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COSAINT: Cattle Exclusion from Watercourses: Environmental and Socio-economic Implications

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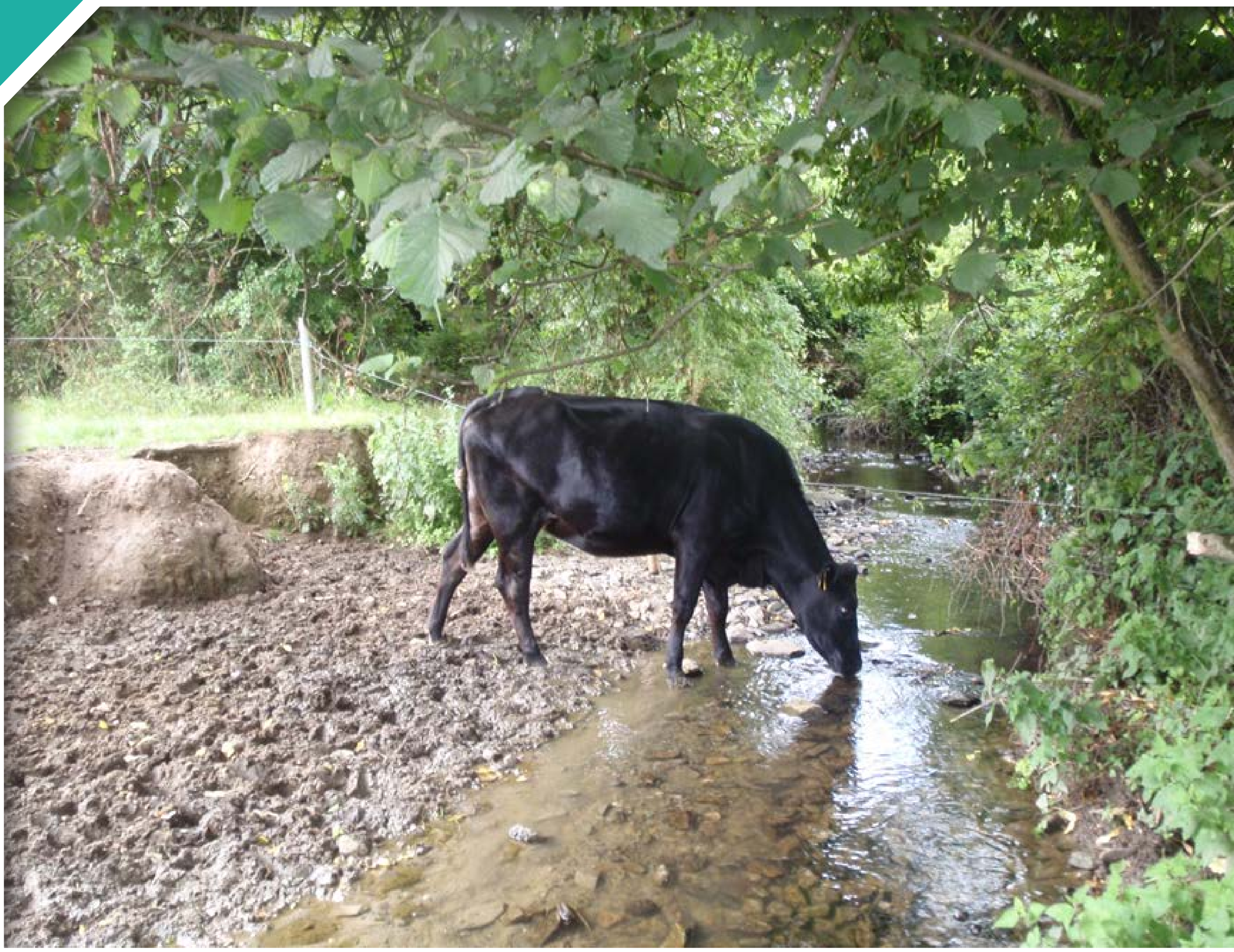

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Government of Ireland

ENVIRONMENTAL PROTECTION AGENCY

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- Office of Environmental Enforcement
- Office of Evidence and Assessment
- Office of Radiation Protection and Environmental Monitoring
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet regularly to discuss issues of concern and provide advice to the Board.

EPA RESEARCH PROGRAMME 2014–2020

COSAINT – Cattle Exclusion from Watercourses: Environmental and Socio-economic Implications

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Prepared for the Environmental Protection Agency

by

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The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

Loss of pollutants from grassland systems to water bodies is a significant threat to water quality and represents one of the main environmental problems facing agri-ecosystems in Ireland. The European Union Water Framework Directive requires Member States to achieve or maintain at least “good” ecological and chemical status in all waters by 2027. Previous studies suggest that unrestricted cattle access to watercourses can result in deteriorating water quality; however, conflicting studies have indicated that cattle do not have a significant effect on some aspects of stream water quality. Despite diverging opinion in the literature, cattle exclusion measures have been included in most European agri-environment schemes, including Ireland’s. While the effectiveness of riparian buffers as a multi-functional management tool has been widely researched, few studies have specifically assessed the impact of cattle exclusion on water quality parameters, especially within Europe.

The COSAINT (Cattle exclusion from watercourses: environmental and socio-economic implications) project was a 5-year (2014–2019), inter-institutional project funded by the Environmental Protection Agency (EPA). A multi-disciplinary group of researchers from Teagasc, University College Dublin, Dublin City University and the Dundalk Institute of Technology assessed the environmental, ecological and socio-economic impacts of cattle exclusion measures on freshwater ecosystems.

The project evaluated existing literature and generated temporal and spatial data on the environmental impact of cattle exclusion measures. The cost-effectiveness of proposed and potential mitigation measures was assessed through research and expert opinion, along with an analysis of attitudinal responses of land owners in relation to the implementation of proposed and potential measures.

Results from the COSAINT project indicate that cattle access to watercourses can significantly impact on a number of environmental variables associated with water quality. Cattle access points resulted in significant increases in the deposition of fine bed sediment and the infiltration (ingress) of sediment into the interstitial habitat. Increased stream sediments acted as reservoirs for faecal bacteria and phosphorus, which persisted when cattle were removed periodically from the field, but did not persist after cattle access pressures were fully removed. Increased sediment deposition was also a dominant driver of macroinvertebrate community change, although results here were more variable and site specific (reflecting results from some similar international studies). Significant reductions in sediment-sensitive taxa were encountered at points downstream of cattle access points at 7 out of 15 study sites, whereas the abundance of sediment-tolerant groups increased. Near real-time monitoring also showed increases in turbidity and suspended sediment, *Escherichia coli*, total phosphorus (TP) and ammonium when cattle were in the stream.

Results from the COSAINT project highlight that fencing/exclusion of cattle from watercourses can help improve the quality of environmental indicators over the short and long terms. One year of full cattle exclusion resulted in improvements with regard to deposited stream sediment, phosphorus concentrations in sediment and macroinvertebrate communities (in a number of sites). Improvements in environmental parameters also persisted when the period of fencing was longer (e.g. 10 years), for macroinvertebrate communities with significant improvements in sensitive bio-indicators.

A survey (as part of the COSAINT project) indicated that the majority of farmers already prevent livestock from accessing watercourses and, of the remainder, almost 80% intend to exclude livestock from watercourses in the future. The results of the COSAINT project indicate that providing greater knowledge to farmers improves confidence in their own ability to implement water protection measures, such as fencing off watercourses.

Key points that could help inform future policy include:

- Cattle exclusion from watercourses can improve the ecological quality of watercourses in the short and long terms.
- Multiple, targeted mitigation measures should be incorporated and incentivised.

- River restoration projects should aim to restore vertical connections between surface waters and the hyporheic zone.
- Incentivising the provision of alternative water supplies, to avoid the need for cattle to access watercourses for drinking, could be considered in future revisions of the Common Agricultural Policy.
- Providing greater knowledge to farmers on the environmental impact of cattle exclusion, coupled with information on appropriate, cost-effective approaches to prevent livestock from accessing watercourses, improves confidence in their ability to implement water protection measures, such as fencing off watercourses. Moreover, farmers could be encouraged or incentivised to join group learning environments.

1 Introduction

Loss of pollutants (e.g. nutrients, sediment, pesticides) from grassland systems to water bodies is a significant threat to water quality and represents one of the main environmental problems facing agri-ecosystems in Ireland. The European Union Water Framework Directive (WFD) requires Member States to achieve or maintain at least “good” ecological and chemical status in all waters, and prevent deterioration of high-status sites, by 2027. Studies suggest that unrestricted cattle access to watercourses can result in deteriorating water quality; however, there is lack of consensus in the literature.

This project assessed the environmental, ecological and socio-economic impacts of cattle exclusion measures on freshwater ecosystems. The project evaluated existing literature and generated temporal and spatial data on the environmental impact of cattle exclusion measures. The cost-effectiveness of proposed and potential mitigation measures was assessed through research and expert opinion, along with an analysis of attitudinal responses of land owners to the implementation of proposed and potential measures.

It is anticipated that results from the project will provide important information for policymakers in relation to the Nitrates Directive (ND) and the WFD. It will also help guide agri-environmental policy and facilitate the achievement of sustainable intensification objectives under Food Wise 2025.

1.1 Project Aim

The aim of this project was to assess the environmental, ecological and socio-economic impacts of existing and potential measures to prevent cattle from accessing watercourses. The project objectives included the following:

- assess the impact of cattle access and cattle in-stream activity on freshwater geochemical and sediment parameters;
- assess the impact of cattle access points and cattle in-stream activity (Figure 1.1) on freshwater biology, including macroinvertebrates, diatoms and faecal indicator bacteria;
- determine the impact of cattle access on hyporheic water chemistry and invertebrate fauna;
- determine the extent of ecosystem impact and recovery at a spatial scale downstream of cattle access points;
- evaluate the impact of proposed cattle exclusion measures [under the Green Low Carbon Agri-environment Scheme (GLAS)] on freshwater geochemical, biological and ecological (in-stream and hyporheic) parameters;

Figure 1.1. Cattle access point with heavily trampled bank and associated in-stream sedimentation.

- evaluate the cost-effectiveness of fencing (and critically assess natural alternatives to fencing) as measures to improve the hydro-morphological condition of watercourses;
- evaluate the cost-effectiveness of existing and novel water provision mechanisms;
- determine the proportion of farms that have flowing or still water on or adjacent to their land parcel, thus potentially affected by cattle exclusion measures.

1.2 Methodology

The research approach used in this project involved a combination of analysing existing datasets and collecting new field and experimentation datasets (temporal and spatial). The analyses of these datasets were coupled with analyses of existing and newly collected data in relation to farmer attitudes to the environment, their perception of the estimated costs associated with cattle exclusion measures and their likelihood of adopting specific existing and potential measures to prevent cattle from accessing watercourses or of adopting novel water provision mechanisms.

2 Selection and Characterisation of Experimental Sites

2.1 Site Selection

Headwaters in five catchments (Blackwater, Douglas, Milltown Lake, Bracken and Commons Rivers) in Ireland were selected for the primary COSAINT (Cattle exclusion from watercourses: environmental and socio-economic implications) study. Three of the catchments had high cattle stocking intensity and were of moderate water quality (Q-value): a tributary of the Milltown Lake (MT) catchment in County Monaghan; a tributary of the Bracken River (BK) in County Wexford; and the Commons River (CM) in County Louth. In these moderate-status catchments, three cattle access points were located longitudinally along each stream (representing the uppermost, middle and lowermost access points under investigation).

The two other selected catchments [Munster Blackwater (BW) in County Cork and headwater tributaries of the Douglas River (DG) in County Laois] were of a low stocking intensity and a high Q-value status. In these catchments, each cattle access point was located on a separate tributary (labelled A, B and C) and represented the uppermost cattle access point on each of those tributaries. This yielded a total of 15 sampling sites as part of the primary studies [work packages (WPs) 3 and 4].

Study 1 aimed to assess the impact of cattle access points on a variety of biotic and abiotic parameters in headwater sites. Study 2 aimed to investigate potential downstream cumulative effects of cattle access to watercourses on sediment faecal pollution. Here, the upper sites in the BK, CM and MT catchments were used along with two additional sites per stream along a downstream gradient (sites labelled 1–3) (Figure 2.1).

2.2 Sites for Assessing Short-term and Long-term Responses to Cattle Exclusion

Eight cattle access points (Figure 2.2) located in five catchments in the east and south of Ireland were sampled for macroinvertebrates and deposited sediment prior to October 2016, and 1 year following exclusion of cattle from streams via fencing (October 2017). The long-term efficacy of fencing was tested in the MT catchment of County Monaghan. Here, 13 sites were originally sampled in October 2008

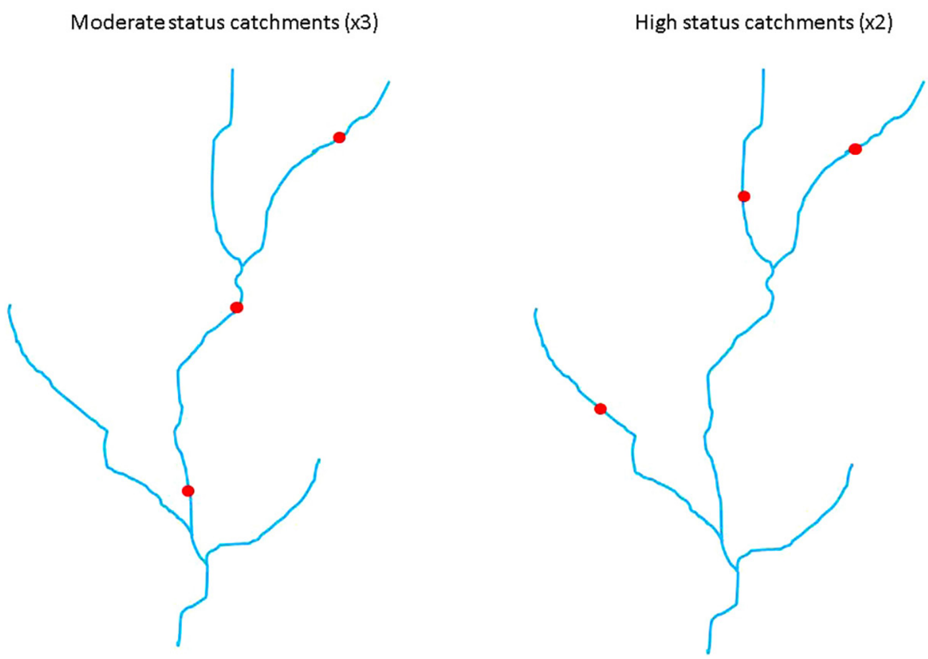

Figure 2.1. Diagram illustrating the organisation of sampling site locations within catchments of moderate Q-value status (left) and of good to high Q-value status (right).

