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The impact of cattle drinking points on aquatic macroinvertebrates in streams in south-east Ireland

D. Madden[1,2], S. Harrison[2], J.A. Finn[1], D. Ó hUallacháin[1†]

[1]Teagasc, Environment Research Centre, Johnstown Castle, Wexford, Ireland
[2]School of Biological, Earth and Environmental Sciences, Distillery Fields, North Mall, University College Cork, Cork, Ireland

Abstract

Measures that prevent cattle access to watercourses are commonly implemented through agri-environment schemes, in an effort to address the objectives of the Water Framework Directive. Despite the widespread implementation, few studies have assessed the impact of cattle access to streams on aquatic macroinvertebrates. This study assessed the local-scale impact of cattle drinking points on water quality parameters (i.e. macroinvertebrate and water chemistry metrics) on 39 intensively-managed grassland farms in the south-east of Ireland. The results indicate that sites that were more than or equal to good quality upstream of cattle drinking points, were more susceptible to cattle access impacts than sites where upstream water quality was less than good. The European Court of Auditors (2011) recommended that there should be a higher rate of EU contribution for measures with higher environmental potential, in this instance, for cattle exclusion measures targeted to sites where background quality is more than or equal to good. Appropriate efforts should thus be made to incentivise farmers in good to high status sites to adopt cattle exclusion measures.

Keywords

Agriculture • agri-environment schemes • aquatic macroinvertebrates • Water Framework Directive • water quality

Introduction

Agricultural land use accounts for approximately 40% of the land area in the European Union (EU) (European Commission, 2013), rising to approximately 70% of the land area in Ireland (Central Statistics Office, 2012). The losses of nutrients (e.g. phosphorus and nitrogen) and sediment from agricultural systems to surface and groundwater, through diffuse sources (e.g. nutrient run-off from fields following fertiliser application) and point sources (e.g. direct cattle access to streams), have been highlighted as one of the main threats to water quality in the EU (Stoate *et al*., 2009) and in Ireland (Bradley *et al*., 2015).

Unrestricted cattle access to streams can lead to a deterioration in water quality, through nutrient enrichment (Davies-Colley *et al*., 2004), faecal contamination (Bragina *et al*., 2017) and increased suspended sediment and turbidity (Lefrançois *et al*., 2007; Vidon *et al*., 2008). Cattle can also cause riparian and instream habitat degradation by trampling and eroding stream banks (Herbst *et al*., 2012) or by disturbing the streambed and resuspending stored nutrients, sediment and bacteria (Terry *et al*., 2014).

Quantifying the scale of the problem of cattle access to streams, and prescribing management measures, is challenging. It is difficult, for example, to ascertain the temporal and spatial scale of the impact of direct cattle access on watercourses (Terry *et al*., 2014). The severity of impact of cattle access on watercourses is influenced by factors such as cattle stocking density, breed, age and condition, e.g. Bond *et al*. (2014) concluded that at appropriate stocking densities, direct nutrient inputs from cattle accessing streams may have only a minor effect on stream water quality (for further reading see O'Callaghan *et al.,* 2018).

EU member states must achieve or maintain at least 'good' ecological and chemical status in all waters by 2027 (Water Framework Directive (WFD) 2000/60/EC). Agri-environment policy has been implemented in an effort to address deteriorating water quality. In Ireland, the Rural Environment Protection Scheme (REPS) permitted a maximum of one cattle drinking point (CDP) within each field for participating farmers; more recently, the Green, Low-Carbon Agri-Environment Scheme (GLAS) bovine exclusion measure did not allow any bovine access to watercourses (DAFM, 2015). The latest EU (Good Agricultural Practice for Protection of Waters) Regulations 2017 (S.I. No. 605 of 2017) excludes bovine access to watercourses on farms with a stocking rate >170 kg N/ha from 2021.

†Corresponding author: D. Ó hUallacháin
E-mail: daire.ohuallachain@teagasc.ie

Aquatic macroinvertebrates are widely used as bioindicators in stream ecosystems (e.g. WFD evaluation of ecological status of rivers) due to their abundance, diversity and range of responses to environmental stressors (Hodkinson and Jackson, 2005; Bonada *et al*., 2006; Li *et al*., 2010). Although measures that restrict cattle access to watercourses are commonly implemented in Ireland (i.e. approximately 50,000 farmers partook in the measure in REPS and up to 12,000 may be affected by the latest EU regulations (SI. 605 of 2017)), few studies have evaluated the impact of CDPs on aquatic ecology (e.g. aquatic macroinvertebrates) under Irish climatic and agricultural conditions. A recent Irish study (Conroy *et al*., 2015) reported a large variability in the response of aquatic macroinvertebrates to CDPs, with some sites even showing an increase in abundance and diversity of macroinvertebrates downstream of access points.

