**Real-time consequences of riparian cattle trampling for mobilisation of sediment, nutrients and bacteria in a British lowland river**

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**Abstract**

Rivers and their catchments support multiple human needs, necessitating integrated management of land and water resources. Agricultural land use, specifically the impacts of riparian cattle trampling, potentially significantly contributes to damage to river systems. This study addresses a knowledge gap stemming from the paucity of prior research correlating generation of pollutants with cattle activity locally and in ‘real time’. Turbidity, soluble reactive phosphorus and faecal coliforms were analysed at upstream control and downstream impact sites correlated with cattle activity over a 65m river margin throughout a two-month summer period. Riparian cattle trampling impacted water quality, specifically turbidity and faecal coliform levels. Average turbidity increased by more than 90% between upstream and downstream sites during cattle activity, whilst average faecal coliform counts almost doubled. Findings for phosphorus concentrations were less conclusive, perhaps due to filtration of suspended sediment-bound phosphorus prior to analysis. Illustrative cost-benefit assessment of potential buffer zone installation to exclude cattle from the river margin at the study site, based on values transferred from a relevant published study, found that investment in a buffer zone would achieve a benefit-to-cost ratio of approximately 38:1 with a distribution of broad societal benefits to the farmer, local people and wider publics.

**Keywords**

Cattle trampling, water quality, turbidity, faecal coliforms, soluble reactive phosphorus, buffer zone

**1. Introduction**

Water quality is a crucial determinant of ecological character, health and the capacities of rivers to support economic and other human activities (Staddon 2010). Agriculture presents a significant pressure on water resources, its intensification including chemical inputs contributing to increasing pollution particularly by nitrogen, phosphorus and sediment inputs reaching watercourses through leaching and run-off (Hill 1978, Hooda *et al.* 2000, Rock and Mayer 2006, Royer *et al*. 2006, Tarkalson *et al.* 2006). Phosphate inputs are linked to sediment loss from land to water (Sekely *et al.* 2002). The impacts of land use and alterative management practices on water quality has consequently been a significant focus for research (Baker 2006). In the UK, over 70% of total land area is farmed in one way or another. Whilst farming is not the only pollution source, it contributes around 50-60% of nitrates, 20-30% of phosphorus and 75% of the sediment entering English watercourses (Defra *et al*. 2015).

Mismanagement of stock can be detrimental to water quality (Hooda *et al.* 2000). Cattle activity in and by rivers, particularly trampling of river margins with associated defaecation, is problematic in many British lowland catchments. Internationally, there is increasing concern about livestock activity near watercourses, documented as increasing river concentrations of sediment, nutrients and potentially pathogenic organisms such as *Giardia, Cryptosporidium* andfaecal coliforms (Derlet and Carlson 2006, Muenz *et al.* 2006, Vidon *et al*. 2008, Myers and Kane 2011). In a US study, Myers and Kane (2011) observed significant increases in *E.coli* and other faecal coliform concentrations and a rise in turbidity attributed to the disturbance of the stream bank from vegetation removal and direct trampling in river water immediately after the commencement of summer grazing by cattle. Dierberg (1991) found total loss of nitrogen in surface runoff to be 340% greater on average in a sub-catchment with cattle grazing pastures compared to an undeveloped catchment of otherwise similar characteristics. Elevated concentrations of phosphorus in rivers can also derive from agricultural drainage (Sims *et al*.1998), with inputs influenced by factors such as soil type, time and rate of fertiliser and manure/slurry application (Hooda *et al.* 2000). Stream channel morphology, hydrology, soils, vegetation and wildlife are also negatively affected by riparian livestock grazing (Belsky *et al*. 1999), which can be a source for both point and diffuse pollution (Parkyn 2005). However, associations between livestock activity and water quality have largely been demonstrated by correlating variables across catchments, rather than observations of direct causality.

Compared to other livestock, cattle exert the most detrimental effect on soils and water quality (Betteridge *et al.* 1999). The activity of cattle cutting up land through repeated trampling negatively affects water quality through direct physical impacts on the soil by animal movement, denudation of vegetation, and the chemical and biological impacts of faeces and urine deposited on trampled banks or directly into the river (Whitmore 2015). Table 1 summarises a range of impacts arising from cattle trampling of river banks and margins. However, despite its importance for river water quality and ecology with associated socio-economic implications, very little research has been conducted at local and ‘real time’ scales on the direct impacts of cattle movement in rivers. Terry *et al.* (2014) concluded that most studies tend to focus on controlled cattle access or secondary impacts of cattle activity such as Byers *et al.* (2005) and Godwin and Miner (1996), which do not differentiate between activity on the bank or in-channel.