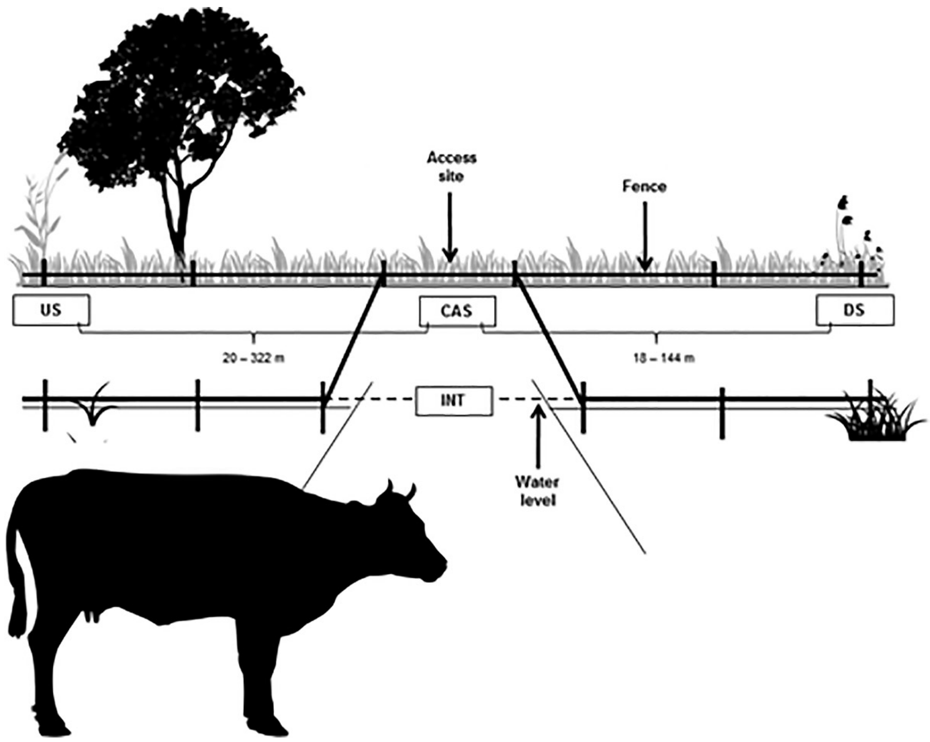

Figure 2.2. Schematic of a discrete cattle access site (CAS) with sampling locations. DS, downstream site; INT, interface site; US, upstream site.

(see Wynne and Linnane, 2008). Seven sites were located in a sub-catchment fed from the Carnagh Lake in Tievenamara (TV), that was entirely fenced off from cattle following sampling in 2008, as part of remediation works for a group water scheme. Six sites were located in a control catchment in the Tullycaghney (TH) that was not fenced as a part of a concerted effort (although some ad hoc, localised fencing had taken place). All sites were re-sampled in October 2017, 9 years post fencing.

3 Collection and Analysis of Geochemical and Microbial Parameters in Freshwater Ecosystems to Assess the Impacts of Cattle Access and Exclusion

Agriculture is recognised as a significant contributor to pollution and the impairment of surface waters throughout the world (Smith *et al*., 1999; Malmqvist and Rundle, 2002; Pärn *et al*., 2012). Bed sediments can act as sinks for, but also as sources of, faecal contamination (Ishii *et al*., 2007; Hassard *et al*., 2017). This WP aimed to investigate the localised impacts of cattle access on stream water and sediment nutrient levels and sediment faecal contamination, and also to assess potential downstream cumulative effects on these parameters across multiple cattle access points in Irish catchments.

3.1 Low-resolution Catchment Scale Evaluation of the Influence of Cattle Access Points and Cattle In-stream Activity on Freshwater Geochemical and Microbial Parameters

3.1.1 Methods

Headwaters in five catchments in Ireland were selected for the study. On each sampling occasion, three sediment samples were collected randomly at the cattle drinking sites and three were collected upstream of these sites; these samples were subsequently analysed for bacterial load. Bed sediment was sampled multiple times at each cattle access site (CAS) sampled in the COSAINT project, at four separate locations. These were as follows: (1) at the CAS, i.e. where cattle access the stream; (2) at an upstream site (US), i.e. upstream of the CAS, where animals had no access to the stream because of either fencing or natural physical barriers; (3) at a downstream site (DS), i.e. downstream of the CAS; and (4) at an interface site (INT), i.e. at the edge of the stream water level, at the access path used by cattle to enter the stream or to stand when drinking from the stream. Water samples were analysed for dissolved nutrients: soluble reactive phosphorus (SRP), NH_4-N and total oxidised nitrogen (TON), and total phosphorus (TP). Sediment samples were analysed to determine organic carbon (OC), total nitrogen (TN) and TP contents, as well as carbon-to-nitrogen (C:N) ratios.

3.1.2 Results

Sediments were significantly more contaminated with *Escherichia coli* at CASs than at USs in the nine headwater sites (Table 3.1). In study 2, a significant difference was found between treatments (i.e. between access sites and reaches not used by cattle). This difference was only significant in mid-grazing season, when bed sediment *E. coli* concentrations were generally one to three orders of magnitude higher at cattle access points than at sites immediately upstream. In post-grazing season, this effect was not observed, as sediment *E. coli* levels at CASs were significantly lower, while *E. coli* contamination did not vary significantly between mid- and post-grazing seasons at USs.

Water nutrient concentrations were generally higher in late grazing season than in early grazing season and did not show any clear patterns of variation in response to cattle access.

At the headwater sites, sediment TP was found to be significantly higher at the INT area than at the upstream reaches. However, there was no significant difference between levels at the US areas and at the CAS or DS areas. There was a significant interaction between the factors “treatment” and “site” (Table 3.2). TP sediment levels at these sites did not vary significantly between sampling times. The remaining parameters measured did not vary significantly between areas of the stream actively used by cattle and reaches not used by cattle. There was also no significant difference in the OC, TN or C:N parameters between sampling times at the headwater sites.

At the sites located along a downstream gradient in study 2, sediment TP was the only parameter that varied significantly at areas directly accessed by cattle

Table 3.1. Comparison of *E. coli* levels in sediments between upstream and cattle access points (treatment) in mid-grazing and post-grazing seasons (time) in study 1 and study 2

Factor	DF	*F*-value	*p*-value
Study 1			
Treatment[a]	1.8	18.406	**0.003**
Time[b]	1.8	9.636	**0.0146**
Time × treatment	8	0.137	0.721
Study 2			
Treatment[a]	1	20.747	**<0.001**
Time[b]	1	5.987	**0.023**
Time × treatment	1	6.428	**0.019**

Figures in bold denote statistical significance at the $p < 0.05$ level.
[a]US vs cattle access point.
[b]Mid-grazing season vs post-grazing season.
DF, degrees of freedom.

Table 3.2. Analysis of sediment TP concentrations at sites in study 1

Factor	DF	*F*-value	*p*-value
Treatment[a]	3	11.8895	**0.0001**
Site[b]	8	24.6888	**<0.0001**
Treatment × site	24	5.8059	**<0.0001**

Figures in bold indicate significance at the $p < 0.05$ level.
[a]US vs cattle access point.
[b]Mid-grazing season vs post-grazing season.
DF, degrees of freedom.

compared with areas not directly used, with sediment TP levels at the INT area being significantly higher than at all three other areas of the sites. TP sediment levels were found not to differ significantly between sampling times. In addition, no significant differences were observed between areas directly accessed by cattle and areas not directly accessed for bed sediment concentrations of OC and TN, and for the sediment C:N ratio.

3.1.3 Discussion

It was notable that bed sediments at all 15 sites upstream of cattle access points were contaminated with *E. coli*. Bed sediment levels of *E. coli* were highly variable within sites, highlighting the patchy nature of bacteria distribution in sediments (Pachepsky and Shelton, 2011), and also within catchments, suggesting that stream faecal contamination is governed by local management practices. This includes field-specific factors such as stocking rate, period of grazing, grazing rotation practices, existence of other access sites or alternative drinking water sources, and slurry spreading. Sediment *E. coli* concentrations were significantly higher at CASs than at USs in mid-grazing season, with a subsequent general decrease of *E. coli* levels at the access sites in post-grazing season. These findings suggest that direct cattle access to watercourses can exacerbate stream sediment pollution. This study shows that, where cattle access watercourses, they can contribute to faecal bacteria reservoirs that are able to persist after cattle removal from the grazing fields, with implications for water quality and both human and animal health. This effect can be particularly concerning in small order streams where the low ratio of water volume to sediment area and the limited amount of submerged aquatic vegetation make bed sediments the largest available substrate for faecal bacteria accumulation (Badgley *et al*., 2011). Our findings show that *E. coli* persists in stream sediments after cattle access pressures have been removed; thus, the threat to human and animal health posed by unrestricted cattle access to watercourses and cattle-based agriculture is not confined to the grazing period.

The results of this study indicate that TP tends to accumulate in the sediment at the point where cattle enter the stream, which is inevitably affected by cattle when the animals use the watercourse. This accumulation effect seems to be attenuated, which might be explained by the fact that this area is more heterogeneous (i.e. there are more opportunities for phosphorus reaction and uptake) and sediment disturbance as well as flushing mechanisms can operate. The results of this study show that unrestricted cattle access to watercourses can lead to localised accumulation of phosphorus (i.e. TP) in sediments at access sites. These TP reservoirs could represent a source of phosphorus to waters (including SRP, which is used in WFD assessments of stream water quality) through release or remobilisation into the water column), potentially contributing to a legacy effect in streams that can hinder the effects of mitigation measures, with subsequent implications for water quality and the achievement of WFD objectives.

Finally, the absence of a downstream cumulative pattern reflects the variable patterns of nutrient uptake, mineralisation and deposition within the stream channel, and it is congruent with the general absence of evidence of nutrient accumulation in sediments at access sites. Similarly, no evidence of a cumulative effect on sediment *E. coli* concentrations along a downstream gradient was found in this study.

3.2 High-resolution Sampling to Assess the Impact of Cattle Access Points and Cattle In-stream Activity on Freshwater Geochemical Parameters

Several studies have investigated the impacts of unrestricted cattle access to farmland streams on water column faecal contamination levels and water physico-chemical parameters such as nutrient and total suspended solid (TSS) concentrations (e.g. Line, 2002; Vidon *et al*., 2008; Terry *et al*., 2014; Smolders *et al*., 2015). However, to our knowledge, this is the first study specifically investigating the impacts of cattle in-stream activity at a discrete cattle access point on a wide range of water quality parameters at a high-resolution temporal scale.

3.2.1 Methods

A site in the CM catchment was selected as an experimental site. The site is the access site to the stream in a field grazed by typically 20 animals. Two autosamplers were set to collect water samples every 3 minutes for a period of 4 to 5 hours [which were subsequently analysed for concentrations of dissolved nutrients (SRP, NH_4-N, NO_3-N), total reactive phosphorus (TRP), TP, TSSs, faecal bacteria, and for pH and conductivity]. Camera imagery recorded when animals were accessing the site.

3.2.2 Results

Cattle in-stream activity resulted in increases in *E. coli* levels downstream of the site during all events. Increases in the water concentrations of faecal indicator bacteria were observed both when in-stream defecation was registered and when defecation was not captured in the camera images, indicating that cattle disturbance of the sediment alone can cause resuspension of viable faecal bacteria into the water column.

Average TP and total suspended sediment concentrations in waters downstream of the site were higher than upstream levels during cattle in-stream activity in all instances. There was a correlation between stocking rate and TP in sediment upstream, i.e. phosphorus in upstream sediment was significantly higher at sites with stocking rates of >1.30 [measured in livestock units (LUs) per hectare] than at sites with stocking rates of $<1.30\,LU\,ha^{-1}$. Ammonium concentrations increased downstream of the access site during cattle access on all events that captured cattle in-stream activity. However, similar average increases in ammonium concentrations were also registered on a number of occasions when cattle were absent from the stream. Peaks in ammonium concentrations at the upstream location that were not detected downstream were also observed on certain occasions. These observations make it difficult to determine the impact of cattle in-stream activity on ammonium levels; however, there is an apparent tendency for ammonium concentrations to increase in response to episodes of in-stream urination.

Soluble reactive phosphorus and average nitrate concentrations did not show a consistent pattern in response to cattle in-stream activity.

3.2.3 Discussion

The findings of this study indicate that cattle access to watercourses has a localised impact on water faecal bacteria and TSS concentrations. There was also a consistent pattern of an increase in TP concentrations during and immediately following cattle in-stream activity, while ammonium levels were apparently affected by urination episodes. Impacts on SRP concentrations are unclear, and there was no evidence of increases in nitrate levels as a result of cattle access.

These findings show that cattle access to watercourses significantly contributes to faecal pollution of waters, representing an important animal and human health concern. Similarly, increases in TSS concentrations in response to cattle access to waters had been demonstrated elsewhere (e.g. Vidon *et al*., 2008; Smolders *et al*., 2015), including in a study by Terry *et al*. (2014) in which a similar approach to that taken in the current study was used, and further demonstrated by O’Sullivan *et al.* (2019). It was observed that cattle access events with the same number of entries by cattle to the stream but with different durations had different levels of change in downstream turbidity.

The increases in TP concentrations observed in this study are consistent with the findings of other studies that show decreases in TP water concentrations following cattle exclusion from watercourses (e.g. Meals, 2001; Line, 2002; Line *et al*., 2016). Furthermore, this study shows that cattle access to watercourses can lead to a localised accumulation of TP in sediments in the most affected areas of the stream, as a result of in-stream defecation and cattle entering the stream, and soil particles attached to the animals’ legs being deposited. TP in sediments can in turn be resuspended in the water column through sediment disturbance caused by cattle movements in the stream.

Ammonium levels showed a more erratic pattern and an indefinite response to cattle in-stream activity. Nevertheless, the findings of this study indicate that in-stream urination can lead to increased concentrations of ammonium. Increases in ammonium concentrations resulting from unrestricted cattle grazing have been reported by Vidon *et al*. (2008). The same authors also reported no effect of cattle access on nitrate concentrations.

In conclusion, the findings of this sub-task confirm the results from work developed elsewhere in the COSAINT study showing that cattle in-stream activity can negatively impact freshwater levels of faecal contamination, phosphorus and suspended sediments, and therefore has significant implications for water quality.

3.3 The Impact of Cattle Restriction Measures on Stream Water and Sediment Biogeochemical Parameters

Streamside fencing is used as a method to exclude livestock from waterways (Vidon *et al*., 2008; Miller *et al*., 2010). The main effect of fencing is the reduction of inputs from livestock directly defecating and urinating within watercourses (e.g. Miller *et al*., 2010). Exclusion fencing also allows for the establishment of the vegetation in riparian buffer areas, which further aids in the reduction of particulate inputs to streams through filtering overland discharge and retention in vegetation (Liu *et al.*, 2008). The aims of this task were to:

1. assess changes in sediment parameters at CASs after 1 year of fencing;
2. assess changes in sediment parameters at CASs after long-term fencing using data from the MT fenced catchment, where fencing was implemented in 2008.

3.3.1 Methods

Stream bed sediment at six GLAS sites was sampled for OC, TN and TP. This included the collection of sub-samples from three locations: (1) upstream of the CAS (US), (2) at the CAS and (3) in the shallower littoral zone of the edge of the stream, referred to as INT. Stream water column nutrient concentrations were also measured at the six sites using standard sampling procedures. All field sampling was repeated twice: once in autumn 2017 and again in October–December 2018.