The objectives of this study were to assess the local-scale impact of CDPs on water quality parameters (i.e. macroinvertebrates and water chemistry metrics) and investigate whether streams with higher water quality scores are more likely to be adversely impacted by cattle access than those with lower water quality scores. It is anticipated that lessons learned from this study will help improve the targeting of future cattle exclusion measures.

Materials and methods

Study sites

The study was conducted in an intensively managed grassland region in the south-east of Ireland (Figure 1), where the average farm size (>41 ha) is amongst the largest in the country (Central Statistics Office, 2012).

The study focussed on first-order (i.e. the uppermost tributaries) and second-order streams (i.e. where two first-order streams have merged) on 39 REPS farms, where the entire stream length on the farm was fenced and cattle access to watercourses was restricted to designated, localised drinking points. All stream sites selected were as follows:

(a) less than 4.5 m wetted width,

(b) adjacent to a grazed grassland field and

(c) used as a CDP at least once in the current grazing season.

Sampling protocol

At each site, sampling was conducted upstream and downstream of the CDPs on a single occasion in late summer or autumn (July to September) of 2009. Sampling was undertaken during this period after livestock had access to

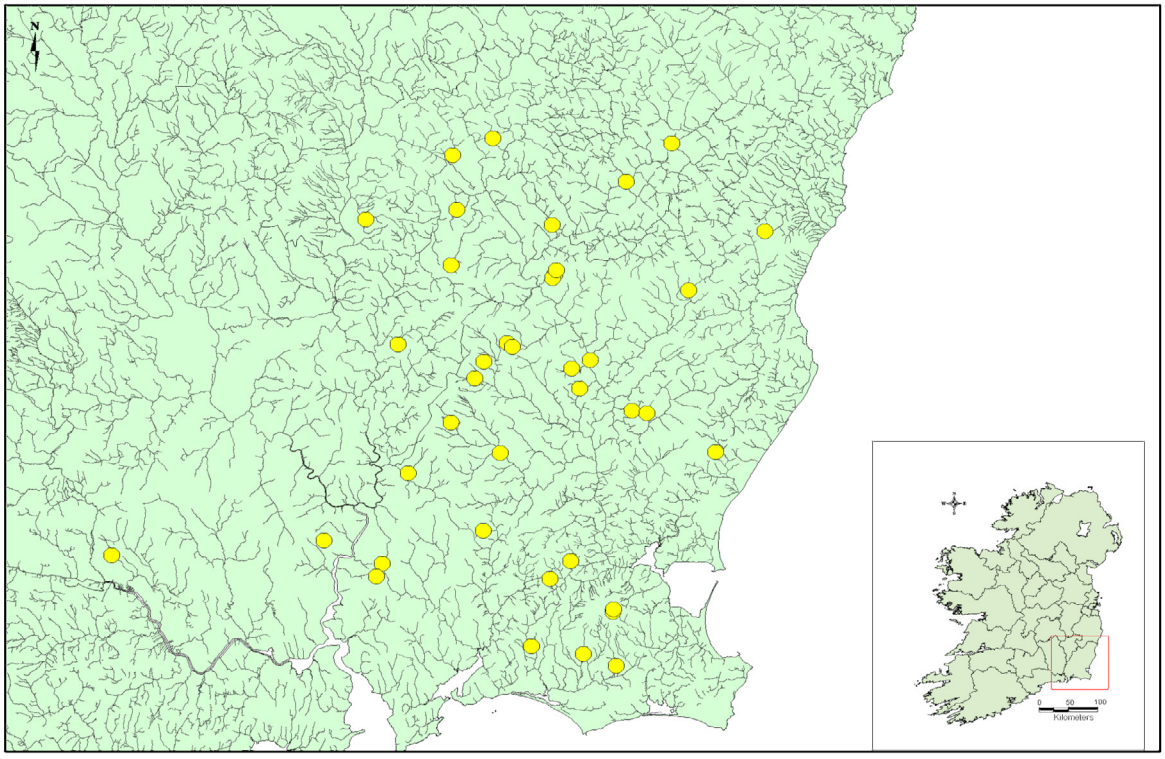

Figure 1. Map highlighting location of study sites.

the CDPs for a number of months; thus, the impact of cattle access was expected to be at its greatest.

Sampling was undertaken at the first stream riffle habitat (Rabeni and Minshall, 1977) downstream of the CDP and subsequently at the first riffle upstream (both sampling points were typically <30 m from the access point). Upstream and downstream sampling points were matched, as far as possible, with respect to channel width and depth, riverbank height, flow regime, and riparian vegetation, as these factors can potentially influence aquatic macroinvertebrate distribution (Murphy and Davy-Bowker, 2005).