*Table 1: Overview of the principal impacts of cattle trampling of river banks*

|  |
| --- |
| **Impacts** * **Description**
 |
| **Physical impacts** |
| Loss of vegetation* Increases susceptibility of bank to erosion and generates debris in watercourse (Kilfeather and Feehan 2009).
* Slow recovery of vegetation following cattle removal due to loss of soil dry matter (Sheath and Carlson 1998).
 |
| Increase in suspended sediment and bed load from bank erosion * Terry *et al.* (2014) found that cattle activity in river margins affected suspended sediment:
	+ 57.9% of instances of suspended sediment exceeding the 25mg/l EC Freshwater Fish Directive standard were attributed to cattle in the stream.
	+ No relationship was found between the concentration of suspended sediment and the absolute number of cattle in the river.
	+ There was a temporal lag between cattle presence and their contribution to sediment load.
* Increase in suspended sediment can cause downstream sediment accumulation, potentially altering flow regime and contributing to flooding or further erosion (Kilfeather and Feehan 2009).
* Bank erosion contributed to 32% of sediment discharge and 10% of phosphorus export from an agricultural catchment in Canada (Kilfeather and Feehan 2009).
* Sediment deposition on river gravels can destroy fish nursery and spawning areas (Kilfeather and Feehan 2009).
* Nutrients, significantly phosphorus and nitrates particularly when applied as fertiliser, and organic matter are mobilised with sediment and vectored into watercourses (Warren *et al.* 1986).
 |
| **Chemical and biological impacts from faeces and urine** |
| Increase in nutrients * Associations between nutrient inputs and sediment inputs to rivers (noted above).
* Chemical impacts include increasing concentrations of nitrates and phosphates (Whitmore 2015).
* There is a lack of research into direct impacts from cattle poaching on both phosphorus and nitrogen concentrations in the water column.
 |
| Increase in bacteria * Biological impacts include increasing concentrations of bacteria (Whitmore 2015).
* Cattle directly accessing watercourses may pose a risk to human health though increased risk of pathogen transmission, such as *Cryptosporidium* (Kilfeather and Feehan 2009).
 |
| * Macro-invertebrate and plant life tend to be depleted by poaching, with potential detrimental effects on river ecology and functioning (Kilfeather and Feehan 2009).
 |
| Overall decline in water quality* Increases in sediment, nutrients and bacteria.
* Habitat enhancement can potentially enhance water quality (Kilfeather and Feehan 2009).
 |
| **Socio-economic impacts** |
| Health risks to people and livelihoods* Introduction of potential pathogens from cattle exposes people and livestock to infection risk.
 |
| Economic Implications * Need for increased water treatment downstream with potential major cost implications (Kilfeather and Feehan 2009).
* Adverse impacts across a wide range of ecosystem services (provisioning, regulatory, cultural and supporting) with associated externalised societal costs (Everard and Jevons 2010)
 |

A range of initiatives have been implemented in the UK to control cattle trampling of river margins, working with farmers to improve farm practices. (The cutting up of land through repeated trampling by stock is often referred to as ‘poaching’ in the UK.) In East Devon, the River Otter Catchment Management Project aims to reduce nitrate inputs to watercourses by changing land use practices through targeted farm visits and advice (South West Water 2013). Restricting cattle access generally results in better water quality compared to similar streams with unlimited access (Nagels *et al.* 2002, Line 2003, Muenz *et al.* 2006). This is achieved through reductions in risks of run-off affecting water quality, improved buffering of flows and regeneration of ecologically functional zones (Everard and Jevons 2010). Riparian buffer zones, comprising fenced strips of land limiting cattle access, allow the natural regeneration of a vegetated interface between terrestrial and aquatic ecosystems (Martin *et al.* 1999) providing substantial ecosystem service benefits (Everard 2015). Well-developed riparian zones help maintain bank stability due to soil binding by roots, increasing sheer strength and resistance to erosion with reported substantial decreases in sediment exports to rivers (Knighton 1998, Smith 1976, McKergrow *et al.* 2003). They also act as barriers for nutrient and pesticide runoff (O’Grady 2006), and return direct benefits to farmers such as reducing stock straying (Everard and Jevons 2010) and protecting the microbial quality of water supplies (Kilfeather and Feehan 2009). Other changes to farming practices can also reduce the impacts of cattle trampling, although these are generally less effective that buffer-zoning (Line *et al.* 2000).

A growing body of legislation seeks to address the contributions of farming activities to contamination of the water environment, including for example the EC *Nitrates Directive* (European Commission 1991)and the *Water Framework Directive* (European Commission 2000).The EU Common Agricultural Policy (CAP) is the principal instrument governing agricultural practices across Europe, establishing conditions allowing farmers to manage and fulfil their multiple functions in society (European Union 2014). However, enforcement of farming practices has not been consistent, despite the availability of sanctions for non-compliance with environmental protection requirements (European Union 2013). Failure to mitigate environmental impacts are also starting to be addressed by other legal routes, such as damage through cattle bank trampling of rivers protected under European law (Shropshire Star 2015, Wild Trout Trust 2015). However, more effective measures to protect rivers and targeted research to support the case for their implementation are clearly required.

This study addresses the knowledge gap of ‘real time’ impacts on suspended sediment, nutrient mobilisation and bacterial contamination caused by cattle trampling of the banks and channel edge of a lowland river in the west of England. Temporal relationships of these parameters are correlated with cattle activity in a stretch of watercourse with unrestricted and sporadic access, an indicative cost-benefit assessment is developed to support a case for better management at the farming/water interface, and further recommendations are derived for policy, practical and multi-beneficial solutions and further research.

**2. Methods**

Methods deployed in this study include: site selection and characterisation; monitoring of cattle activity; and monitoring and analysis of water quality parameters.

