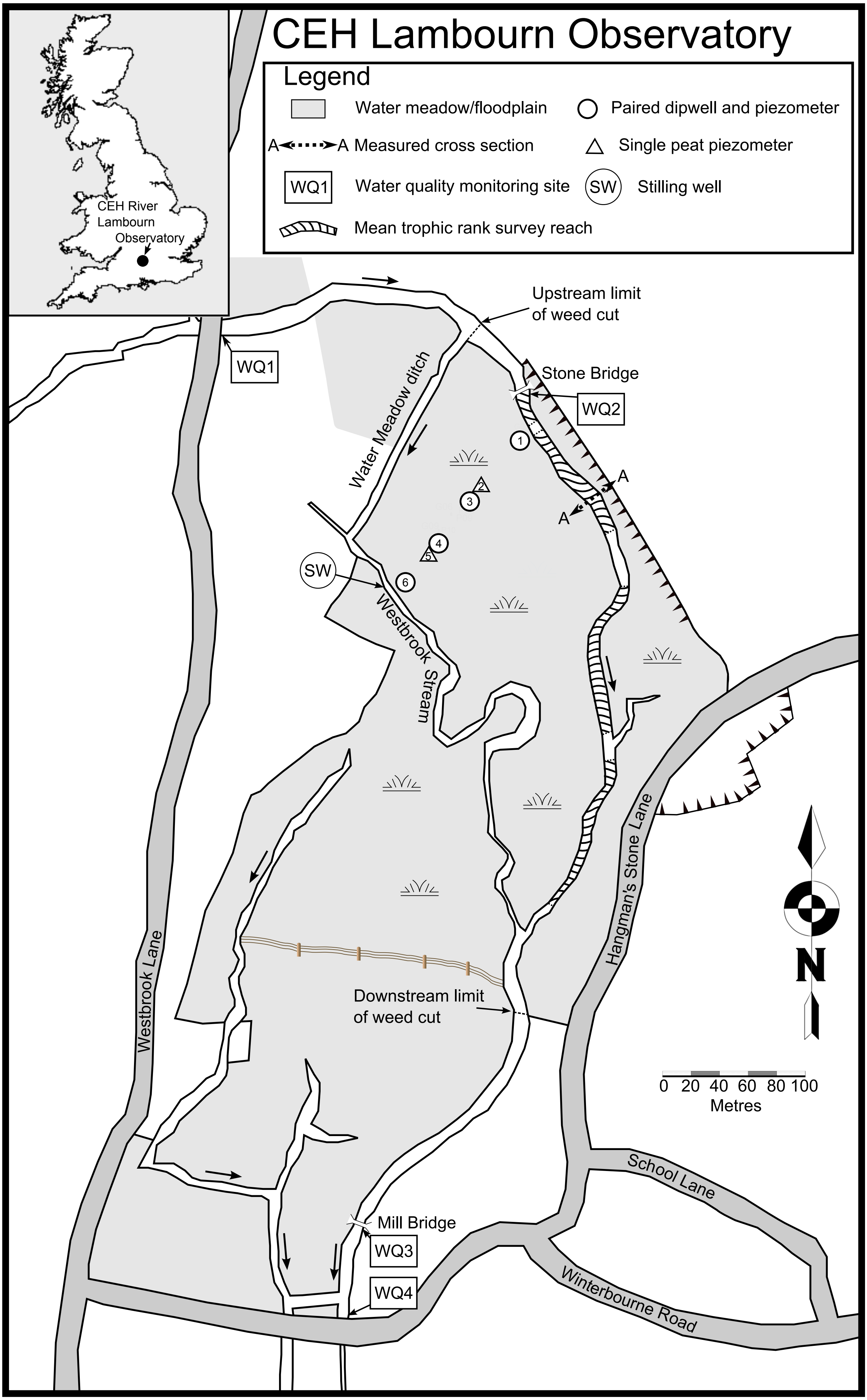
Piezometer (P=Peat; G=Gravel)	2009		2010	
	Pre-cut	6 days post-cut	Pre-cut	4 days post-cut
P1	-0.08	0.16	0.01	0.11
P2	0.10	0.24	0.06	0.13
P3	0.14	0.26	0.26	0.33
P4	0.15	0.24	0.12	0.18
P5	0.10	0.21	-	-
P6	-	0.27	-0.04	0.10
G1	-0.05	0.15	-0.01	0.08
G3	0.21	0.35	0.03	0.11
G4	0.17	0.31	0.14	0.21
G6	0.04	0.28	-0.06	0.09