Assessment of stream water nutrient concentrations was undertaken for the MT catchment in the fenced western tributary of the Drumleek River and in one of the two unfenced tributaries (Linnane *et al*., 2011). Data were available for the sites from 2006 and 2007. For comparison, the same parameters were measured between December 2017 and November 2018. These samples were also analysed for TP and NO_3-N, and concentrations of *E. coli*.

3.3.2 Results

There was no significant difference in sediment OC, TN or TP between the USs, i.e. the control sites, and the CAS either before or after fencing across the six sites. However, sediment concentrations of OC, TN and TP were significantly higher at the INTs, where cattle would have been most likely to congregate, than at the US locations for all six sites. These higher concentrations at INT than at US locations were generally consistent across all sites. In contrast, there was no significant difference between the US and INT areas for any of the three sediment nutrients assessed post fencing.

Sediment *E. coli* levels were higher at the CAS than at the US locations at three of the five GLAS sites in the autumn of 2017 before fencing was installed, but these were not significant when all five sites were considered. It was also notable that concentrations at the CASs were in general closer to those at the USs post fencing in autumn 2018 than they were before fencing in autumn 2017.

There was no significant difference at the GLAS sites for any of the four stream water nutrient parameters assessed (SRP, TP, NO_3-N and NH_4-N) between the control US and CAS locations. This was particularly noticeable for the three dissolved nutrient parameters where values were almost identical. Concentrations of TP did show more variability, but the overall difference for all six sites was not significant.

For the stream water data collected over one annual cycle in the MT catchment, there were no significant differences between the fenced stream and unfenced tributary for concentrations of SRP, TP, NO_3-N and NH_4-N. For the water column *E. coli* concentrations that were measured four times (once in December 2017 and once in three of the following months: January, February, May and November 2018) there was no significant difference between the fenced and unfenced tributaries. Similarly there was no significant difference for stream water *E. coli* concentrations measured.

3.3.3 Discussion

The data presented here indicate that discrete zones within the study streams represented critical source areas for both nutrients and *E. coli*. The concentrations of OC, TN and TP for the pre-fencing assessment, in the bed sediment at edge of the stream (where cattle congregate to drink) were significantly higher than those for the bed sediments upstream of these sites. The sediments in the main channel did not have significantly higher concentrations, suggesting an ongoing flushing of material downstream. These differences, however, were not apparent for the same comparison undertaken 1 year post fencing (Table 3.3).

The levels of nutrients in the sediments that were found were not exceptionally high, even for the interface zones. While the number of sites and the assessment time in the current study were restricted,

Table 3.3. Bed sediment data for upstream control sites (US) vs the stream littoral zone (INT) of the CAS for pre-fencing (2017) and post-fencing (2018) periods

	Pre-fencing period		Post-fencing period	
Parameter	US	INT	US	INT
Sediment OC, mg g^{-1} DW	**12.0±6.2**	**23.4±6.6****	12.2±4.4	12.2±5.2
Sediment TN, mg g^{-1} DW	**1.0±0.4**	**2.1±0.6****	1.3±0.	1.2±0.5
Sediment OC:TN ratio	10.0±1.4	11.0±0.3	9.3±1.0	9.2±1.6
Sediment TP, mg g^{-1} DW	**0.28±0.08**	**0.57±0.21***	0.35±0.07	0.35±0.10

Figures in bold indicate significant values. *p<0.05; **p<0.01.
DW, dry weight.

the results indicate that excluding cattle reduced the bed sediment nutrient concentrations in these access point stream margins. It may also be probable, however, that in a longer study increased vegetation in the stream margins of the fenced cattle access points could act as a trap for fine sediment, thus potentially increasing concentrations in these areas (Sand-Jensen, 1998; Walling and Collins, 2016).

For *E. coli*, bed sediments were sampled in the main channel only. While the overall change across the six sites was not significant, there were significant increases at two sites. Again, this difference was not apparent after 1 year of fencing, indicating that cattle exclusion had a positive impact on the reduced levels of contamination of the bed sediment at the sites. This effect was similar to that reported by a larger 2-year study in the MT catchment by Bragina *et al*. (2017). These authors reported similar concentrations and found significantly higher levels of *E. coli* in the bed sediments of the western tributary in the MT catchment, which had been fenced in 2008, than in the other two unfenced tributaries in that catchment. While high levels of *E. coli* in bed sediment can also persist over time, Jamieson *et al*. (2005) noted that *E. coli* in bed sediments will be flushed and transported downstream. Bragina *et al*. (2017) also reported a decrease in bed sediment concentrations between October and April, which they suggested was due to flushing over the winter.

There was no significant increase in the stream water concentrations of nutrients between the upstream and cattle access point sites in the absence of cattle in the water. While the concentrations differed between sites and between times, as would be expected for dynamic stream systems in agricultural catchments (e.g. Mellander *et al*., 2015), there was no difference between the US and the CAS following fencing. There was also no significant difference in the nutrient concentrations for the fenced and unfenced streams over the annual cycle or over the months when cattle would have been in the field (April to October) for the MT catchment. This was in line with previous studies, although there was some indication that overall nutrient export (as TRP) for both the fenced and the unfenced tributaries was lower in 2017–2018 than in 2006–2007. This could be related to changes in the management of nutrient sources across the catchment, but no conclusion on that could be made in the present study.

3.4 Modelling the Impact of Cattle Access at the Catchment Scale and Assessment of Management Scenarios

An alternative approach to assess cattle exclusion as a best management practice for mitigating the impacts of agriculture is to use a catchment model that includes sediment and nutrient loading from all sources, including with a sub-routine for the effect of cattle access to the stream (McGechan *et al*., 2005; Rao *et al*., 2009). These simulations can provide estimates of loadings in the context of the whole catchment, and allow for scenario testing for management options. In this task, data from the catchment and the Generalized Watershed Loading Function model were used to estimate nutrient loading resulting from cattle access to streams in the MT catchment in County Monaghan, and to place it in the context of loading from other sources and total catchment loading. Estimates of the change in loading if cattle were excluded from all catchment streams were also made.

3.4.1 Results

For simulated TP loads in 2015, the annual load from the catchment was 2429 kg TP year^{-1}, equivalent to 0.88 kg ha^{-1} year^{-1}. Of this total, “cattle in stream” contributed 310 kg TP year^{-1}, based on one defecation event per head (10% of daily defecation output), which represented a total of 13% of the annual TP load. Septic systems contributed a low 69 kg TP year^{-1} (3%) in the same period. In contrast, however, the contribution from cattle in stream over the grazing period from 1 April to 31 October, a time period when the general daily loads from diffuse sources in the catchment were low, represented 43% of the total load. When the cattle in stream TP load was excluded from the calculations, the annual TP load decreased to 2119 kg TP year^{-1}, equivalent to 0.77 kg ha^{-1} year^{-1}. The percentage contribution from cattle in stream to the TN load was similar, contributing 15% of the total 34,377 kg TN year^{-1}.

3.4.2 Discussion

The contribution of cattle access to the stream to TP loading in the MT catchment was 16% on an annual scale. This is of a similar order of magnitude to, in terms of percentage contribution, but slightly higher than, that estimated for the Cannonsville Reservoir catchment (New York, USA). Uncertainties in the current modelling exercise relate especially to the estimates of the numbers of cattle that enter the stream and the proportion of those cattle that defecate in the stream in any given day. The scenario used assumed that 21% of all cattle in the catchment would have access to the catchment streams on any given day. Based on the earlier assessment by Linnane *et al*. (2011), which took place before the western tributary was fenced off, i.e. that 74% of all fields were adjacent to streams, this estimate would not be excessive, and is in fact almost identical to that from the current study. No field-by-field data were available on cattle numbers, however, nor were data available on the duration that any given herd occupied a field. The scenario also assumed that cattle urinated and defecated once each per head in the streams. This would represent approximately 10% of typical cattle total defecation of approximately 10 defecation events per day. The bulk of TP in total excretion would come from faeces, while the bulk of TN would come from urine.

Carson *et al*. (2015) estimated that TP loads peaked at about 1.00 kg TP ha^{-1} $year^{-1}$ in the 2000s, with a slight decrease up to 2008. Those loads were moderate compared with the losses reported by some other studies (e.g. Jordan *et al.*, 2005; Cassidy and Jordan, 2011; Macintosh *et al*., 2011) for similar inter-drumlin catchments. These loadings were sufficient for the lake to be classified as eutrophic for much of the time period assessed based on algal pigments (highlighting the low concentrations of phosphorus needed to impact on aquatic ecological quality). Moreover, they found a strong correlation in the sediment record between algal pigments and their reconstructed phosphorus load from cattle (Carson *et al*., 2015). The comparison of water column phosphorus concentrations from the fenced and unfenced catchments described in the previous section did not show any difference between the fenced and unfenced catchments in the MT catchment, even for the comprehensive study undertaken by Veerkamp (2020), although that study did find a downstream decrease in concentrations for the fenced tributary for TP, suggesting retention of TP, while the opposite was found for the unfenced tributary. Despite this lack of differences at the catchment scale, the data from real-time monitoring of “cattle events” in the current study showed increases in TP when cattle were in the stream. These differences highlight the difficulties in capturing changes in nutrient dynamics related to cattle presence in streams, or cattle exclusion using fencing, at the catchment scale as described in the review by O’Callaghan *et al*. (2019). However, the scenarios for nutrient loading from cattle used in this modelling exercise indicated that cattle exclusion would result in a decrease in nutrient export from the catchment and moreover have quantified those potential reductions.

4 Collection and Analysis of Ecological Datasets Associated with Cattle Access to Watercourses

4.1 The Impact of Cattle Access Points on Deposited Sediment Levels in Headwater Streams in Ireland

Excess fine sediment is considered one of the most significant pollutants affecting water bodies worldwide (Waters, 1995; Kjelland *et al*., 2015; Davis *et al*., 2018). This sub-task investigated patch-scale deposited fine sediment at cattle access points in headwater streams in Ireland.

4.1.1 Methods

Sites for this study were located in the headwaters of the BW and headwater tributaries of the DG, a tributary of the MT catchment and a tributary of the BK and the CM. Sampling points were located in riffle units immediately upstream and downstream of the cattle access point and at the next consecutive riffle habitat, hereafter referred to as "control", "pressure" and "recovery" sites, respectively.

Samples of deposited sediment were taken from riffle habitats at control, pressure and recovery points (upstream, immediately downstream and further downstream of cattle access points, respectively) in April/May 2016 and October 2016 using the "Quorer" resuspendable sediment sampling technique (Conroy *et al*., 2015; Duerdoth *et al*., 2015). The procedure was repeated six times at each sampling point, from random locations within each riffle, during spring and autumn. The resuspendable sediment samples were prepared in the laboratory using standard techniques. A habitat assessment was carried out in the autumn (2016), 2–3 weeks prior to the autumn sediment sampling period. Various sub-indices from habitat assessments, such as the United States Environmental Protection Agency Rapid Bioassessment Protocols and the Riparian, Channel and Environment Inventory, which measures stressors, were included.

4.1.2 Results

An effect of cattle access on resuspendable sediment mass was detected only in the autumn, indicating a significantly higher resuspendable sediment yield at the access point. There were no significant differences in resuspendable sediment measurements at control points between upper, middle or lower sites in any of the moderate-status catchments. These findings suggest that, in relation to the catchments in the current study, there were no cumulative effects of cattle access points on levels of resuspendable sediment. Effects of cattle access points on the percentage of organic matter (OM) were detected in the catchments with a less-than-good status in autumn only.

An analysis of River Habitat Index (RHI) scores in study 1 identified a significant effect of cattle access points across all catchments. Significant differences between control and pressure points were detected, demonstrating that cattle access reduced habitat quality. There was no significant effect of cattle access points in the catchments with a less-than-good status (study 2) with respect to RHI scores.

4.1.3 Discussion

Significantly greater masses of resuspendable sediment were measured at points downstream of cattle access points during the autumn season. Furthermore, some of the most conspicuous riparian habitat degradation was observed where levels of resuspendable sediment (Figure 4.1) were substantially greater downstream of the cattle access points than upstream. Overall, the current study did not demonstrate a cumulative effect downstream of cattle access points on levels of deposited fine sediment in the stream (note: the study did not assess the cumulative effect further downstream, in receiving lakes or estuaries).

The effects of cattle access points on deposited sediment levels in headwater streams were seasonal in nature, with levels generally highest in the autumn.

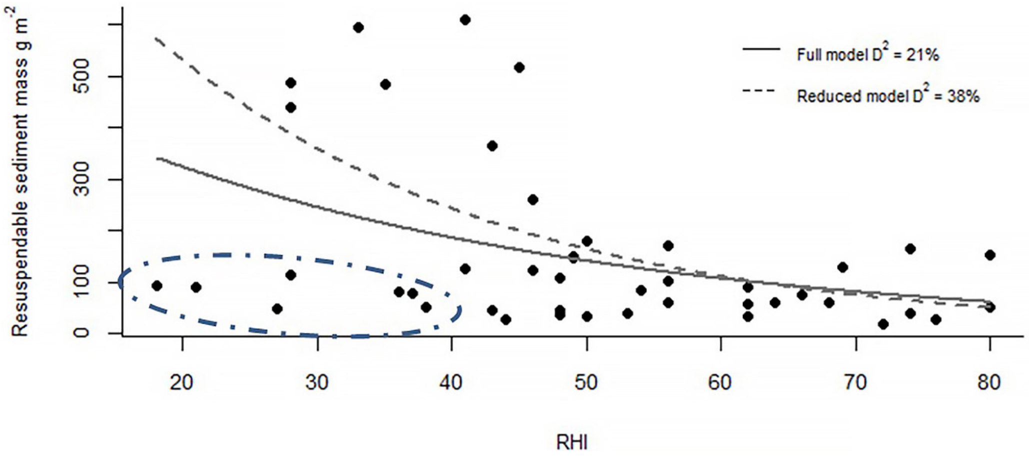

Figure 4.1. Relationship between resuspendable sediment mass and RHI scores in autumn. Solid line: full model; dashed line: reduced model with some outliers removed.

Low-flow conditions, which are common in upland streams in Ireland over the summer period, can exacerbate sedimentation (Wood and Armitage, 1997; Braccia and Voshell, 2006; Vidon *et al*., 2008; Conroy *et al*., 2015) and probably contribute to this seasonal trend. Furthermore, cattle are generally housed in slatted sheds over winter in Ireland, allowing potential temporal recovery of stream banks and substrate embeddedness as reported by McIver and McInnis (2007).

Bruen *et al*. (2017) highlighted seasonal patterns in sediment transport in Irish streams, with significant loads occurring in the wettest months. Thus, any sediment deposited during the grazing season is likely to be mobilised and transported downstream by high-flow events over the winter period. In contrast, Stone *et al*. (2005) suggested that recovery from substrate sedimentation can take a long time, with sediment retention possible for over a decade. The complex structure of coarse substrates facilitates the ingress of sediment into interstitial spaces (Conroy *et al*., 2015; Naden *et al*., 2016) and this material can become an "internal" source of suspended sediment during high flows or can be carried via vertical flow patterns into the hyporheic zone (Kibichii *et al*., 2015).