*2.1 Site selection and characterisation*

Targeted monitoring of the direct consequences of cattle trampling were directed at a single study site on a rural section of a major river in the West of England. Site selection was determined by ready and safe access for the sampler, secure locations for siting automatic sampling and monitoring equipment, consent of landowners, and a history of discolouration of river water following cattle freely accessing the river margin. Due to the sensitive nature of the research, the exact location is anonymised. However, site characteristics are illustrated in Figure 1.

*Figure 1: Characteristics of the anonymised study site*

The host catchment is >2,000 km2 in area with a human population of approximately 1,000,000. The study site is situated on a relatively flat and low-lying river reach at around 60 mASL (Digimap 2015) running mostly over Kellaways Clay member mudstones, sandstones and siltstones of the mid-Jurassic epoch. This is heavily overlain by alluvium (silt, sand and gravel deposits), which is readily eroded through trampling (Digimap 2015) heightening risks from trampling early and late in the grazing season (LandIS 2015). The surrounding land use includes seasonally wet pastures and sections of broadleaved woodlands, the fields on the right bank used permanently as pasture for beef farming (Digimap 2015, LandIS 2015). The river has an average width of approximately 10m and is fairly shallow (between 0.2m and 3m) over most of the study site with some deeper sections downstream of the trampling zone. Planform gently meanders and in parts is deeply incised following historic dredging, which has resulted in a loss of channel diversity and much of the hard substrate. Consequently, species such as brown trout (*Salmo trutta*) are not common, though there is a mixed fishery containing a robust population of coarse fish including roach (*Rutilus rutilus*), chub (*Squalius cephalus*) and barbel (*Barbus barbus*) (Lewis 2005). There is significant vegetation growth both in-channel and riparian including reed sweet grass (*Glyceria maxima*), unbranched bur-reed (*Sparganium emersum*), milfoil (*Myriophyllum spicatum*) and beds of yellow water lily (*Nuphar lutea*), with trees also lining parts of the river bank including several species of willow (*Salix* spp.), hawthorn (*Crataegus monogyna*) and elder (*Sambucus nigra*) (Lewis 2005). Ecological status of this section of river has been classified as ‘poor’ under the EU *Water Framework Directive* (2000/60/EC), with extensive agricultural land use including poor management of the farming/water interface contributory to suboptimal biological quality and presence of specific pollutants (Environment Agency 2015).

The experimental site was centred on the cattle trampling zone, spanning approximately 65m along the right bank. Frequent trampling had caused extensive localised erosion, demonstrated by the lack of vegetation and broken soil surface in Figure 2. The trampling zone was bounded upstream by a wire fence installed across the river to prevent cattle accessing the far bank under low flows. There was no physical barrier downstream where deeper water limited cattle access, though in the period of declining flow during the summer sampling season some cattle were observed wading in waters below the major trampling zone.

The climate in the area is generally warm and temperate with an average annual temperature of 9.7˚C, the warmest month being July. An average of 689mm of precipitation falls annually, with the driest month being February although there is significant year-round rainfall (Climate-Data.org 2015).

*2.2 Monitoring cattle activity*

Research into cattle point source pollution events often uses sites downstream of pollution sources and an upstream control to gather comparative water quality data, as well as a mechanism to quantify cattle activity (Terry *et al.* 2014). Cattle activity can be captured by direct timed observations, or by technical means including time lapse or motion-sensing photography, each of these methods with different strengths and weaknesses (Brown and Gehrt 2009, Terry *et al*. 2014). Benefits of the selected direct timed observation approach include low cost, set-up time and security issues, and avoidance of limitations imposed by fixed camera angle and image analysis. However, it does not provide post-survey evidence and is limited by the availability of the observer and at least one other volunteer for assistance and safety purposes, which constrained available days for sampling and limited observations to daylight hours.

Observations of cattle trampling in the trample zone took place across 18 sampling visits between 2nd June and 2nd August 2015. Observations were recorded by the principal investigator and at least one well-briefed field assistant, counting from the top of an eroding cliff on the opposite (left) bank of the river to afford a good view of the whole 65m trampling zone yet without disturbing cattle. Numbers of cattle entering the river, recorded when one or more parts of its body was in the river (illustrated by the eight cattle recorded in the river in Figure 2), were registered at five-minute intervals commencing when cattle were observed approaching the river. This sampling frequency may not have accounted for every cow in the river during each period, but avoided double-counting and provided an overall profile of extent and duration of cattle activity each time the herd entered the river.

*Figure 2: Eight cattle counted in the river margin by contact with the water by at least one parts of their body*



*2.3 Monitoring and analysis of water quality parameters*

Upstream control and downstream impact monitoring sites were identified for secure yet accessible installation of automated samplers and loggers and for safely accessible manual sampling. The ideal location for a downstream site is below the mixing zone, but not so far downstream that other factors have a significant effect (Parr 1994). Unfortunately, security of location and accessibility for manual sampling meant that the automated sampler and loggers were installed and concealed on the right bank 147m downstream of the trampling zone, far enough downstream to enable mixing of turbid and clean river water but unfortunately downstream of a tributary (Figure 1). Whilst the tributary could potentially compromise the validity of data, frequent visual observations of the tributary through sampling visits confirmed no silt egress arising from the tributary and that its discharge across a width of less than one metre and a depth of up to 10cm was very small during the dry weather. Due to the steep gradient on which the autosampler was located on the right bank, manual samples were taken from a safer location directly opposite from the left bank. The upstream control site, unaffected by cattle activity, was on the left bank approximately 12m upstream of the trampling zone above the fence limiting cattle access.