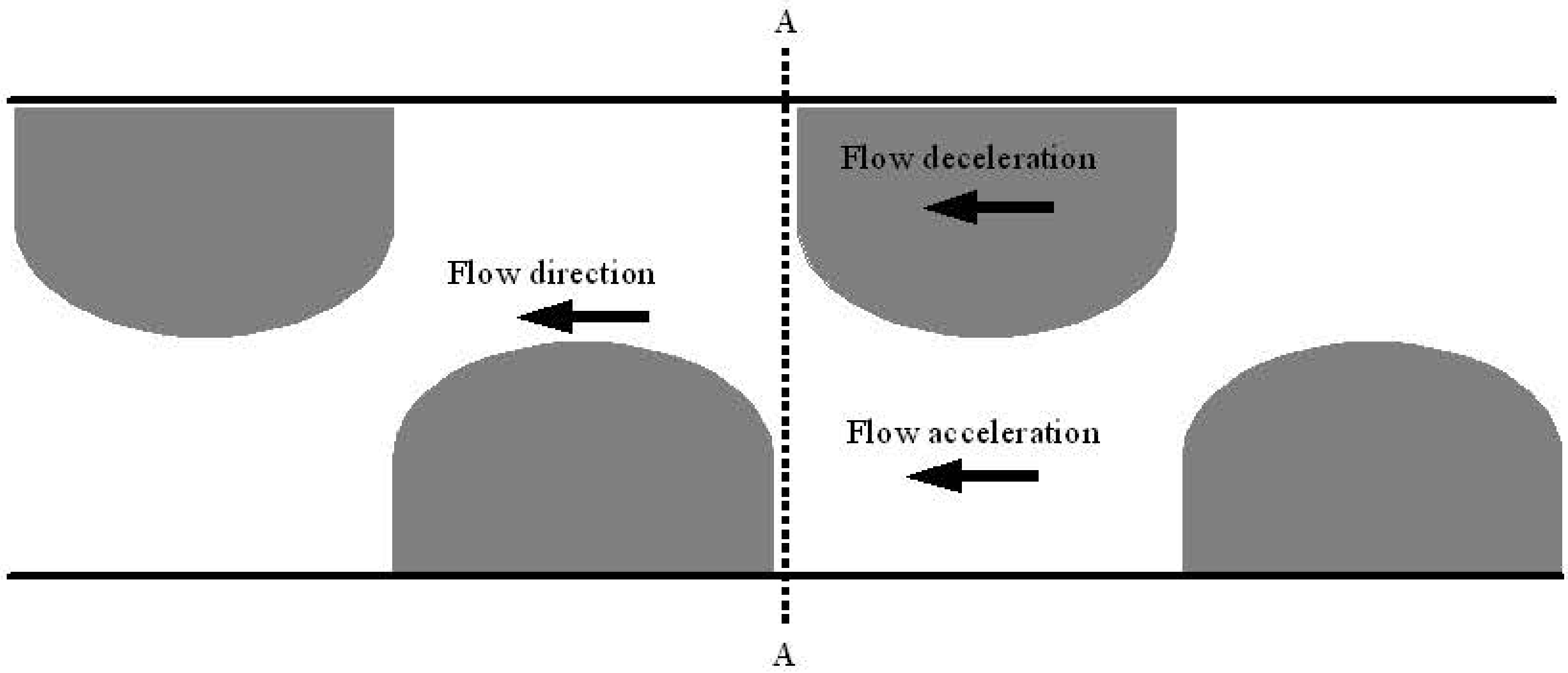
Table 4. Average water quality up and downstream of weed cut (9:00h to 15:15h July 2008; 5 samples).