4.2 Cattle Access: A Key Pressure on Aquatic Macroinvertebrate Communities in Headwater Streams?

This study aimed to determine the impact of cattle access on the macroinvertebrate communities, which are useful bio-indicators because of their sensitivity to changes in stream habitat and physico-chemical conditions (Herringshaw *et al*., 2011), of headwater streams and also assess the potential cumulative effect of multiple cattle access points.

4.2.1 Methods

Headwaters in five catchments in Ireland were selected for the study. The same study design was used as outlined in the study on sediment levels. Sampling points were located in riffle units immediately upstream, immediately downstream and at a riffle habitat further downstream, hereafter referred to as "control", "pressure" and "recovery" sites, respectively.

Two seasons of macroinvertebrate sampling were carried out: April/May (spring) and September/October (autumn) of 2016. Six replicate macroinvertebrate samples were taken using a standard, 0.09 m^2 Surber sampler at control, pressure and recovery points. Specimens were identified using Freshwater Biology Association keys and enumerated. Most insect taxa were identified to species level; Coleoptera and Diptera were identified to family level; and oligochaetes were left at sub-class level.

One-off measurements of pH, dissolved oxygen (DO), conductivity and temperature were made using WTW automatic field probes. Single, manual grab, water column samples were collected and analysed for SRP, ammonium (NH_4^+), TON and TP.

4.2.2 Results

Community structure: study 1

Total richness was lower at the pressure point than at the control point. There was a significant interaction effect between treatment and site in relation to community structure in the spring and autumn. Pairwise results showed statistically significant differences in invertebrate community structure between control and pressure points at specific sampling points in a number of the catchments.

Where community structure differences were detected, *Gammarus duebeni* and *Ancylus fluviatilis* were less abundant downstream of cattle access points. Similarly, *Rhithrogena semicolorata*, *Agapetus* sp., (substantial to a moderate degree), and *Elmis aenea* and *Leuctra inermis* were also significant contributors to dissimilarities in community structure. Differences in abundance, both increases and reductions, of Simuliidae and Chironomidae between control and pressure points were more variable, being higher or lower at pressure points than at control points depending on the specific site. Two coleopteran taxa, Hydrophilidae and Scirtidae, contributed weakly to moderately to dissimilarities in community structure at four and three sites out of seven, respectively, and their abundances were lower at pressure points than at control points in all cases.

Community structure: study 2

The results highlighted significant differences between control and pressure points at four out of nine sites in spring, and eight out of nine sites in autumn. Simuliidae were lower in abundance at pressure points at most sites, while Chironomidae and *Baetis rhodani* were higher in abundance at most sites downstream. Oligochaeta generally contributed either moderately or strongly to dissimilarities between sites in study 2, with abundances being higher upstream relative to downstream at four sites

There was significant treatment × site interaction in relation to Ephemeroptera, Plecoptera and Trichoptera (EPT) abundance in study 2 ($p = 0.005$), with this metric being lower at recovery points than at control points at two sites.

There was also significant treatment × site interaction in relation to percentage simuliid abundance. Significant, or marginally significant, reductions in the percentage abundance of simuliids relative to controls was found at the CM2 and BK3 recovery and pressure points, at the CM1 pressure point and at the BK2 recovery point. At BK1, however, a higher percentage simuliid abundance was found downstream of the cattle access point (recovery) than at the upstream control point.

No cumulative effect (of multiple sites) on community structure was found.

A significant, weak to moderate correlation was found between the environmental data (namely SRP, width-to-depth ratio, conductivity and deposited sediment mass) and biological data during the autumn sampling period. The single environmental variable that best explained the community structure data was conductivity, followed by deposited sediment.

4.2.3 Discussion

Results from the current study are variable; however, it is apparent that there are differences in community structure between upstream control points and downstream pressure and recovery points. Differences in community structure were detected, during at least one sampling season for every site in the study. The changes noted in community structure in most cases represented a deterioration in stream water quality; however, as with the majority of previous studies related to cattle access (see Braccia and Voshell, 2006; Herringshaw *et al*., 2011), the identification of specific drivers of changes in macroinvertebrate communities was difficult in this study. This is unsurprising, considering the variety of variables that influence the suitability of a habitat for various species; for example, the availability of suitable stable substratum influences whether or not a habitat is suitable for filter feeders such as Simuliidae.

The changes in macroinvertebrate community structure identified point to sediment as a dominant driver of community change at certain sites in the present study. Results relating to fine sediment sensitivity ratings (FSSRs), functional feeding group metrics and other macroinvertebrate diversity metrics further highlight the susceptibilities of benthic macroinvertebrate communities to change as a result of cattle access and sediment deposition. Here, significant reductions in sediment-sensitive FSSR A class taxa at points downstream of cattle access points were encountered at 6 out of 15 study sites, with no significant trends (in FSSR A class taxa) observed at the other nine sites.

Despite variability in the responses of macroinvertebrate communities to cattle access, a detrimental effect of cattle access, linked most likely to sediment deposition, was apparent at several sites. At other sites, however, where streams were moderately polluted but cattle access points show signs of light use (O'Sullivan *et al*., 2019) and where streams were of good to high status and cattle farming activities and grazing practices were extensive in nature, the relatively light use of cattle access points may not be substantial enough to elicit significant ecological changes. A gradient of impact associated with a gradient of use of streams by cattle may help to explain why certain sites in the current study showed intermediate to light or no impact.

There was no definitive evidence to suggest cumulative effects of multiple cattle access points in the less-than-good status catchments. This may suggest that catchment-scale influences have a greater impact on macroinvertebrate community structure at a larger scale than the effects of cattle access points at a localised scale.

4.3 The Impact of Cattle Access on Primary Producers (Diatoms and Macrophytes) and on Trophic Interactions with Primary Consumers (Macroinvertebrates)

In the current study, the impacts of cattle access on freshwater plant community (diatoms and macrophytes) composition and structure, as well as phytobenthos biomass, were assessed. This research also utilised stable isotope analysis. Ratios of stable isotopes are widely used in aquatic ecology, helping researchers to identify different sources of food in aquatic food webs and to trace pathways of OM between primary producers and consumers (O'Sullivan *et al*., 2019).

4.3.1 Methods

Headwaters in five catchments in Ireland were selected for the study. Samples for this study were collected at the reach scale (40-m reaches) to facilitate standard macrophyte and diatom sampling routines. Reaches were located upstream and downstream of cattle access points. Chlorophyll *a*, diatoms and macrophytes were sampled at study sites in 2016 using standard techniques.

A habitat assessment was carried out in the autumn (2016), consisting of a qualitative assessment of in-stream and riparian habitat conditions. In addition to this qualitative habitat assessment, the percentage cover of different substrates (cobble, gravel, sand, etc.) and geomorphic units (riffle, run, pool) were estimated and stream dimensions were measured.

Stable isotope sampling was conducted in October 2017. Macroinvertebrate samples were collected from riffle habitats upstream and downstream of cattle access points. Five consumer macroinvertebrate taxa were selected for inclusion (Baetidae, Hydropsychidae, Simuliidae, Chironomidae and Oligochaeta). Periphytic algal scrapings, deposited sediment and suspended sediment samples were collected from each sampling point to represent the baseline samples on which the consumer taxa chosen could potentially feed. Samples of cattle faeces were also taken adjacent to pressure points to assess for any change in macroinvertebrate resource use associated with availability at pressure points. The stable isotope analysis was carried out in SINLAB (Stable Isotope in Nature Laboratory) using standard techniques.

4.3.2 Results

The results of study 1 and study 2 were variable, with significantly more chlorophyll *a* at a number of pressure points than at control points, less chlorophyll *a* at both the pressure and recovery points than at control points for some sites and no differences for other sites.

There was no effect of cattle access points on diatom community structure, community composition, Trophic Diatom Index version 3 (TDI3) values, percentage planktic taxa, percentage motile taxa or percentage OM-tolerant taxa for study 1 or study 2. Across all study sites, taxon richness was significantly greater at control points than at pressure points.

There was a significant treatment effect in relation to macrophyte taxon richness in study 1, with greater taxon richness at pressure reaches than at control reaches (Figure 4.2c). Higher occurrences of four taxa (*Brachythecium plumosum*, *Conocephalum conicum*,

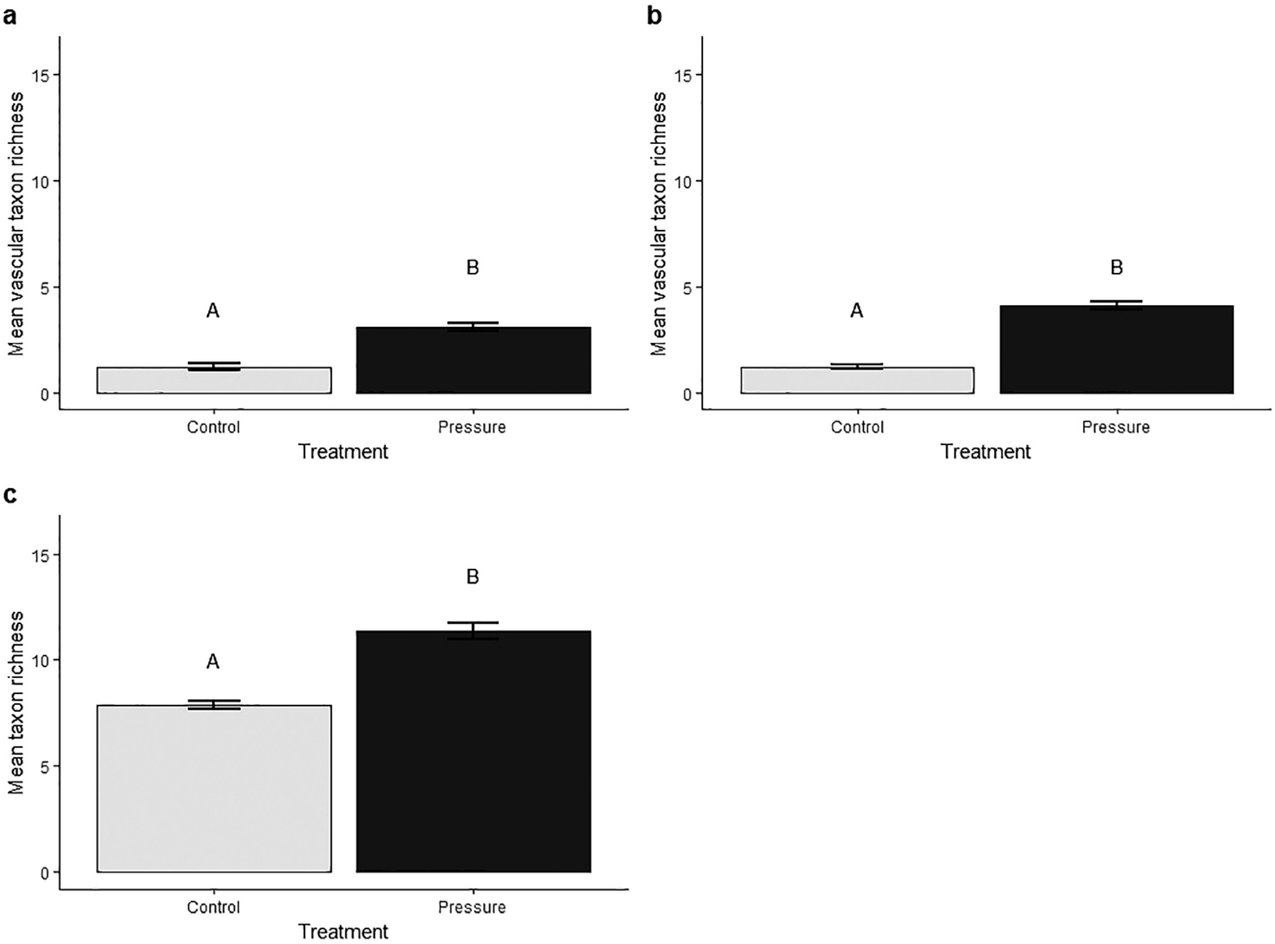

Figure 4.2. Mean vascular macrophyte taxon richness for study 1 (a) and study 2 (b), and mean taxon richness for all macrophytes for study 1 (c).

Melosira sp. and *Agrostis stolonifera*) at pressure reaches accounted for almost 20% of the observed difference in taxon richness. Cattle access points also had an effect on the taxon richness of vascular plant communities in study 1 and study 2, again with greater richness at pressure reaches than at control reaches (Figure 4.2a and b).

Differences in values of $\delta^{13}C$ between individual consumer variables

There was a significant main-term group effect on $\delta^{13}C$ values in relation to consumer data. Results showed that, in the BK catchment, there were significant differences in $\delta^{13}C$ values between all consumer groups except for between Chironomidae and Hydropsychidae, and Hydropsychidae and Simuliidae. In the CM catchment, $\delta^{13}C$ values differed between all consumer groups except Baetidae and Hydropsychidae, and Oligochaeta and Simuliidae. In contrast, in the DG catchment, significant differences in $\delta^{13}C$ values were detected only between Baetidae and Hydropsychidae, and Oligochaeta and Simuliidae.

Differences in values of $\delta^{13}C$ and $\delta^{15}N$ between treatment levels for individual consumer variables

A significant main-term treatment effect for $\delta^{13}C$ was detected in relation to Chironomidae and Hydropsychidae. Pairwise tests demonstrated that ^{13}C was depleted in Chironomidae samples from pressure points in the BK catchment only and that ^{13}C was depleted in Hydropsychidae samples from pressure points in the CM catchment only. No other significant pairwise differences were observed for any of the other consumer groups in relation to $\delta^{13}C$. For $\delta^{15}N$, pairwise test differences were significant in relation to Oligochaeta in the CM catchment, with samples at pressure points depleted of ^{15}N.

Sediment appears to be the largest dietary contributor to Chironomidae. Mean contributions of sediment range from 90% across pressure points to 94% across control points. Sediment too appears to be the largest contributor to the diet of Hydropsychidae, ranging from 41% to 98% at pressure points. Mean contributions of faeces to the Hydropsychidae diet tend to be greater downstream of cattle access points.

Two-source carbon mixing model

When the dietary contributions of algae and sediment to individual consumers were analysed, no significant effects of cattle access were detected. However, when contributions of faeces and sediment were compared, significant main-term treatment effects were detected in relation to the contributions of sediment to Hydropsychidae, Chironomidae and Oligochaeta. For each consumer, the contribution of sediment to diet was lower at pressure points than at control points. Significant main-term treatment effects were also detected in relation to the contributions of faeces to the diets of Hydropsychidae, Chironomidae and Oligochaeta. For each of these consumers, the dietary contributions of faeces were higher downstream of access points.

4.3.3 Discussion

In the current study, there were mixed results in relation to the impacts of cattle access on the taxonomic composition and structure of macrophyte and diatom communities. Differences in vascular macrophyte community composition were detected, with higher community richness downstream of cattle access points; however, no accompanying decline or shift in community structure or change in the composition of submerged macroalgal or diatomic metrics were observed.

There is no evidence, from the current study, to suggest that there is a relationship between riparian condition and periphyton chlorophyll *a* mass.

Stable isotope analysis identified sediment as the primary basal food source for Chironomidae, Hydropsychidae, Oligochaeta and Simuliidae. Data suggest that faeces or algae may make up a more substantial part of their diets at pressure points. It is probable, however, that the slight shift towards ^{13}C-depleted food sources for these taxa is due to the availability of faeces as a novel source of carbon.