Water quality sampling was synchronised with cattle observations during the 18 summer field visits, with two prior visits for field orientation and equipment installation and testing. Access to the laboratory only during the working week for time-intensive analysis, particularly bacterial testing that spanned two consecutive days and had to be initiated within a 24-hour window of sample collection, constrained days available for data collection.

Water samples were taken for analysis of turbidity, phosphorus and bacterial concentrations, correlated with observed cattle activity in the river margin, with additional data collection using sensors and dataloggers. Sampling and analytical methods are outlined in Table 2. Itbecame apparent that cattle activity was generally greater towards the evening, so field days were adjusted to commence from mid-afternoon. Whilst enabling more data to be gathered when cattle were accessing the river, drawbacks included the lack of daylight hours with sampling bottles frequently collected in near darkness necessitating retention of samples in dark, chilled conditions to minimise transformations prior to analysis the following day.

*Table 2: Sampling and analytical methods used in this study*

|  |  |
| --- | --- |
| **Activity or determinant** | **Sampling procedure or analytical method** |
| Automatic sampling | ISCO 3700 autosamplers and associated accessories (ISCO 2012) – a controller, peristaltic pump, sample tubing extending to a weighted suction head into the river and 24 internal space-efficient 1-litre polypropylene sample bottles – were installed on site for the duration of the study, one upstream and one downstream. |
| Sensors and data loggers | Pairs of data loggers, one each measuring conductivity and turbidity, were installed alongside the autosampler heads for a two-week period only (9th June to 23rd June 2015) due to high demand on the equipment. |
| Manual water sampling | Manual water sampling was achieved using a well-flushed metal canister suspended from a telescopic pole. Manual pole samples were taken every 30 minutes from the left bank from the time at which cattle were observed approaching the river, decanting the water sample into an appropriately labelled polypropylene sampling bottle that had been washed with deionised water, avoiding the sampling canister touching the sides of the bottle and immediately securing the washed lid before storing the bottle in a cool bag before analysis could take place. The most important element of this research was synchronisation of sampling with cattle activity. However, practical time and health and safety constraints limiting pole sampling to one sample per 30 minute interval, introducing potential error relative to a more frequent sampling from varying depths and widths across the river. The autosamplers were also turned on as cattle were observed approaching the river, collecting sequential samples of 500ml every five minutes spanning an overall two-hour sampling period. On completion of this sampling programme, the autosamplers were turned off and the water treated the same as pole-collected water samples. |
| SRP analysis | Soluble reactive phosphorus (SRP) concentrations were analysed on site using a Palintest Photometer 8000, using colorimetry comparing control (distilled water) and filtered river water samples following introduction of ammonium molybdate and ascorbic acid reagents in tablet form to measure in the range 0-1.3mgP l-1 with an accuracy of ±0.8% transmittance (Palintest Ltd 2015). The photometer was calibrated by the Earth Sciences department at the University of the West of England (UWE). |
| Turbidity analysis | Turbidity was analysed using a Hanna Instruments HI-93703 portable turbidity meter, detecting scattered infrared radiation with a resolution of 0.01 FTU and an accuracy of ±0.5 FTU or ±5% of reading (Hanna Instruments Ltd 2014). The turbidity meter was calibrated by the Earth Sciences department at the University of the West of England (UWE). |
| Faecal coliform analysis | Faecal coliforms (CFU/100ml) were chosen as best representing impacts of cattle activity (Wilkinson 2002) and as indicators of the potential presence of pathogenic microorganisms posing potential health risks and increasing water turbidity, odour and oxygen demand (Environmental Protection Agency 2012). The membrane filtration process was selected as, though less precise than the multiple-tube fermentation procedure (American Public Health Association 1999), it is a more rapid methods appropriate for larger samples that provides a more affordable means to estimate bacterial populations (Hach 2012).Due to cattle activity peaking in the evening, samples often had to be kept in cool, dark conditions for analysis the following day and then counted after overnight incubation.Plates and broth used for bacterial analysis were sterilised in an autoclave the day prior to analysis, based on the ELE Paqualab kit and its associated standard method including overnight incubation for 16 hours at 44˚C. Yellow-stained colonies (oxidase-negative organisms producing lactose or β-galactosidase) classified as coliforms were counted by eye using a magnifying glass and tally counter (Environment Agency 2009). For dense colonies, average count per grid square was recorded and multiplied to account for total petri dish area. Counts were compared with controls and also before and after cattle activity.  |

Timed water samples were collected before, during and after cattle activity at both upstream and downstream sites to determine what impacts cattle trampling was having on key water quality parameters. Precipitation and temperature data were obtained for the nearest weather station (World Meteorological Organisation WMO 2015a) situated within 10km of the study site. The Environment Agency supplied stage and flow data in 15-minute intervals from a gauging station 0.84km river length downstream from mid-point of the trampling zone.