Water quality parameter	Concentration at WQ 1 (upstream of weed cut)	Concentration at WQ 4 (downstream of weed cut)
Suspended sediment concentration (mg/l)	3.1	21.3
Total Phosphorus (µg/l P)	65.2	100.6
Chlorophyll (µg/l)	1.2	5.9
Pb – Total (µg/l)	0.264	1.074
Cd – Total (µg/l)	0.0058	0.019

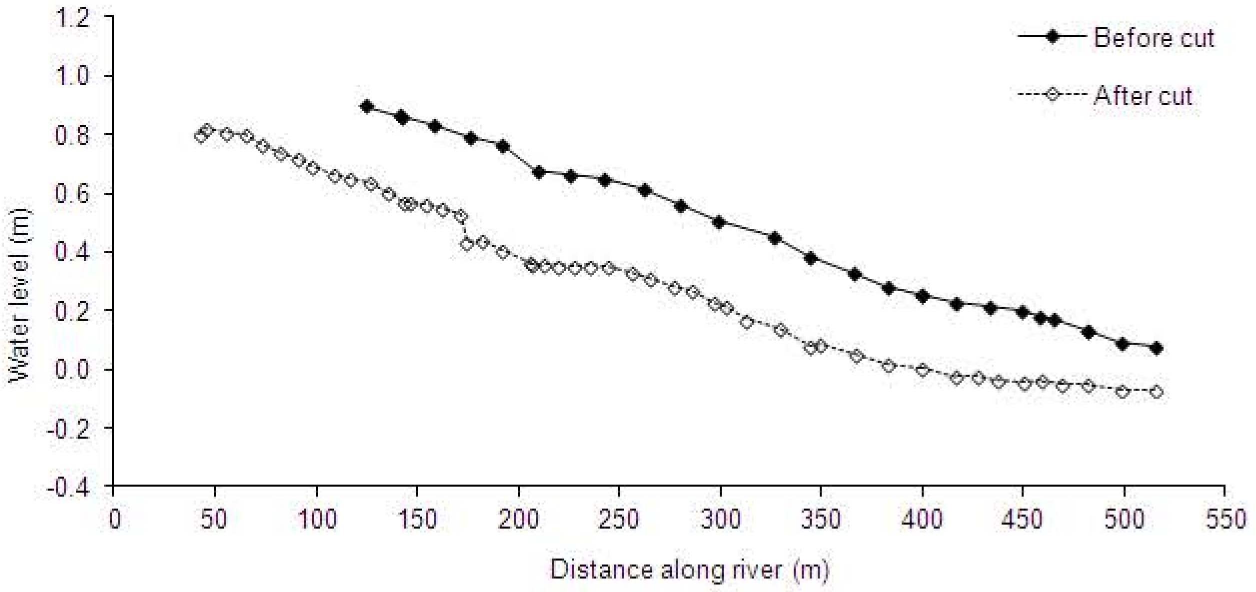
Table 5 Weighted Useable Width (WUW) for velocity (m) of the River Lambourn before and after weed cuts for *S. tutta* (0-7 cm) and *T. thymallus* (fry).

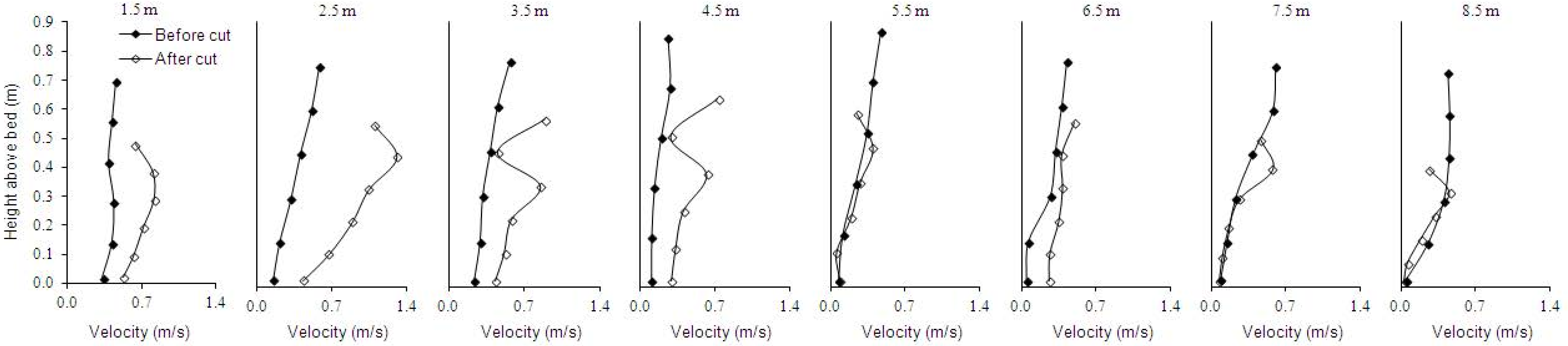
Fish Species	July 2008		May 2009		May 2010	
	before	after	before	after	before	After
S. trutta (0-7 cm)	9.67	6.87	8.81	8.76	6.03	7.16
T. thymallus (fry)	2.7	2.59	3.9	2.6	3.6	0.3