The significantly greater δ^{15}N values for algae than for sediment in each catchment and the subsequent absence of any shift in δ^{15}N values in these consumers at pressure points suggest a shift in use to this new resource (faeces) rather than consumption of the already available algae. Braccia and Voshell (2006) observed an increase in collecting and gathering macroinvertebrate taxa in streams with high cattle density in Virginia, and attributed said observations to increased fine particulate organic matter from, *inter alia*, the breakdown of OC in cattle faeces. The findings here may also be reflective of a situation where nutrient-affected algal communities have become unpalatable (Braccia and Voshell, 2006) or where abundance of sediment deposits, as has been shown by O’Sullivan *et al*. (2019) in a study of streams, has made algae resources unavailable as a result of burial (Rabení *et al*., 2005; Burdon *et al*., 2013), thus forcing a shift in resource use.

In this study, significant shifts have been identified in certain components of macrophyte communities (vascular plants). These shifts are probably driven by reduced riparian shading downstream of cattle access points. Furthermore, increases in periphytic algal biomass have been highlighted at certain sites.

4.4 The Impact of Proposed Cattle Exclusion Measures on Freshwater Ecology: Efficacy of Fencing

This study aimed to assess the environmental benefits of cattle exclusion via fencing in the short term (1 year post fencing) by examining changes in levels of deposited sediment, habitat condition and macroinvertebrate communities in streams in Ireland. In addition, a case study on the longer term (9 years post fencing) impacts of fencing is also presented.

4.4.1 Methods

Eight cattle access points located in five catchments in the east and south of Ireland were sampled for macroinvertebrates and deposited sediment prior to and 1 year following exclusion of cattle from streams via fencing (as a part of GLAS) in October 2016 and October 2017, respectively.

The long-term efficacy of fencing as a means of improving ecological water quality was tested in the

MT catchment of County Monaghan. Here, 13 sites were originally sampled in October 2008 (see Wynne and Linnane, 2008). Seven sites were entirely fenced off from cattle following sampling in 2008. Six sites were not fenced off. All sites were re-sampled in October 2017, 9 years post fencing.

Six macroinvertebrate samples were collected at each site prior to fencing, in October 2016, and 1 year post fencing, in October 2017, using a standard, Surber sampler. The macroinvertebrates were identified using Freshwater Biology Association keys and enumerated. For the long-term fencing study, samples were collected from riffle habitats at each sampling point using a kick net and identified to family level.

Sediment sampling was undertaken as part of the short-term study only. Samples of deposited sediment were taken from riffle habitats at control and pressure points at the same time as macroinvertebrate sampling was carried out, using the "Quorer" resuspendable sediment sampling technique.

Habitat assessment was carried out as part of the short-term study only at each sampling point as per O'Sullivan *et al*. (2019), and as described earlier. Assessments were carried out prior to fencing (in 2016) and following 1 year of exclusion (in 2017).

4.4.2 Results

Significantly greater masses of deposited sediment were recorded at pressure points than at control points prior to fencing but no significant difference was found following fencing (Figure 4.3).

In relation to EPT richness, the results show that there were higher values at the control points than at the pressure points at two sites in the pre-fencing period. None of these differences persisted following fencing. There were also significant increases in EPT richness at pressure points following fencing relative to before fencing at the same two sites.

Analyses of habitat index scores [Total Habitat Index (THI) and RHI] did not show any differences between pre- and post-fencing periods.

The results showed significant differences in community structure in both the fenced and the unfenced control catchments between pre- and post-fencing periods (in the long-term fencing study). The results also showed that prior to fencing there was a significant difference in community structure between the "to be fenced" catchment and the unfenced control catchment; this difference did not persist following fencing.

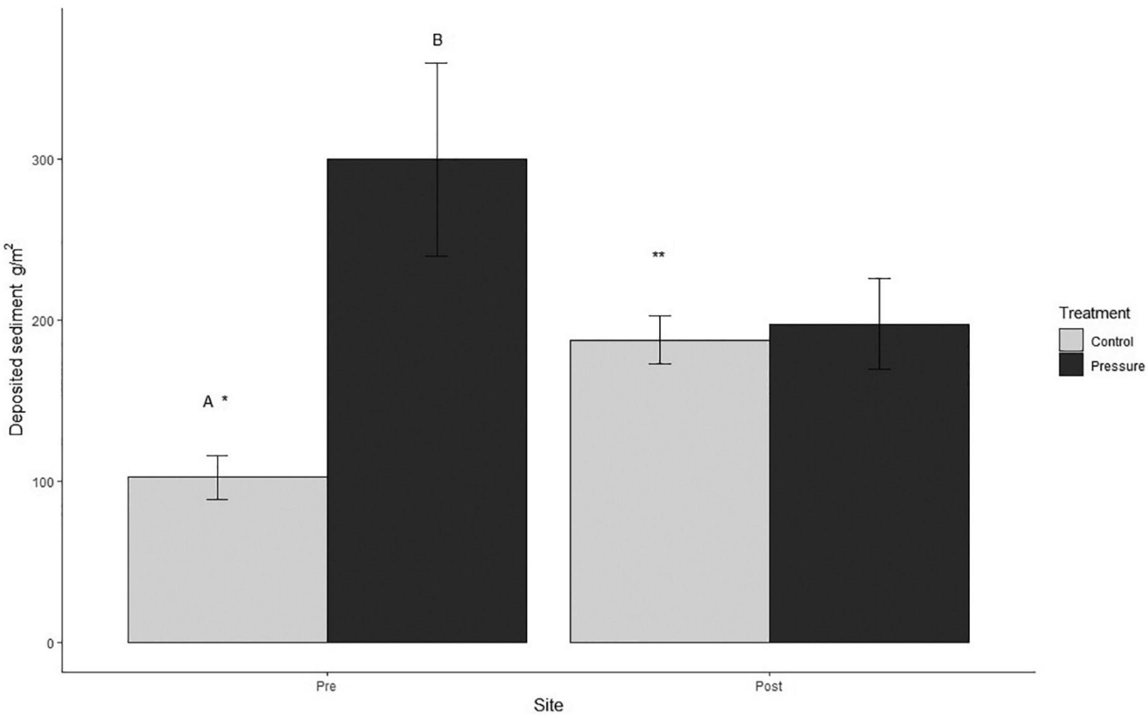

Figure 4.3. Mean deposited sediment at control and pressure points prior to and following fencing.

In the fenced catchment, values for ephemeropteran abundance and EPT abundance generally increased following fencing, while in the control catchment values for both generally decreased.

4.4.3 Discussion

In this study, significantly greater mean masses of deposited sediment were observed at pressure points than at control points prior to fencing, but no significant difference was found following fencing, despite a general increase in background levels of deposited sediment.

Habitat assessment results did not indicate any improvement in bank stability following exclusion of cattle, although increased ground cover in riparian areas was observed. The timeframe of the current study may have been too short to allow improvements in bank stability following fencing.

The results show that 1 year of cattle exclusion via fencing eliminated disparities in the mass of deposited sediment found at control and pressure points. Results for EPT richness and total richness suggest that improvements in stream water ecological quality also occurred following 1 year of cattle exclusion at certain sites. During the post-fencing sampling season, *R. semicolorata*, *Saldidae pallipes* and *Agapetus* sp. increased in abundance at both control and pressure points (across all sites) compared with the pre-fencing period. During the pre-fencing period, these taxa were all greater in abundance at control points than at pressure points. Interestingly, however, this pattern was reversed in the post-fencing period, with abundances at pressure points increasing beyond the levels of those seen at control points, across sites. Such a response may indicate that affected streams are in a state of intermediate disturbance, with community niches developing as a result of an abundance of food resources (algae) for grazing taxa following a reduction in the main community stressor, sediment.

The site-specific nature of the responses seen here may reflect differences in the time scale required for stream ecological parameters to manifest changes following the exclusion of cattle, or may reflect the initially limited impact of cattle access at some of the sites studied.

In the present study, significant improvements in stream macroinvertebrate community structure were seen following the long-term fencing off of a sub-catchment of the MT catchment in County Monaghan. Increases in the abundance of taxa such as *A. fluviatilis* and Glossomatidae (taxa that also responded positively to fencing in the short term) and Elmidae [a taxon that is shown to be sensitive to cattle access (Braccia and Voshell, 2006) and was more abundant downstream of access points following short-term fencing] occurred in the post-fencing sampling period of the fenced catchment. These results are more emphatic given the apparent decrease in ecological water quality in the control stream, where cattle access was still permitted over the 9-year period.

The current study also demonstrated improvements in the fenced catchment and deteriorations in the control catchment following the fencing period. It is unclear what the driver of the continued decline in ecological metrics in the control catchment was. Future research in this area could focus on identifying potential drivers of decline. The scope for inferences in relation to the impact of fencing are, however, limited because of the lack of temporal replication over the course of the 9 years between fencing being installed and the post-fencing sampling period.

4.5 The Impact of Cattle Access on Hyporheic Chemistry and Invertebrate Fauna

The hyporheic zone is an area of transition between surface water and groundwater bodies that regulates hydrological, chemical and biological exchanges between these two ecosystems (Braccia and Voshell, 2007; Kibichii *et al*., 2015). The current study is the first study to specifically assess the impacts of cattle incursion into streams on the hyporheic zone.

4.5.1 Methods

Hyporheic zone samples were collected from four streams in three catchments in east and south-east Ireland. These were in the DG catchment [sites A (DGA) and B (DGB)] in County Laois, the CM catchment in County Louth and a tributary of the BK in County Wexford. At each site, samples were taken upstream (control) and downstream (pressure) of a cattle access point. Sites were sampled in November

2016 for fauna, sediment and water chemistry and again in January 2017 for only sediment and water chemistry. A modified Bou-Rouch pumping technique was used to collect hyporheic water samples from which faunal, chemistry and sediment samples were taken.

Physico-chemical measurements (DO, pH, conductivity and temperature) were taken from each well using standard techniques. Samples were analysed for total ammonia, nitrite, nitrate and orthophosphate using standard methods (APHA, 1995). Macroinvertebrate samples were identified and enumerated. Most larva and nymphs were identified to species or genus level using standard keys; however, a few difficult groups such as Chironomidae were identified to family level only.

4.5.2 Results

There was a marginally significant interaction effect for fine sediment concentration in autumn but none for the percentage of OM. Pairwise results for autumn showed that there were significantly greater concentrations of fine sediment in pressure samples than in control samples at the BK site (Figure 4.4). Although general increases were observed between control and pressure points at all other sites, these differences were not statistically significant.

In winter, there was a significant main-term treatment effect in relation to fine sediment concentration.

There was a significant interaction between season and site in relation to the seasonal effect design. Pairwise results show significantly greater and marginally greater concentrations of fine sediment in winter samples than in autumn samples at DGA and DGB, respectively.

In autumn, there were significant treatment × site interactions for temperature, DO (mg L^{-1}) and conductivity. The results showed that there were significantly higher temperatures (°C) at pressure points than at control points at DGA and BK sites; significantly lower DO at the CM and BK pressure points than at the respective control points; and significantly or marginally greater conductivity levels at CM, BK and DGA pressure points than at control points.

There were no statistically detectable effects of cattle access on hyporheic water chemistry during the winter sampling period. The analysis showed significant differences in community composition between control and pressure points at both BK and DGA sites. The analysis found no correlation between hyporheic community structure and all environmental variables.

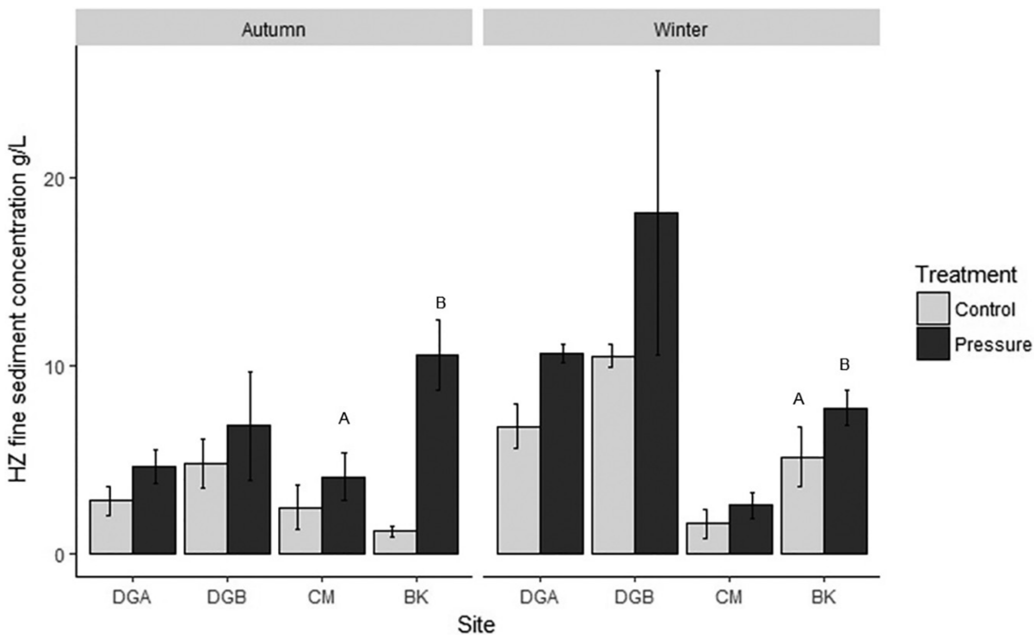

Figure 4.4. Hyporheic zone (HZ) fine sediment concentrations for autumn (November 2016) and winter (January 2017). Different letters indicate significant differences, e.g. a site with the letter "A" is significantly different from a site with the letter "B".

4.5.3 Discussion

Increased ingress of fine sediments into the hyporheic zone downstream of cattle access points was demonstrated in a few cases in the current study during the autumn and winter sampling periods, although the increases were not statistically significant at all sites. Differences in community composition were encountered at DGA and BK sites, with the occurrence of a greater number of taxa in control samples than in pressure samples at both sites. Higher taxon richness was detected at control points at these sites, while marginally significantly greater EPT richness was observed at the DGA control point. In the current study, hyporheic fine sediment concentration was the single most influential variable to affect the communities studied. Changes in hyporheic communities facilitated by fine sediment ingress and resulting colmation could be due to the smaller interstitial pore sizes, resulting in a community composed of smaller bodied species. Here, community compositional changes at the DGA cattle access point in particular represented a change to a depleted community more sparsely populated by large-bodied invertebrates such as *Alainites muticus*, *Agapetus* sp., Collembola and Cyclopoida.

Colmation also reduces vertical exchanges of DO, carbon and nutrients as a result of reduced connectivity with the oxygen- and carbon-rich surface water and often enriched groundwater. Thus, diminished hyporheic exchanges as a result of reduced particle size can result in more extensive hypoxic patches (Boulton *et al*., 1998; Boulton, 2007; Datry *et al*., 2007). In the current study, a significant reduction in DO concentration was seen at the CM and BK pressure points. Moreover, the best agreement between community data and environmental variables included DO content along with fine sediment concentration.