River flow affects fluvial entrainment and mobilisation of sediment, nutrients and bacteria following the weakening of the river bank from cattle trampling (Sear *et al*. 2010). Bed and bank substrates become mobilised and entrained into river water beyond threshold flow velocities that vary with material cohesiveness (Charlton 2008, Hugget 2003). Where bed material is unconsolidated due to repeated trampling, it is likely to be readily suspended with adverse effects on river ecology (Conroy *et al*. 2016).

**3. Results**

Results are recorded for: weather and stream hydrology; correlations between cattle activity in the river margin and water quality; and indicative cost-benefit assessment.

*3.1 Weather and stream hydrology*

The data collection period was typified by warm, dry weather with mean daily air temperature of 15.1˚C (minimum 3.9˚C, maximum 31.3˚C) (WMO 2015b), spanning only 14 rain days producing a total of 32mm of precipitation (WMO 2015b). This accounts for low and declining flow and stage levels (Figure 3), with an average of 0.454m³/s and 0.162m. Low flows may have resulted in minimal fluvial entrainment of sediment, with a risk that a proportion of sediments, associated nutrients and bacteria would have been deposited before reaching the sampling site 147m downstream.

*Figure 3: Stage and flow data from the nearest gauging station approximately 0.84km downstream (location not disclosed to preserve site anonymity)*

*3.2 Correlations between cattle activity in the river margin and water quality*

Although 18 data collection visits were undertaken, cattle were only observed trampling the river margin on eight of these visits. Analytical difficulties, particularly with laboratory access for bacterial analysis, also meant that it was not possible to collect data for all parameters from each visit. Table 3 outlines site visit dates and data collected.

*Table 3: Cattle activity and data collection on visits to study site (Y = Yes; N = No)*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Date of field visit**  | **Cattle in river**  | **Time cattle first entered river**  | **Turbidity**  | **SRP** | **Faecal coliforms**  |
| 02/06/15 | **N** |  |  |  |  |
| 08/06/15 | **N** |  |  |  |  |
| 10/06/15 | **N** |  |  |  |  |
| 11/06/15 | **Y** | 17:35 | **Y** | **N** | **N** |
| 15/06/15 | **Y** | 16:43 | **Y** | **Y** | **Y** |
| 17/06/15 | **N** |  |  |  |  |
| 18/06/15 | **N** |  |  |  |  |
| 19/06/15 | **N** |  |  |  |  |
| 22/06/15 | **N** |  |  |  |  |
| 23/06/15 | **Y** | 18.35 | **Y** | **Y** | **Y** |
| 25/06/15 | **Y** | Already in on arrival at 17:30  | **Y** | **Y** | **N** |
| 28/06/15 | **N** |  |  |  |  |
| 30/06/15 | **Y** | Already in on arrival at 17:00  | **Y** | **Y** | **Y** |
| 08/07/15 | **Y** | 19:29 | **Y** | **Y** | **N** |
| 14/07/15 | **Y** | 18:40 | **Y** | **Y** | **Y** |
| 27/07/15 | **N** |  |  |  |  |
| 28/07/15 | **N** |  |  |  |  |
| 02/08/15 | **Y** | 14:00 | **Y** | **Y** | **N** |

The maximum number of cattle observed in the water at one time was 35 animals on 23rd June 2015. Numbers of cattle observed in contact with the water at five-minute intervals reveal that a large number of cows enter the river at the commencement of trampling activity, with numbers then tending to decrease until the herd recommenced grazing away from the bank. Whilst in the stream, some cows stayed stationary for long periods and others tended to move around and, on some occasions, wandered a number of metres upstream and downstream of the trampling zone. A large amount of urine and faeces was also observed deposited on the bank or directly into the stream. These movements all affect the amount of sediments, nutrients and bacteria added to the water or re-suspended from the bed (Terry *et al.* 2014). The amount of time the cattle spent trampling the bank and river bed varied greatly between visits, ranging from around 20 minutes to over two hours. Therefore, automatic samples were able to capture the rising limb of contamination, but not necessarily the falling limb for all events.

This is unfortunate as, allowing for the observed rises, conductivity values downstream were consistency higher than at the upstream control site. Though not quantified, the influence of the tributary was considered insignificant in influencing this and other comparative upstream/downstream results due to its minimal flows and high water clarity.

Turbidity (suspended solid)data were collected by water sampling on all eight visits that cattle were present. During visits when cattle trampling occurred, upstream and downstream automatic samplers ran for a two-hour period. Successive pairs of five-minute samples were mixed, representing an average for each 10-minute period. Despite limited replication, the datasets show a highly significant average turbidity increase of more than 90% over the 224m river distance between the upstream (control) and downstream (impacted) sites during cattle trampling (see Figure 4). Figure 5 is a correlation of average downstream turbidity and average number of cows in the river over a five-minute interval, showing a small but significant positive correlation between cattle activity and turbidity. Regrettably, data from the turbidity and conductivity sensors and data loggers appears to have been corrupted, so had to be discounted. No clear relationship between average cattle count and turbidity was evident (consistent with observations by Terry *et al*. 2014), the highest average cattle counts coinciding with the lower turbidity values, although this may be an artefact of using average data with lower cattle counts indicating that cattle did not stay in the river for long.