CEH Lambourn Observatory
Legend
Water meadow/floodplain
Paired dipwell and piezometer
A A Measured cross section
Single peat piezometer
WQ1 Water quality monitoring site
SW Stilling well
Mean trophic rank survey reach
CEH River Lambourn Observatory
Upstream limit of weed cut
Stone Bridge
WQ1
WQ2
Water Meadow ditch
A
A
1
2
3
4
5
6
SW
Westbrook Stream
Westbrook Lane
Hangman's Stone Lane
Downstream limit of weed cut
School Lane
Winterbourne Road
Mill Bridge
WQ3
WQ4
N
0 20 40 60 80 100
Metres

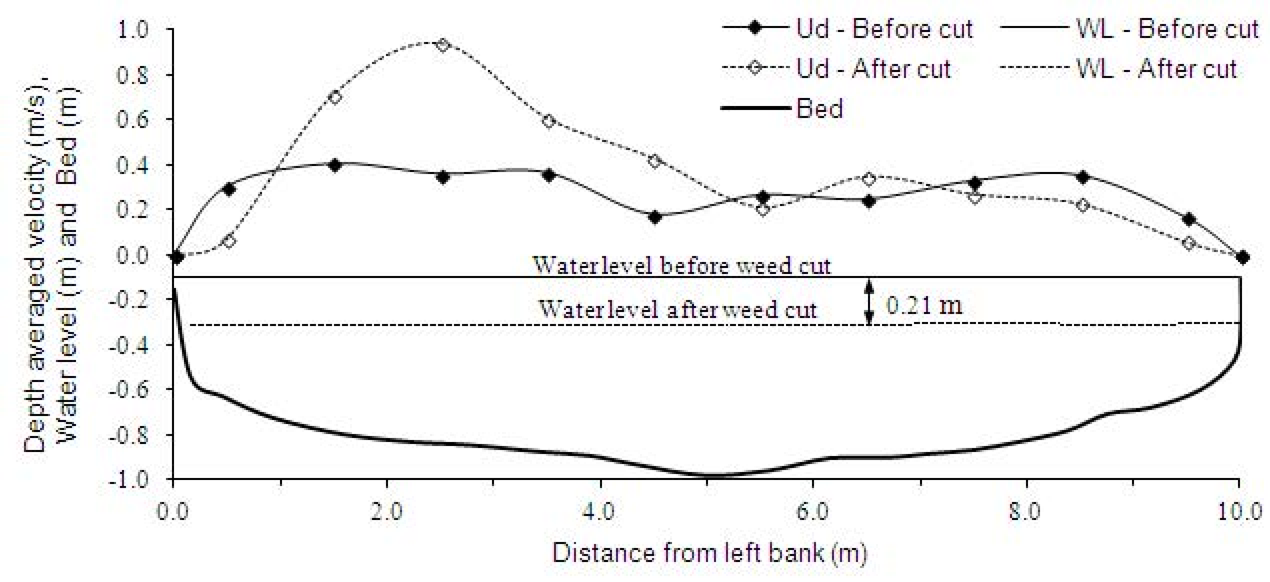


A
Flow deceleration
Flow direction
Flow acceleration
A

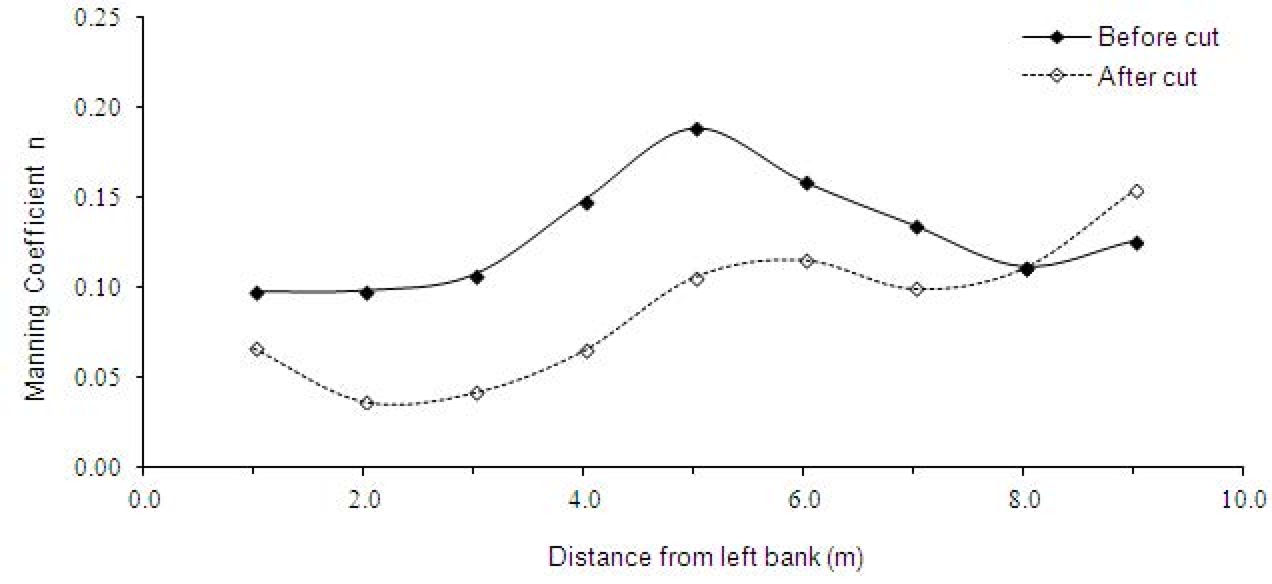

Before cut
After cut
Water level (m)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
50
100
150
200
250
300
350
400
450
500
550
Distance along river (m)



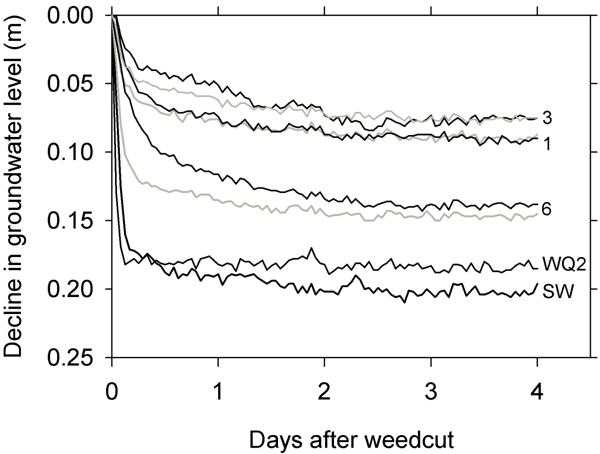
1.5 m
2.5 m
3.5 m
4.5 m
5.5 m
6.5 m
7.5 m
8.5 m
Before cut
After cut
Height above bed (m)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.0
0.7
1.4
Velocity (m/s)