Interestingly, mean fine sediment concentrations across all sites, regardless of location in relation to cattle access points, were higher in winter than in autumn samples. This seasonal variation indicates the potential sediment storage capacity of hyporheic zones, even in small headwater streams where such capacities are diminished relative to those of lowland streams (Gomi *et al*., 2002). Significantly, levels of fine sediment (in the hyporheic zone) were elevated regardless of location relative to cattle access points in the absence of cattle over the winter period. In the current study, deposited sediments were probably carried into interstitial spaces by higher flows over the winter period where this material may, in turn, have become an “internal” source of suspended sediment during separate high-flow events (Kurashige, 1996).

5 National Estimates of On-farm Watercourses

The Department of Agriculture, Food and the Marine (DAFM) has detailed information on farmers, farms and farmland; however, there is not a map showing all individual farm boundaries. The DAFM database is called the Land Parcel Identification System (LPIS) and the basic mapping elements are parcels of a particular land use farmed by the same person. The aim of this WP was to create a national synthetic farm map based on real parcel boundary data. Moreover, a spatial intersection of these synthetic farm boundaries with a national water body layer allows us to calculate a suite of statistics on on-farm watercourses, including total length, number of farms affected, average area and length of farm watercourse.

5.1 Methodology

Spatial datasets on farms and watercourses were collated, including the LPIS dataset and PRIME2 (P2) dataset, the principal mapping resource for Ireland, which acts effectively as a national cadastre database containing over 50 million "objects" making it the richest spatial database in Ireland). A geographic information system (GIS) methodology was utilised to merge the data to create a farm boundary layer. A similar process was used to create a new river network dataset. The rivers included in the study are based upon those identified in the WFD and are included in the Ordinance Survey Ireland (OSi) 1:50,000 Discovery Series dataset.

5.1.1 Agronomic clustering

In order to put the spatial data regarding river/farm intersections in a socio-economic context, a number of agro-economic indicators were clustered at the townland level using simple k-means approaches. The five clusters identified were "high intensity", "mid-intensity", "low intensity", "marginal" and "upland". There are clear differences between the most productive cluster, high intensity, and the least productive cluster, upland (Table 5.1). The high-intensity cluster has on average a higher temperature, less precipitation, a lower elevation, a higher stocking rate and better soil and physiological conditions.

The majority of marginal areas are located along the west coast in rough grazing type areas where agricultural intensity is very low (Figure 5.1). Soils in these areas tend to be mostly wet. Low-intensity areas have a similar agricultural intensity to marginal areas. Soils in these areas are mostly peaty and poorly drained. The mid-intensity clusters make up the

Table 5.1. Agronomic, environmental and climate summary statistics by cluster

Variable	Upland	Marginal	Low intensity	Mid-intensity	High intensity
Continentality	5.2	4.03	5.96	5.89	5.04
Mean temperature (°C)	7.94	9.37	9.01	9.14	9.49
Mean precipitation (mm)	1617.85	1486.69	1044.49	1052.18	1161.63
Wind (km hour^{-1})	7.91	7.64	6.97	7.07	6.96
Mean elevation (m)	222.39	72.58	83.5	73.17	93.01
LU ha^{-1}	1.09	1.09	1.05	1.06	1.17
Wet/dry (mode)	Poorly drained	Poorly drained	Poorly drained	Well drained	Well drained
Soil (mode)	Marginal	Marginal	Marginal	Productive	Productive
Land use potential	Very limited	Limited	Limited	Wide	Wide
Principal soil (mode)	Peaty podzolic	Gley	Gley	Grey-brown podzolic	Brown podzolic
Physio (mode)	Mountain and hill	Rolling lowland	Drumlin	Flat to undulating lowland	Rolling lowland

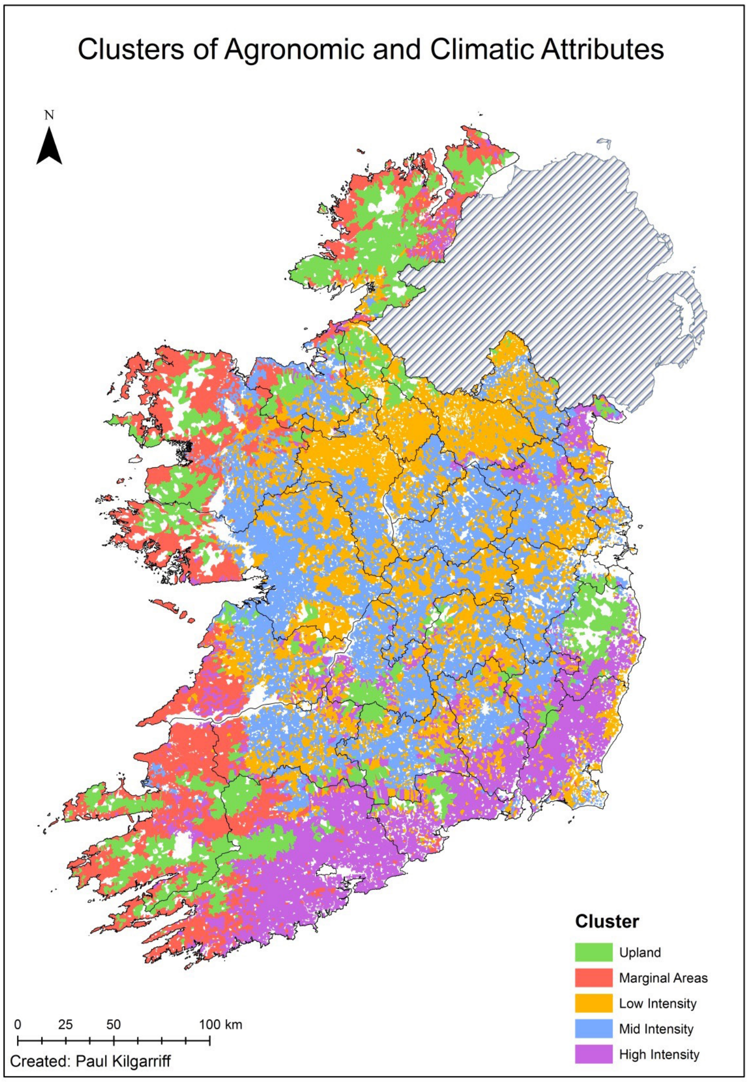

Figure 5.1. Clusters of agronomic and environmental conditions.

majority of the land area in the centre of the country. Finally, the high-intensity clusters are the areas with the highest agricultural intensity. The majority of this cluster is located along the south coast in areas where dairy is the dominant farm system.

5.2 Results and Discussion

A total of 129,600 farms were recorded. Of these, 73% have an on-farm watercourse (Table 5.2), with the highest percentage occurring in upland areas (Table 5.3).The density of on-farm watercourses per sub-catchment is presented in Figure 5.2.

5.3 Conclusions

This is the first Irish dataset that contains individual farm boundaries along with individual fields. This is now a seamless spatial database of the farm/watercourse geography intersected with watercourses relevant for the WFD. Further analysis will allow the identification of watercourses shared between farms (water boundaries) or a complete characterisation of cumulative farm area along river stretches.

The datasets created in this WP can be used to create a spatially rich model, to improve targeting of mitigation, e.g. to identify the areas with the greatest level of cost-effectiveness for a particular measure and thus the areas in which the largest impacts can be achieved. The results of this WP can also inform policy in relation to land fragmentation. Land fragmentation has negative and positive outcomes. External boundaries can increase the persistence of hedgerows and improve biodiversity.

Table 5.2. Farms with an on-farm watercourse

	On-farm watercourse
Yes	94,612 (73%)
No	34,988 (27%)
Total	129,600

Table 5.3. Percentage of farms in each cluster with an on-farm watercourse

Cluster	Watercourse (%)	No watercourse (%)
High intensity	74	26
Low intensity	76	24
Marginal areas	75	25
Mid-intensity	65	35
Upland areas	85	15

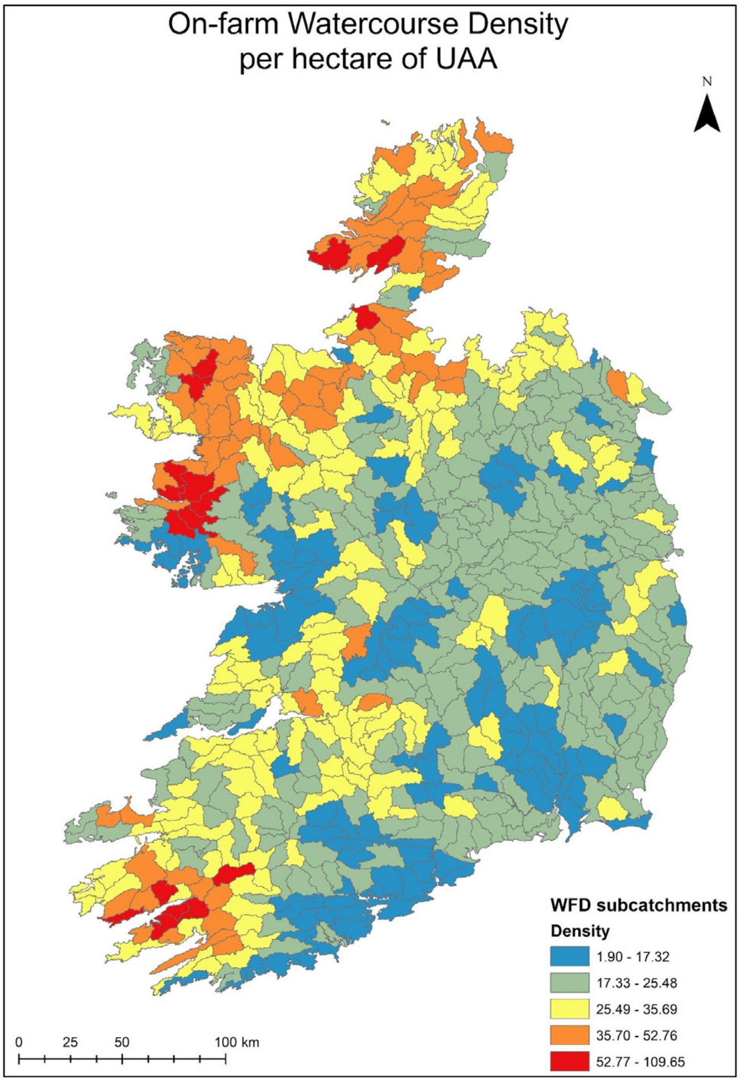

Figure 5.2. Mean on-farm watercourse per sub-catchment for all farms.

6 Cost-effectiveness of Existing and Potential Cattle Exclusion Measures: Socio-economic Implications

Livestock exclusion through the fencing off of watercourses prevents access and therefore removes sources of pollution and damage (Cuttle *et al*., 2007). Exclusion measures can also reduce nitrogen, phosphorus and sediment inputs associated with cattle access to watercourses (Line *et al*., 2016). River bank stability, in-stream vegetation and river margin vegetation cover also improve as a result of exclusion (Scrimgeour and Kendall, 2003). The fourth national Nitrates Action Programme (NAP) of the ND requires farms with a derogation to farm at a grassland stocking rate of over 170 kg N ha^{-1} to prevent cattle from accessing watercourses from January 2021. However, in providing improved water quality for society, this measure is likely to have economic implications for farms.

6.1 Cattle Exclusion Measures

6.1.1 Methodology

We utilised the new national farm boundary spatial database for Ireland to examine cattle exclusion at individual farm level, using farm boundary data and river data for all 130,000 farms in Ireland. These datasets were utilised in combination to examine the cost-effectiveness of cattle exclusion for all farms and on a subset of farms, namely those with a grassland stocking rate of over 170 kg N ha^{-1} (incorporating derogation farms) and named “intensive” for this study. The effectiveness of cattle exclusion in this study was measured in terms of the reduction in faecal matter deposited in a watercourse. This information was utilised to undertake an *ex ante* case study examination of the implications of a national policy to restrict cattle access to water bodies for specific categories of farmers (namely those with a stocking rate of over 170 kg N ha^{-1}) in relation to one metric of effectiveness.

The costs of cattle exclusion relate first to the erection of permanent fencing and second to the provision of alternative water sources for livestock. The benefits of cattle exclusion from watercourses include a reduction in sediment, the improvement of river banks and a reduction in direct faecal discharge by cattle into watercourses. The average rate of defecation was estimated to be 11.5 times per 24-hour period (Bagshaw, 2002), corresponding to between 1.6 and 2.5 kg of faecal matter deposited directly in-stream, per cow daily. Using these values, we estimated the level of defecations in watercourses as a function of livestock density (LU ha^{-1}). We assumed that cattle spend an equal amount of time throughout the farm during the grazing season. Thus:

$$\text{Total faecal matter}_i = 0.067 \times (\text{total LU}_i \times 23.6) \times 210 \qquad (6.1)$$

where *I* is an individual farm, 0.067 is the lower bound estimate of defecations in stream (Gary *et al*., 1983) and 23.6 is the total mass of faecal matter defecated by cows in kilograms in 24 hours (Kenner *et al*., 1960). It is also possible to use an average outdoor grazing period of 210 days (Butterfield *et al*., 2006). In this example we focus on kilograms of faecal matter per day of grazing:

$$\text{Cost-effectiveness}_i = \left(\frac{\text{total faecal matter}_i}{\text{NPV costs}_i} \right) \qquad (6.2)$$

where NPV is the net present value. The cost-effectiveness of cattle exclusion was calculated for each farm, i.e. kilograms of faecal matter reduced in the stream per euro spent on fencing.

6.1.2 Results and discussion

Table 6.1 presents the shares in terms of area, length, cost and benefit accounted for by fencing on intensive farms (> 170 kg N ha^{-1}) and non-intensive farms (< 170 kg N ha^{-1}). Although the costs of watercourse fencing on intensive farms represent 13% of the total costs of fencing, they account for 17% of the benefits of a cattle exclusion policy. Given the agricultural intensity of these farms, this result is not surprising. Moreover, given resource limitations, targeting cattle exclusion measures at the most intensive farms (largely derogation farms) appears to be a valid

Table 6.1. Estimated shares in terms of land area, watercourse length, cost and benefit of exclusion fencing on intensive (> 170 kg N ha^{-1}) and other farms (< 170 kg N ha^{-1})

Farm type	Area	Length	Costs	Benefits
Intensive	0.16	0.13	0.13	0.17
Non-intensive	0.84	0.87	0.87	0.83

Table 6.2. Shares of attributes by cluster (calculated in WP5)

Cluster	Costs	Benefits	Area	Length	Farms	Intensive farms	Cost-effectiveness ratio
Upland areas	0.14	0.09	0.09	0.14	0.09	0.02	0.023
Marginal areas	0.17	0.13	0.14	0.17	0.18	0.10	0.027
Low intensity	0.28	0.26	0.26	0.28	0.27	0.21	0.032
Mid-intensity	0.25	0.31	0.31	0.25	0.30	0.30	0.044
High intensity	0.16	0.21	0.20	0.16	0.16	0.37	0.046

approach (when “removal of faecal matter” is used as the effectiveness metric, as in this study).