*Figure 4: Average number of cows counted at five-minute intervals and average turbidity (NTU) at the upstream and downstream sites on each visit*

*Figure 5: Relationship between cattle activity (average number of cows in the river over a five minute period) and average turbidity*

Higher turbidity levels were observed at the downstream compared to the control site during cattle trampling events (see example from 2nd August 2015 in Figure 5). There was, however, significant variability in turbidity during visits (an average of over three Standard Deviations from the mean) potentially reflecting the unevenness of trampling intensity during herd visits to the river margin. Two-sample t-tests comparing turbidity data upstream and downstream of the trampling site for sampling periods with no cattle present and when cattle trampling was occurring yielded P-values of 0.500 and 0.000 respectively, indicating statistical significance at a 95% confidence interval between upstream and downstream sites only when cattle trampling was occurring. Turbidity levels also generally peaked early on, decreasing until then steadily increasing to another peak (the event recorded in Figure 6 does not show this second peak). These data are generally consistent with previous research findings that direct cattle effects on turbidity are often short-lived (Davies-Colley *et al.* 2004, Vidon *et al*. 2008) attributed to the instantaneous manner in which cattle introduce sediment to the channel or re-suspend streambed materials from instream trampling. Whilst it had been assumed that the number of cattle in contact with river water would influence the magnitude of turbidity increase due to hooves carrying sediment into the channel and displacing it from the channel bed, although episodic and sporadic cattle access complicates this relationship (Terry *et al.* 2014), no such correlation was observed in the dataset gathered in this study. Potentially, this lack of correlation may be due to confounding factors such as the time lag taken for suspended sediment to travel 147m to the downstream monitoring site, travel time and fall-out becoming more significant as the stage/flow of the river declined during the dry weather throughout the sampling period. Figure 7 plots the relationship between average flow per day and average turbidity value following cattle activity at the downstream site for each visit at which trampling activity was observed, revealing a positive albeit weak relationship (R2 = 0.01).

*Figure 6: Turbidity readings upstream and downstream and cattle activity over time (5 minute counts) during the 2nd August 2015 field visit*

*Figure 7: Relationship between river flow and average turbidity at the downstream site during/after cattle activity*

SRP concentration data were collected from all but one of the eight visits when cattle were present instream. As with turbidity readings, not all the phosphorus data represents the full two-hour period. The data collected over the study period suggests that instream cattle activity has no evident correlation with stream phosphorus concentration (Figure 8), Figure 9 revealing a very small and statistically weak negative correlation between cattle activity in the water and downstream phosphorus concentrations. Whilst there is a face-value increase of around 10% in SRP concentration between upstream (averaging 0.187mgP l-1) and downstream (averaging 0.206mgP l-1) sites during cattle activity, this difference in concentration was consistent with relatively higher values recorded at the downstream site in background (no trampling) conditions. Various factors could account for this, such as more significant phytoplankton growth or ‘spiralling’ of previously deposited phosphorus at the more ponded downstream site (impacts from the tributary were discounted for reasons already given). Two-sample t-tests comparing SRP data upstream and downstream of the trampling site for sampling periods with no cattle present and when cattle trampling was occurring yielded P-values of 0.475 and 0.172 respectively. Neither indicating statistical significance at a 95% confidence interval between upstream and downstream sites with cattle present or absent. However, there was a difference in P-values with cattle activity compared to when cattle were absent suggesting differences between the upstream and downstream values during cattle activity were more significant than when cattle were absent. The observation of no apparent relationship between cattle activity and SRP concentration is inconsistent with other research recording an increase in phosphorus in river water downstream of areas of unrestricted access to streams (Vidon *et al*. 2008). Methodological differences may account for some of this discrepancy as filtration of water to test for SRP may have removed a significant proportion of phosphorus associated with remobilised particles. Despite the lack of evidence of SRP increase due directly to cattle trampling events, a temporal trend was nevertheless evident with rising phosphorus concentration in the river across the sampling period (Figure 8). This is believed to be accounted for by reduced dilution, consistent with the relationship between declining river flow and average turbidity across the sampling window (see Figure 7).

*Figure 8: Average number of cows counted at five-minute intervals and average phosphorus concentration (mg/l P) at the upstream and downstream sites on each visit*

*Figure 9: Relationship between cattle activity (average number of cows in the river over a five minute period) and average downstream phosphorus concentration*

Due to limitations on presence of cattle during sampling visits and access to the laboratory for analysis, faecal coliform data were gathered only on four of the visits. Although low sampling density creates uncertainties, the data indicate a strong correlation between instream cattle activity and elevation of downstream faecal coliform numbers, the average count of 344 CFU/100ml at the upstream control site almost doubling to 635 CFU/100ml at the downstream site over the two hours during/after cattle activity. Around 26% higher faecal coliform counts were recorded at the downstream site relative to the control prior to cattle activity. This may be explained by bacterial retention from previous cattle trampling events in the sluggish water and unconsolidated marginal sediment, or released from cow faeces where bacteria may remain for up to seven weeks in hot, dry conditions (Buckhouse and Gifford 1976). However, increases during/after trampling events were far greater (an 85% increase from the control site), strongly suggesting that cattle trampling events are a major contributor. A plot of coliform concentrations with cattle activity over a 45-minute window on 15th June 2015 (Figure 10) is typical of the four events recorded, generally supporting the conclusion that instream cattle activity is affecting the levels of coliforms in the stream though, as with other monitored parameters, there was a high level of inconsistency between sampling visits. Figure 11 plots the relationships between cattle activity (average number of cows in the river over a five minute period) and average faecal coliform counts downstream, showing only a weak positive correlation. Two-sample t-tests comparing faecal coliform data upstream and downstream of the trampling site for sampling periods with no cattle present and when cattle trampling was occurring yielded P-values of 0.428 and 0.000 respectively, indicating statistical significance at a 95% confidence interval between upstream and downstream sites only when cattle trampling was occurring.