Macroinvertebrates

Sampling methodology was based on an adapted version of standard techniques (Furse *et al*., 2006). At each downstream and upstream sampling point, macroinvertebrates were sampled via one three-minute kick sample, using a standard pond net (1 mm mesh). Samples were preserved *in situ* in 70% ethanol. In the laboratory, individuals were counted and identified to the family level using Freshwater Biological Association keys. Rare taxa (i.e. those occurring in <5% of samples or with <0.1% abundance) were removed (McCune and Grace, 2002). Macroinvertebrate data were used to calculate ecological metrics, namely, Biological Monitoring Working Party (BMWP) scores (Hawkes, 1998) and Ephemeroptera, Plecoptera and Trichoptera percentage.

Water chemistry parameters

Water chemistry grab samples were collected to quantify the water chemistry at the time of sampling. A more in-depth quantitative assessment of water chemistry would require higher frequency temporal sampling of sites and was beyond the scope of this study. Sampling of water chemistry parameters was undertaken at sites prior to macroinvertebrate sampling. *In situ* measurements of water temperature, conductivity, pH, redox potential and dissolved oxygen (DO) were collected using Wissenschaftlich-Technische-Werkstatten (WTW) automatic instream probes (Xylem Inc.). Grab samples for inorganic nutrients analysis were collected from the water column using clean polyethylene containers. Samples were chilled to 1–4°C in the dark and transported to the laboratory within 24 hours. All samples were sent to the water laboratory at Teagasc Environment Research Centre, Wexford, for analysis within 24 hours of sampling. Samples were analysed for total phosphorus, molybdate reactive phosphorus, ammonia, total nitrogen, total organic nitrogen, nitrate, calcium, chloride, sodium, potassium, magnesium and sodium according to standard methods. Bed sediment samples were collected, returned to the laboratory, air-dried and sieved to 2 mm. The percentage of organic matter was calculated by the loss on the ignition method (APHA, 1995).

Data analysis

All data were checked for normality using the Shapiro–Wilk test with PROC UNIVARIATE in SAS (SAS 9.3.1; SAS Institute Inc., Cary, NC, USA). Macroinvertebrate and water chemistry variables upstream and downstream of CDPs were compared with a combination of paired *t*-tests (normal distribution) and Wilcoxon rank-sum tests (non-normal distribution) using PROC UNIVARIATE in SAS.

Macroinvertebrate assemblages were analysed by performing an ordination of the data with non-metric multidimensional scaling (nMDS) using PRIMER 7 software. Ordination of data in nMDS is a method of visually assessing the similarity between individual points within a dataset. SIMPER analysis in PRIMER 7 was used to analyse similarity of macroinvertebrate assemblages (Van Sickle, 1997). This analysis gives the overall mean similarity between all pairs of sites both within a group and between groups. The difference between the two is a measure of classification strength (Van Sickle and Hughes, 2000).

In a *post hoc* analysis, the value of upstream ecological metrics and the difference between upstream and downstream values were correlated. No correlation would suggest that higher upstream values are not associated with larger differences in values between pairs of upstream and downstream sites; conversely, a negative correlation indicates that the higher the upstream value, the greater the difference between upstream and downstream values, suggesting an effect of CDPs that is dependent on background water quality.

Results

The BMWP scores indicated that 41% of upstream sites had good or very good quality, 38.5% had moderate water quality and the remaining 20.5% were deemed to have poor quality (Table 1). Comparisons (ecological and community metrics) between sites upstream and downstream of cattle access indicated that there were no significant differences in any of the ecological (Table 2) or community metrics (P (perm) = 0.182); Figure 2).

Although differences in ecological metrics between upstream and downstream sites were not apparent when the entire dataset was analysed (Table 2), *post hoc* analysis revealed that where upstream water quality (based on BMWP) was deemed to be more than or equal to good, the impact of the CDPs was significant ($P < 0.05$). 56% of sites with good water quality upstream, declined to less than good quality downstream of CDP. This trend was not apparent for sites that were moderate upstream sites, i.e. no moderate upstream site declined in status downstream of the CDPs (Table 1).

Post hoc analysis of the data also indicated that there was a significant inverse correlation between upstream

Table 1. Upstream water quality status (BMWP score) and change in status between upstream and downstream sites, where '=' signifies no change in status, '-ve' signifies a decrease in downstream status and '+ve' signifies an increase in downstream status. BMWP categories are given in parenthesis

BMWP category (score)	Upstream status	Downstream change in status		
		No change	-ve	+ve
Very good (>101)	1	0	1	0
Good (71–100)	15	6	8	1
Moderate (41–70)	15	10	0	5
Poor (10–40)	8	6	0	2
Very poor (<10)	0	0	0	0

BMWP = Biological Monitoring Working Party.