Table 6.2 illustrates, using cost-effectiveness ratios, that fencing is most cost-effective in the most agriculturally intensive clusters. This is because of the high level of faecal matter that would be deposited in streams in the absence of watercourse fencing in these clusters. The “high intensity” cluster has the highest number of intensive farmers, who will be most affected by the 2021 cattle exclusion obligations under the ND.

6.1.3 Conclusions

The analysis confirms that fencing areas according to agricultural intensity as recommended in the fourth NAP of the ND is a cost-effective solution in relation to the removal of faecal material from watercourses. The high volume of faecal matter produced on farms with a high stocking rate makes it most cost-effective to fence off the watercourses on these farms, particularly if the on-farm watercourse is short. As the length of on-farm watercourse increases, the relative cost also increases. The spatial analysis undertaken here graphically illustrates how the trade-off between costs, benefits, and length and area of fields adjacent to a watercourse impact on the cost-effectiveness of fencing. It should be noted that a limitation of this study arose from the lack of available data on the extent to which watercourses on intensive farms were already fenced off; thus, the level of additionality of compulsory fencing on intensive farms is unclear.

The spatial distribution maps highlight the differences between areas in terms of costs, benefits and extents of watercourses. Grouping analysis (as opposed to relying on county or sub-catchment boundaries) is a useful method of grouping similar areas. Using this methodology, areas with similar soil, climate, environment and farm intensity were grouped together into clusters. The analysis of the clusters shows that the mid- and high-intensity farms are the most cost-effective farms on which to exclude cattle from watercourses. Future research could assess alternative groupings, e.g. WFD status objectives (high, good, moderate water quality), with costs and effectiveness (in removal of faecal matter) being compared between watercourses of good quality and those of less-than-good quality.

6.1.4 Areas for future research

- It is noted that the metric of effectiveness used in this section is the “prevention of faecal matter from entering a stream”. There are undoubtedly other metrics of effectiveness that could be used, either in isolation or in combination. Other metrics relate to not only water quality but also biodiversity and carbon sequestration (e.g. as stated in previous sections, targeted fencing and the establishment and appropriate management of riparian margins can have multiple benefits and provide a variety of ecosystem services).
- It is also the case that the impact of faecal matter on water quality is highly variable (as highlighted in previous sections). Here, information is

provided in relation to the reduction of faecal material entering a watercourse. The study does not take into account the characteristics of the receiving watercourse (bio-physical, hydrology, status). The environmental parameters relating to individual watercourses will undoubtedly influence the impact of faecal matter on water quality parameters.

The approach provided in this section highlights how results and databases created as part of the COSAINT project can be coupled with available datasets (e.g. in relation to water quality), such that future studies could assess the effectiveness of cattle exclusion from watercourses at a catchment, regional or national scale.

6.2 Willingness to Adopt Cattle Exclusion Measures and Level of Incentives Required to Ensure Adequate Participation in Voluntary Cattle Exclusion Measures

Few studies have examined the determinants of the adoption of measures for livestock exclusion from watercourses and previous studies have primarily focused on examining the influence of farm and farmer socio-economic factors on the adoption of farm management practices that improve water quality. Here, a conceptual framework is developed based on the theory of planned behaviour (Ajzen, 1991) in order to advance our understanding of the factors that influence farmers' intentions to exclude livestock from watercourses.

6.2.1 Data and methodology

The data used in this study were derived from a structured survey of 1009 farmers across Ireland. The survey was designed to collect information in relation to farmer attitudes and socio-economic characteristics, in conjunction with farm agronomic and economic information, in relation to farmers' intentions to adopt environmentally positive farm management practices, including fencing off watercourses. The survey was divided into four sections. First, questions were administered to collect data on farm (e.g. farm size and system) and farmer characteristics (e.g. age, education and contact with an agricultural advisor) for use as independent variables in the analysis. The second section contained questions in relation to general attitudes about farming. Third, dedicated questions were presented to the "fencing" sub-sample of farmers to collect information in relation to (1) the presence of watercourses; (2) the level of livestock access; and (3) awareness of the benefits of fencing off watercourses. The final section was based on the theory of planned behaviour, with farmers being asked to evaluate various statements designed to reveal their beliefs and intentions towards fencing off watercourses.

Variables

Four types of psychological latent constructs were of relevance to this study: attitude, subjective norm, perceived behavioural control and perceived resources. Respondents were asked to respond on a five-point Likert scale, from strongly disagree (1) to strongly agree (5), to statements relating to these constructs.

Farmers evaluated eight statements regarding their attitudes towards the outcomes of fencing off watercourses, four statements regarding subjective norm (social pressure), seven statements regarding perceived behavioural control (ability) and four statements regarding perceived resources.

Farm and farmer characteristics are also expected to influence farmers' intentions to fence off watercourses. The selected variables included farm size and system, farmer age, formal and agricultural education, contact with an agricultural advisor and participation in a farmer discussion group.

Only a small proportion of farmers responded "strongly disagree" to the intention statement; therefore, similar to other studies (Läpple and Kelley, 2013; Hyland *et al*., 2018), the responses "strongly disagree", "disagree" and "unsure" were grouped into the category "do not intend" and labelled as "0" and the responses "agree" and "strongly agree" were grouped into the category "intend" and labelled as "1".

6.2.2 Results and discussion

The results show that 66.4% of the farms in the survey had a watercourse. Livestock had access to water on approximately 40% of the respondent farms. The majority of farms with watercourses reported

Table 6.3. Farms with watercourse fencing by livestock access to watercourse

What proportion of the watercourse is fenced off?	Access of livestock to watercourse?				
	Yes	No	Not applicable	Total	Share
25% or less	48	12	3	63	9.49
26–50%	22	11	2	35	5.27
51–75%	40	14	2	56	8.43
76–100%	111	338	2	451	67.92
None	40	11	2	53	7.98
Do not know/not sure	2	4	0	6	0.90
Total	263	390	11	664	100.00

that 76–100% of the watercourse was fenced off (Table 6.3); results, however, differed between farms where animals had access to watercourses and farms where animals had no access. On farms where animals had no access, 86% of farms had 76–100% of the watercourse fenced; on farms where animals had access to watercourses 42% of farms had 76–100% of the watercourse fenced.

Nationally, a total of 79% of farmers intend to fence off watercourses. These intentions are influenced significantly and in a positive direction by subjective norms and perceived behavioural control. Farmers who feel social pressure and farmers who feel that they have the knowledge and capacity to undertake fencing have positive intentions to implement the practice. A perceived lack of resources on the other hand has a negative influence on the intention to undertake fencing, indicating that the cost of fencing is a negative factor. Attitudes are not significant in relation to fencing.

6.2.3 Conclusions

The results of this study suggest that farmers who feel a larger degree of social pressure are more likely to fence off watercourses. One possible explanation for this result is that a fear of further regulation, or fear of penalties, motivates farmers to behave in a way that is perceived as "socially desirable" and that will avoid further regulation in the future (Savage and Ribaudo, 2013; Mills *et al.*, 2018).

In theory, farmers who have a strong belief in their own capability to fence off watercourses should be more likely to do so (Ajzen, 1991). Our results support this assertion. The results also indicate that farmers who do not believe that they have the necessary resources, such as time, finance and labour, to fence off watercourses are less likely to do so. While this result is contrary to the finding of Zeweld *et al.* (2017), it is consistent with expectations, as the exclusion of livestock from watercourses necessitates the provision of an alternative water supply, which often requires additional finance, time and labour, to which a farmer may not readily have access, and which may hinder adoption. The results demonstrate that farmers aged 45–50 are more likely to intend to fence than older farmers (65 and over). One possible explanation for this result is the fact that relatively young farmers have a longer planning horizon and therefore are more likely to adopt practices that maintain or increase production (Knowler and Bradshaw, 2007) and/or may be more aware of environmental objectives. In our analysis, "agricultural adviser" is not significant but the influence of "other farmers" is significant and negative in relation to the intention to fence, while the influence of "family" is significant and positive.

7 Conclusions

7.1 Key Findings

- There are 129,600 farms with 2.9 million fields in Ireland, with 95,000 of these farms and 382,000 fields adjoining a watercourse. Of these, 73% have an on-farm watercourse.
  - Of these farms, 10% are “intensive farms” (> 170 kg N ha^{-1}), the majority of which are therefore affected by mandatory fencing measures under the fourth NAP.
  - The share of farms having watercourses is disproportionately higher for intensive farms.

7.1.1 Impact of cattle access on sediment deposition and turbidity

- Cattle access to watercourses resulted in a significant increase in deposited sediment in streams:
  - Elevated levels were seasonal and present only during the grazing season.
  - Elevated levels were limited spatially to the pressure point (for the majority of sites).
- Higher concentrations of fine sediments were recorded in the hyporheic zone at cattle access points than at upstream control points at all sites.
- No evidence of an impact of cattle access points on the percentage of OM within deposited sediment was found.
- No evidence that there was a cumulative impact of cattle access points on sediment deposition was found.
- A significant correlation was found between cattle numbers in the stream and the difference between upstream and downstream turbidity (indicator of suspended sediment).
- A moderate correlation was seen between the length of time cattle spend in a stream and the difference in upstream and downstream turbidity.

7.1.2 Impact of cattle access on stream habitats and associated biodiversity

- There was evidence of a negative impact of cattle access points on riparian habitat condition:
  - a correlation between deterioration in riparian habitat condition and deposited sediment;
  - a stocking rate (modelled) of above 1.30 LU ha^{-1} was linked with a lower RHI score and there was a higher decline in the RHI score at access points.
- Macroinvertebrate responses to cattle access points were found at certain sites in both autumn and spring sampling seasons:
  - Impacts on the macroinvertebrate community were more substantial during autumn and were probably related to additional deposited sediment downstream of cattle access points.
  - There was limited evidence to support nutrient-driven changes in macroinvertebrate communities.
  - Increased suspended solids may have been subsidising the diet of filter-feeding Hydropsychidae spp., while simultaneously limiting the recovery of sediment-sensitive species such as *R. semicolorata.*
- Site-specific effects of cattle access points on hyporheic macroinvertebrate community were found:
  - DO and fine sediment concentrations were the major drivers of change.
- There was some evidence to suggest enrichment effects downstream of cattle access points, possibly as a result of cattle faeces being deposited in or adjacent to streams.
- Significant impacts of cattle access points on periphytic algal biomass were observed, during the summer season in particular.
- No downstream cumulative pattern in relation to habitats and associated biodiversity was found.

7.1.3 Impact of cattle access on nutrient parameters

- Water nutrient concentrations did not show any differences between upstream levels and levels at cattle access points for samples taken in the absence of cattle.
  - Water nutrient concentrations were generally higher in late grazing season than in early grazing season.
  - Ammonium levels showed an erratic pattern and an indefinite response to cattle in-stream

activity. This study indicates that in-stream urination can lead to increased concentrations of ammonium. However, ammonium is a highly reactive ion, and its detection and true quantification at an experimental site might be difficult.

- Bed sediment phosphorus concentrations were significantly affected by cattle access.
  - This impact was found at the interface, where cattle have access, an area that is likely to be subjected to less flushing of sediments by stream water.
  - Bed sediment TP concentrations were significantly higher in late grazing season than in early grazing season.
  - There was a correlation between stocking rate and TP in sediment (upstream), i.e. phosphorus in upstream sediment was significantly higher at sites with a stocking rate of $> 1.30\,\text{LU}\,\text{ha}^{-1}$ than at sites with a stocking rate of $< 1.30\,\text{LU}\,\text{ha}^{-1}$.
  - Phosphorus in upstream sediment was significantly higher at sites of less-than-good biological status than at sites of good biological status or higher.
  - There was a correlation between stocking rate and TP in sediment (for INTs).
- Bed sediment TN concentrations did not vary significantly between areas with cattle access and without cattle access:
  - TN levels decreased significantly from the early grazing season to the late grazing season.
- The OC sediment concentrations did not vary significantly between areas with cattle access and areas with no cattle access.
- Cattle in-stream activity resulted in increases in TP and ammonium.
- Nutrient concentrations in the sediments were not exceptionally high, even in the interface zones.
- No downstream cumulative impact of cattle access points on sediment nutrient parameters was found.

7.1.4 *Impact of cattle access on* E. coli *levels in sediment and water*

- The bed sediments at all sites in this study, even those upstream of cattle access points, were contaminated with *E. coli*:
  - The results highlight the widespread contamination of stream sediments with *E. coli* in agricultural catchments.
- Sediment *E. coli* concentrations were significantly higher at CASs than at USs in the mid-grazing season. Cattle in-stream activity resulted in increases in *E. coli* levels downstream of the access site during all events:
  - There was a subsequent general decrease in *E. coli* levels at the access sites in the post-grazing season.
- No downstream cumulative pattern of faecal contamination was found at the study sites.

7.1.5 *Impact of fencing and cattle exclusion on water quality parameters (GLAS sites)*

- Sediment mass was significantly higher at cattle access points than at the upstream locations prior to fencing:
  - There was no significant difference in sediment mass between the USs and CASs post fencing.
- Sediment concentrations of OC, TN and TP were significantly higher at the stream INTs, where cattle would have been most likely to congregate, than at the US locations prior to fencing:
  - There was no significant difference between the US and INT locations for any of the three sediment nutrients assessed post fencing.
- Sediment *E. coli* levels were higher at CAS than at US locations at three of the five GLAS sites in the autumn of 2017 (before fencing), but differences were not significant when all five sites were considered:
  - Cattle exclusion had a positive impact on levels of *E. coli.* contamination of the bed sediment at a number of sites.
- There was no significant difference at the GLAS sites in any of the four stream water nutrient parameters assessed (SRP, TP, NO_3-N and NH_4-N) between the control, US, and pressure, CAS, locations.
- There was no significant difference at the long-term fenced sites in any of the four stream water nutrient parameters assessed (SRP, TP, NO_3-N and NH_4-N) between fenced and unfenced tributaries.

- For *E. coli*, there was no significant difference between the long-term fenced and unfenced tributaries.
- Increased riparian vegetation cover was observed 1 year post fencing.
- Significant improvements occurred in stream macroinvertebrate communities in long-term fenced sites:
  - Some site-specific improvements in macroinvertebrate communities were observed in short-term fenced sites.

7.1.6 Targeting and attitudinal response

- Targeting cattle exclusion to more intensive farms (> 170 kg N ha^{-1}) is more cost-effective (at removing direct faecal material) than focusing on less-intensive farms.
- Socio-economic, demographic and psychology variables all contribute to influencing farmers' intentions to fence off watercourses:
  - Farmers who feel a large degree of social pressure from important reference groups are more likely to fence off watercourses.
  - Farmers who feel they have the necessary knowledge and information to undertake fencing and provide alternative water supplies are more likely to intend to fence.
- If farmers believe that the adoption of a measure such as the fencing off of watercourses is going to be costly in terms of time, money and hassle, they are less likely to adopt such a measure voluntarily. In this case, it is probable that a regulatory approach will be more successful, particularly in light of the significant influence of policy compliance on adoption.
- Participatory and collective approaches are likely to have a positive influence on the intention to fence (social norms).