*Figure 10: Faecal coliform readings upstream and downstream and cattle activity over time (5 minute counts) during the 15th June field visit*

*Figure 11: Relationship between cattle activity (average number of cows in the river over a five minute period) and average faecal coliform counts downstream*

*3.3 Indicative cost-benefit assessment*

Trampling of the river bank and margin by cattle has a range of negative ecosystem service impacts, directly via water quality but also indirectly by reducing riparian habitat, filtration of run-off, aesthetic value and associated cultural services. Management options need to explore associated costs and ecosystem service benefits.

An affordable and effective method for managing riparian cattle trampling, co-beneficial for habitat regeneration and water quality simultaneously with farming benefits such as reduced disease transmission and stock straying, is installation of buffer zones (Everard 2015). Buffer zones entail fencing off a strip of riparian habitat, allowing the regeneration of riparian habitat presenting a buffer to run-off and infiltration of sediment, nutrients and other contaminants. Everard and Jevons (2010) undertook an ecosystem services assessment and valuation of a 330m buffer zone installed at a capital cost of £4,700 to limit cattle access to a formerly severely trampled bank within the same broad reach of the sampled river (Everard and Jevons 2010). Following Everard and Jevons (2010), a semi-quantitative ‘likelihood of impact’ assessment of impacts was undertaken across the full range of ecosystem services using the Defra (2007) scoring system (ranging from ++, +, 0, -, -- and ?) to ensure that the system as a whole was considered before then looking at emerging significant impacts relative to a baseline condition. Significant outcomes from buffer zoning were then quantified where possible consistent with UK Government-approved guidance on ecosystem services assessment (Everard and Waters 2013). Given strong similarities between both study sites, a simplistic proportionate reduction of costs and benefits reported by Everard and Jevons (2010) – 65m of trampled zone in the study site divided by 330m representing the length of the previously studied buffer zone – was calculated for illustrative purposes. Whilst a range of uncertainties is acknowledged, for example that this approach compounds already substantial uncertainties recognised in the donor study and also that 2010 values were not adjusted, this was not believed to be important as derived values are purely illustrative.

On this basis, installation of a buffer strip to exclude cattle from the currently trampled study zone would cost a modest £925 but return annual benefits of £2,081, compounding up to a lifetime benefit of £35,057 when a discount rate of 3.5% is applied over a 25-year future (sumarised in Table 4). Potential benefits accruing from buffer zone installation are clear and significant, this study also highlighting that assessments can be transferable, lessons learnt can be applied to other river restoration works and these types of solutions may be effective in addressing goals under the EU Water Framework Directive (WFD) and other policy priorities.

*Table 4: Summary of ecosystem service benefits potentially generated by buffer zoning of the study site trample zone, transferred by proportionate reduction from Everard and Jevons, 2010)*

|  |  |  |
| --- | --- | --- |
| **Ecosystem service category (Millennium Ecosystem Assessment 2005)** | **Annual benefit assessed** | **Notes** |
| Provisioning services | **£101** | £80 from ‘fresh water’ and £21 for savings on ‘food’ production |
| Regulatory services | **£362** | £47 in ‘climate regulation’ with £315 on ‘erosion regulation’ (£197 for costs of soil loss and £315 for removal from river) |
| Cultural services | **£1,140** | £586 from ‘recreation and tourism’ (of which £163 is angling benefit and £423 is tourism), £208 as an addendum service of local amentity and informal employment, and £310 for social relations |
| Supporting services  | **£478** | All related to costs averted in ‘provision of habitat’ |
| **Gross annual benefits**  | **£2,081** |  |
| **Lifetime benefits** | **£35,057** | Compounded over 25 years with an discount rate of 3.5% |

**4. Discussion**

Field research demonstrated generally positive correlations between elevated turbidity and faecal coliforms and cattle activity, though no trend for SRP emerged. However, turbidity and phosphorus both increased over the fieldwork time period, perhaps consequent from reduced dilution and declining river flows. Other trends may have been obscured by low effective sampling driven by time, equipment and laboratory constraints, occasional failure of automated equipment and synchronisation of field visits with cattle accessing the river. (All factors summarised in Table 5). This general conclusion is consistent to those in the literature, except for phosphorus for which a stronger association would have been expected. It is acknowledged that practical realities limited data density, introducing uncertainties. However, as most prior studies integrate stocking and water quality across catchments, the localised ‘real-time’ monitoring and its correlation with local and immediate impacts of cattle activity addresses a research gap. This study identifies practical difficulties in part accounting for a paucity of prior ‘real time’ studies, informing recommendations for future improvements in experimental design.