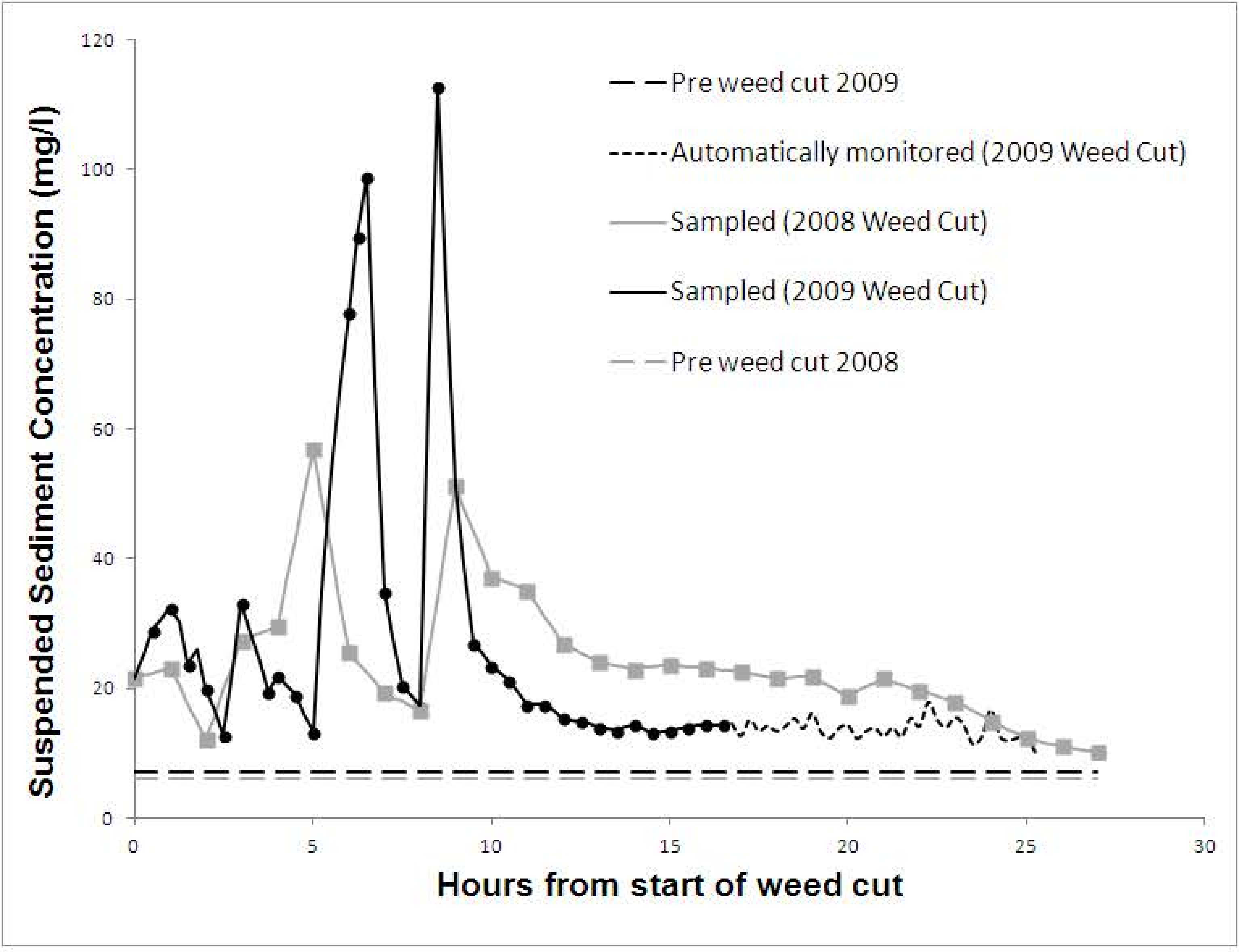
Ud - Before cut
WL - Before cut
Ud - After cut
WL - After cut
Bed
Water level before weed cut
Water level after weed cut
0.21 m
Depth averaged velocity (m/s), Water level (m) and Bed (m)
Distance from left bank (m)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0.0
2.0
4.0
6.0
8.0
10.0



Before cut
After cut
Manning Coefficient n
Distance from left bank (m)
0.00
0.05
0.10
0.15
0.20
0.25
0.0
2.0
4.0
6.0
8.0
10.0



0.00
0.05
0.10
0.15
0.20
0.25
Decline in groundwater level (m)
0
1
2
3
4
Days after weedcut
3
1
6
WQ2
SW



Suspended Sediment Concentration (mg/l)
120
100
80
60
40
20
0
0
5
10
15
20
25
30
Hours from start of weed cut
Pre weed cut 2009
Automatically monitored (2009 Weed Cut)
Sampled (2008 Weed Cut)
Sampled (2009 Weed Cut)
Pre weed cut 2008