7.1.7 Additional observations

- Across the majority of sites, elevated levels of deposited sediment were found to be limited to the pressure point.
- No clear trend regarding sites of good status or better versus those of less-than-good status was found:
  - There was no significant difference in RHI scores between USs of good or better and less-than-good biological quality
  - The COSAINT study highlights that cattle access can be a significant stressor for freshwater ecosystems at both good or better status and less-than-good status sites. There was no significant difference, in relation to the impact of cattle access points, at sites where the background water quality was of good or better status and those sites that were of less-than-good status.
  - These results differ slightly from a recent study by Madden *et al*. (2019), which indicated that the impact of cattle access points was more significant at sites where the background condition was of good or better status. It is probable that intensity of use (cattle numbers and frequency of use) and landscape-scale processes are more substantial drivers of impact than background quality.
- This study did not find any evidence that there was a cumulative impact of cattle access points on the water quality parameters that were assessed.

7.2 Drivers of Impact

The COSAINT study suggests that cattle access to watercourses can significantly impact on the habitat quality of watercourses. There is a correlation between the (projected) level of use of the access point (i.e. stocking rate per hectare) and the degree of impact. Sites where the estimated stocking rate was > 1.30 LU ha^{-1} had a lower RHI score than sites where the stocking rate was < 1.30 LU ha^{-1}. Moreover, sites where the stocking rate was > 1.30 LU ha^{-1} were also found to have a greater difference in RHI scores between upstream (no access) and access points.

The results suggest that the direct impact on habitat and the associated higher level of sediment deposition at these access points was the most significant driver of change in macroinvertebrate communities, as opposed to a nutrient-driven change in macroinvertebrate communities.

7.2.1 The role of sediment in freshwater ecosystems

Results from the COSAINT study highlight the significant influence of sediment on the quality of freshwater ecosystems. Cattle access points resulted in significant increases in bed sediment and infiltration of sediment into the hyporheic zone.

The COSAINT project has highlighted that, where changes in macroinvertebrate community structure occurred at cattle access points (in-stream and in the hyporheic zone), sediment was a dominant driver of community change. Significant reductions in sediment-sensitive taxa were encountered at points downstream of cattle access points at 7 out of 15 study sites. Reduced abundances of sediment-sensitive taxa were observed downstream of cattle access points, whereas increased abundances of sediment-tolerant groups including Chironomidae and Oligochaeta were noted. The changes in macroinvertebrate communities reported in this study and the respective augmentations in deposited sediment mass downstream of cattle access points correspond to those identified by Braccia and Voshell (2007). Recent studies have suggested that sediment is the most serious threat to the ecological integrity of agricultural streams (Matthaei *et al*., 2010; Conroy *et al*., 2015; Bruen *et al*., 2017; Davis *et al*., 2018, 2019).

Cattle access to watercourses can contribute to faecal bacteria reservoirs in stream sediments, which can persist after cattle access pressures have been removed. Significant releases of faecal bacteria from sediments to waters can occur under baseflow conditions via hyporheic exchange (Pachepsky *et al*., 2017) or through resuspension of accumulated faecal organisms following sediment disturbance (Jamieson *et al*., 2005; Cho *et al*., 2016). Thus, the threat to human and animal health posed by unrestricted cattle access to watercourses and cattle-based agriculture is not confined to the grazing period.

The COSAINT study highlights that unrestricted cattle access to watercourses can lead to localised accumulation of phosphorus in sediments at access sites. These phosphorus reservoirs can represent a source of phosphorus to waters through its release into or remobilisation in the water column.

7.2.2 The role of fencing/cattle exclusion in freshwater ecosystems

The results of this study highlight that fencing/exclusion of cattle from watercourse can help improve the quality of environmental indicators over the short and long terms. For example, following 1 year of exclusion levels of deposited stream sediment and concentrations of phosphorus in the sediment were significantly reduced and improvements in macroinvertebrate communities were observed at a number of sites. Improvements in environmental parameters also persisted over a longer period of fencing, particularly with regard to macroinvertebrate communities, with significant improvements in sensitive bio-indicators (EPT abundance and percentage ephemeropteran abundance) persisting for 10 years post fencing.

7.3 Recommendations to Inform Policy

7.3.1 Cattle exclusion from watercourses can improve the ecological quality of watercourses in the short and long terms

Improvements due to cattle exclusion from watercourses were particularly apparent in relation to bed sediment mass and macroinvertebrate community health.

7.3.2 River restoration projects should aim to restore vertical connections between surface waters and the hyporheic zone

Activities that result in increased sedimentation of the hyporheic zone can give rise to increased ingress of fine sediment, clogging and colmation of interstices and reductions in interstitial DO, and in turn can impact on ecological communities. This is likely to be of particular importance to species of conservation concern such as the freshwater pearl mussel (*Margaritifera margaritifera*), where a key (sensitive) stage of its lifecycle is focused on the hyporheic zone. River restoration projects should aim to restore vertical connections between surface waters and the hyporheic zone, which can help flush out interstices and support the maintenance of optimal levels of DO.

7.3.3 Multiple, targeted mitigation measures should be incorporated into policy and incentivised

Fencing and cattle exclusion alone may not be sufficient to restore the ecological condition of affected watercourses. Future policy should consider multiple mitigation measures that interact with one another. For example, fencing to exclude cattle could be coupled with targeted riparian buffer management to yield other environmental benefits such as biodiversity and carbon sequestration, thereby achieving maximum environmental improvements. This could take the form of a treatment train. The GIS framework developed in Chapter 6 could be coupled with available datasets in relation to water quality and hydrology [e.g. Environmental Protection Agency (EPA) datasets], and stocking density (LPIS datasets); these combined datasets could be used to model the probable response to different treatment trains, based on best available spatial data. Such an approach could be facilitated under revisions of the Common Agricultural Policy, whereby the quantity of a mitigation measure could be incentivised under Pillar 1 payments, but the performance (linked with targeting and management) of associated measures could be incentivised under Pillar 2 payments (i.e. results-based approaches).

7.3.4 Providing greater knowledge to farmers improves confidence in their own ability to undertake water protection measures such as fencing off watercourses

There are over 90,000 farms with a watercourse that do not have a derogation and are thus currently exempt from excluding cattle from watercourses. The majority of respondents in the study already prevent livestock from accessing watercourses and of the remainder almost 80% intend to exclude livestock from watercourses in the future. While these results are encouraging, it is important to address the concerns and impressions of the cohort of farmers whose cattle have access to watercourses and who do not intend to fence them off. The results from the COSAINT project indicate that providing greater knowledge to farmers improves confidence in their own ability to undertake water protection measures such as fencing off watercourses. This may help to increase the levels of control that farmers perceive they have over fencing off watercourses and selecting appropriate alternative water supplies (Blackstock *et al.*, 2010).

7.3.5 Encouraging or incentivising farmers to join group learning environments

As stated, providing greater knowledge to farmers improves confidence in their own ability to implement water protection measures. Such knowledge transfer can include farmer-led knowledge exchange platforms that have a specific focus on this practice (Blackstock *et al.*, 2010).

7.3.6 Incentivising the use of alternative water supplies could be considered in future revisions of the Common Agricultural Policy

A number of farmers highlighted that fencing was not feasible because the animals needed access to the watercourse. Alternative sources of water supply, such as the provision of mains water (where available) or solar/nose pumps in more extensive areas, and avenues to incentivise their implementation should be explored. Current GLAS incentives for cattle exclusion measures are likely to be insufficient to cover the costs of land removed from production, fencing costs and costs of providing an alternative water supply (Madden *et al.*, 2019).

7.3.7 Regulatory approaches to cattle exclusion may be more successful than voluntary approaches

If farmers believe that the adoption of a measure such as the fencing off of watercourses is going to be costly in terms of time, money and hassle, they are less likely to adopt such a measure voluntarily. In this case, it is probable that a regulatory approach (coupled with incentives) will be more successful, particularly in light of the significant influence of policy compliance on adoption.

7.4 Gaps in Knowledge and Future Research

- The COSAINT project highlights that fencing (short-term and long-term fencing) can help improve a number of water quality parameters. However, additional, more frequent monitoring of short-term and long-term cattle exclusion sites, across a broader range of geographies and farming intensities, would be beneficial to further characterising changes in in-stream biotic and abiotic parameters following such mitigation measures.

- There were some limitations in relation to the replication of sampling in the pre- and post-fencing studies (for sediment, macroinvertebrates and *E. coli*). Future studies should collect multiple replicates prior to fencing and after fencing at control and pressure points.
- Results from the COSAINT study indicate that there was no cumulative impact of multiple cattle access points on a variety of in-stream environmental parameters. However, this study focused on the cumulative impact of a small number of cattle access points in watercourses of moderate water quality. Assessing the cumulative impact of multiple cattle access points in sensitive watercourses or high-status watercourses was beyond the scope of the COSAINT study and is thus a potential area for future research.
- There are additional gaps in knowledge that were beyond the scope of the COSAINT study and these include stocking rate/usage at cattle access points, breed of animal, density of cattle access point per length of watercourse, type of access point and flow conditions in the stream.
- A limitation of this study was that there were no available data on the extent to which farm watercourses were already fenced off or where existing fencing needed to be replaced.
- Targeting fencing based on agricultural intensity is effective in relation to the removal of faecal material from watercourses; however, the "prevention of faecal matter from entering a stream" metric is only one isolated metric. There are undoubtedly other metrics of effectiveness that could be explored in future research, either in isolation or in combination. The multiple other metrics relate to not only water quality but also biodiversity and carbon sequestration (e.g. as stated in previous sections, targeted fencing and the establishment and appropriate management of riparian margins can have multiple effects and provide a variety of ecosystem services).
- The impact of faecal matter on water quality is highly variable. Here, we provided information in relation to the reduction of faecal material entering a watercourse. The study does not take into account any details in relation to the receiving watercourse (bio-physical, hydrology, status). The environmental parameters relating to the watercourse will undoubtedly influence the level of impact of faecal matter on water quality parameters; again, this is an area that could be explored through additional research.
- Elements of the socio-economic study rely on self-reported behaviour, which tends to result in respondents answering questions in a "socially desirable" way (Floress *et al*., 2018).
- The socio-economic study examines intentions rather than actual adoption levels. Previous studies have shown that intentions have a strong direct effect on future behaviour (Bamberg, 2003); however, a future study could examine whether or not farmers actually acted on their intentions.
- The results highlight that elevated sediment is a key stressor and emphasise the need to develop thresholds for deposited sediment. Such thresholds need to be realistic and reflective of natural variability in sediment delivery to watercourses due to factors such as geology, soil type and climate.

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Abbreviations

BK	Bracken River
BW	Munster Blackwater
CAS	Cattle access site
CM	Commons River
C:N	Carbon-to-nitrogen
COSAINT	Cattle exclusion from watercourses: environmental and socio-economic implications
DAFM	Department of Agriculture, Food and the Marine
DG	Douglas River
DGA	Douglas River site A
DGB	Douglas River site B
DO	Dissolved oxygen
DS	Downstream site
EPA	Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera and Trichoptera
FSSR	Fine sediment sensitivity rating
GIS	Geographic information system
GLAS	Green Low Carbon Agri-Environment Scheme
INT	Interface site
LPIS	Land Parcel Identification System
LU	Livestock unit
MT	Milltown Lake
NAP	Nitrates Action Programme
ND	Nitrates Directive
OC	Organic carbon
OM	Organic matter
OSi	Ordinance Survey Ireland
RHI	River Habitat Index
SRP	Soluble reactive phosphorus
TN	Total nitrogen
TON	Total oxidised nitrogen
TP	Total phosphorus
TRP	Total reactive phosphorus
TSS	Total suspended solid
US	Upstream site
WFD	Water Framework Directive
WP	Work package

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL
Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: *Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú
Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:
- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha)*;
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil
- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhíriú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Uisce
- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaol
- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil *(m.sh. tuairisciú tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn
- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil
- Taighde comhshaoil a chistiú chun brúnna a shainaithint, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta
- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch
- Monatóireacht a dhéanamh ar leibhéil radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha.
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta.
- Sainseirbhísí cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas
- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol *(m.sh. Timpeall an Tí, léarscáileanna radóin)*.
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta
- Feasacht chomhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil
Tá an ghníomhaíocht á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:
- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- Oifig um Chosaint Radaíochta agus Monatóireachta Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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COSAINT: Cattle Exclusion from Watercourses: Environmental and Socio-economic Implications

epaResearch
Climate - Water - Sustainability
Identifying pressures • Informing policy • Developing solutions

Authors: Daire Ó hUallacháin, Eleanor Jennings, Patricia Antunes, Stuart Green, Paul Kilgarriff, Suzanne Linnane, Paul O'Callaghan, Matt O'Sullivan, Fiona Regan, Mary Ryan and Mary Kelly-Quinn

Identifying Pressures

The COSAINT project highlights that cattle access to watercourses can significantly impact on a number of environmental variables associated with water quality. The negative impact of cattle access to watercourses on sedimentation and bacterial parameters was particularly strong, whereas the impact on nutrient and ecological parameters was more variable and site specific. Increased sediment deposition is increasingly being identified as a key stressor in watercourses. Cattle access points resulted in significant increases in the deposition of fine bed sediment and the infiltration of sediment into stream bed habitats. Increased stream sediment acted as a reservoir for faecal bacteria and phosphorus, which persisted when cattle were removed periodically from the field, but did not persist after cattle access pressures were fully removed. Increased sediment deposition was also a dominant driver of macroinvertebrate community change, although the results here were more variable and site specific. Significant reductions in sediment-sensitive taxa were encountered downstream of cattle access points at several study sites, whereas abundances of sediment-tolerant groups increased. Near real-time monitoring also showed increases in turbidity and suspended sediment and Escherichia coli when cattle were in the stream.

Informing Policy

Fenced riparian buffer measures have been included in most European agri-environment schemes and are among the most common mitigation measures to prevent cattle access to watercourse. However, fencing and cattle exclusion alone may not be sufficient to restore the ecological condition of impacted watercourses. Future policy should consider multiple mitigation measures that interact with one another. For example, fencing to exclude cattle could be coupled with the provision of alternative water supplies and targeted riparian buffer management to yield multiple environmental benefits (including biodiversity and carbon sequestration), thereby achieving maximum environmental improvements. Such an approach could be facilitated under revisions of the Common Agricultural Policy, whereby the quantity of a mitigation measure could be incentivised under Pillar 1 payments, but the performance (linked with targeting and management) of associated measures could be incentivised under Pillar 2 payments (i.e. results-based approaches).

Developing Solutions

The COSAINT project indicates that fencing/exclusion of cattle from watercourses can help improve the quality of environmental indicators over the short and long term. It is therefore important to provide greater knowledge to farmers on the environmental impact of cattle exclusion, coupled with information on appropriate, cost-effective approaches to prevent livestock access to watercourses. Providing greater knowledge to farmers improves confidence in their own ability to undertake water protection measures, such as fencing off watercourses. Encouraging or incentivising farmers to join group learning environments can also improve the effectiveness of mitigation measures.

Future projects and schemes could also develop multiple targeted novel mitigation measures. This could take the form of treatment scenarios. The geographic information system (GIS) framework developed in the COSAINT project could be coupled with available datasets on water quality, hydrology and stocking density and these combined datasets could be used to model the likely response to different treatments (in isolation or integrated), based on the best available spatial data.

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