*Table 5: Summary of correlation of variables in this study, with notes on confounding factors*

|  |  |
| --- | --- |
| **Variable** | **Correlation** |
| Conductivity | * Equipment failure thwarted attempts to monitor this parameter
 |
| Turbidity | * Strong correlation of turbidity increase with cattle accessing river determined by colorimetric measurement. (Automated sensors/data loggers failed)
* No clear relationship observed between average cattle count and turbidity
 |
| Soluble reactive phosphorus | * No clear correlation with cattle poaching
* Filtration of samples may remove remobilised phosphorus adsorbed to suspended solids
 |
| Faecal coliforms | * Strong correlation between instream cattle activity and elevation of downstream faecal coliform numbers
 |
| Confounding factors | * Drop-off in pollutant concentrations in water between trample zone and downstream monitoring point likely to be exacerbated by decreasing flow during the sampling window
* Influence of tributary between trample zone and downstream sampling location assumed minimal, but untested by analysis
 |

Transferring observations about a spectrum of likely ecosystem service enhancements and their associated societal benefits from a neighbouring buffer zoned reach of river suggests that installation of a buffer zone would yield substantial ecosystem service benefits (or, more precisely, would address the distribution of a wide range of externalised disbenefits stemming from current farming practice norms). Creation of a riparian buffer zone would thereby represent a potential systematic solution (sensu Everard and McInnes 2013) comprising “…*low-input technologies using natural processes to optimise benefits across the spectrum of ecosystem services and their beneficiaries*”. A strong benefit-to-cost case (38:1 for quantifiable benefits) is observed as likely to result from installation of a buffer zone to exclude cattle from the currently trampled river margin at the study site. Direct benefits feeding back to the farmer (averting stock straying and disease transmission), to regulators and society through progress towards achieving Good Ecological Status under the EU Water Framework Directive, and for public health (addressing elevated faecal coliform levels) combine to improve broad societal acceptability of the business case. This limited study also highlights how working, farmed landscapes can be reanimated through a practical intervention enabling regeneration of ecological diversity, connectivity, functioning and production of beneficial ecosystem services.

Study findings support further policy development (domestic and international such as reform of the EU Common Agricultural Policy) to better target what are currently often vaguely expressed aspirations to ‘sustainable agriculture’. They highlight the need for effective policy implementation as at present there is only minimal imposition of available sanctions for non-compliance by farmers with environmental obligations (European Union 2013). Even allowing for these minimal sanctions, European farmers receive 47% of the EU’s total budget through CAP payments though they only represent 5.4% of the EU’s population (Debating Europe 2015) bringing into question the net expense – in terms of both cash and disbenefits vectored through damaged ecosystem services – accruing to society from current riparian farming practice. Better targeting of subsidies from the CAP and from domestic schemes such as England’s Catchment Sensitive Farming (CSF) (Defra 2015) could be far more closely aligned to meeting the aims of European Directives (WFD, Nitrates Directive, etc.) Perhaps the biggest gap currently is lack of enforcement of the already strong legal intent to achieve Good Ecological Status, suggesting that regulators need sufficient powers and resources to control point and diffuse pollution by farmers and others, and to be supported in undertaking prosecutions in the public interest as well as offering proactive advice and assisting with access to subsidies for necessary cost-effective protective actions (The Rivers Trust 2004).

This research exposes a range of practical difficulties entailed in ‘real time’ monitoring of water quality correlated with river margin trampling by cattle. It highlights problems relating to cost, accessibility and time requirements for field surveys and laboratory analysis, the unpredictability of cattle behaviour, security and reliability of sampling equipment, and experimenter safety. All of these factors constrain the effective dataset available for trend analysis. This in turn informs recommendations for further refinement of research methods ideally including: a secure downstream monitoring site in closer proximity to impacted banks; higher frequency measurements; potentially multiple downstream monitoring points to assess spatial decay; exploitation of more automation (fixed-point video, sampling and measurements equipment, etc.); use of more modern tools offering greater analytical precision; and greater resource devoted to experimentation. These improvements can combine to generate a larger dataset to analyse more correlations study and to decrease uncertainty. There is also a need for more detailed investigation of the benefits, disbenefits and costs, and their distribution across stakeholder constituencies, from both current riparian trampling impacts and their potential solutions in order to generate a more compelling business case for practical and policy solutions.

**5. Conclusions**

* The ‘real time’ impacts of marginal cattle trampling on river water quality are under-researched.
* Practical difficulties entailed in ‘real time’ research – synchronising observations with cattle activity, time demands on sampler and assistant, access, security and reliability of monitoring equipment, laboratory working hours – are identified, informing further research design to optimise the effective dataset.
* Notwithstanding uncertainties in experimentation, cattle trampling activity is strongly correlated with increased downstream turbidity and faecal coliform counts, though these effects are variable, may be short-lived and are potentially affected by particulate fall-out and bacterial remobilisation under low flows.
* Instream cattle activity accounted for no significant elevation of stream phosphorus concentration, though this may be related to filtration of sediment-bound phosphorus from water samples prior to analysis.
* Transfer of ecosystem service assessment from a related study suggests that significant benefits are likely to accrue to multiple stakeholders from buffer zone installation, with substantial overall benefit-to-cost outcome, potentially addressing regulatory goals and representing an effective ‘systemic solution’ optimising benefits across a spectrum of ecosystem services and beneficiaries.

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