Table 2. A univariate comparison of ecological metrics between paired sites (n = 39) upstream and downstream of CDPs

	Upstream	Downstream	P-value
Taxon abundance	406.385 ± 453.650	440.000 ± 392.694	0.306
Taxon richness	14.103 ± 4.352	14.846 ± 4.088	0.315
% EPT abundance	24.421 ± 20.242	20.843 ± 16.327	0.282
% EPT richness	35.186 ± 11.874	35.519 ± 12.194	0.887
E abundance	61.872 ± 20.242	51.821 ± 86.930	0.873
BMWP	62.641 ± 132.169	64.308 ± 18.404	0.549

% EPT = Ephemeroptera, Plecoptera and Trichoptera percentage; E = Ephemeroptera; BMWP = Biological Monitoring Working Party; CDPs = cattle drinking points.

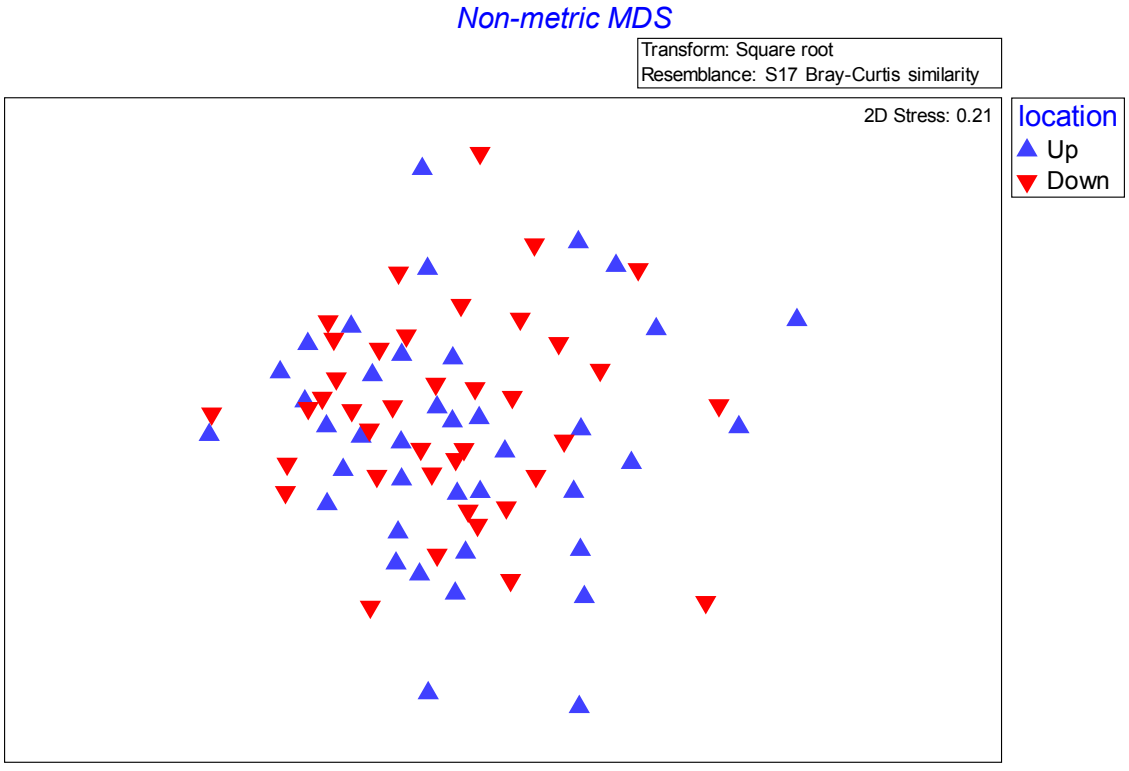

Figure 2. nMDS plot for upstream sites (triangle) and downstream sites (inverted triangle) based on ecological community abundance data. nMDS = non-metric multidimensional scaling.

ecological metric and the difference between upstream and downstream metrics (e.g. the higher the BMWP upstream, the greater the reduction in BMWP downstream of the CDPs). This pattern was true for five of the six ecological metrics assessed (Table 3).

Table 3. Correlation (Pearson correlation coefficient) between upstream ecological metric and change in score between upstream and downstream sampling points

	Correlation	P-value
Taxon abundance	-0.595	**<0.001**
Taxon richness	-0.541	0.315
% EPT abundance	-0.601	**<0.001**
% EPT richness	-0.499	**<0.01**
E abundance	-0.772	**<0.001**
BMWP	-0.625	**<0.001**

% EPT = Ephemeroptera, Plecoptera and Trichoptera percentage; E = Ephemeroptera; BMWP = Biological Monitoring Working Party.

Values in bold indicate significance at $P < 0.05$

The majority of water chemistry parameters showed no significant differences between paired sites upstream and downstream of CDPs (Table 4). Only calcium and potassium had significantly different concentrations between sites, in both cases being higher downstream of the CDPs. DO was significantly lower at downstream sites; however, DO saturation was consistently above 80% for all sites, indicating good DO condition. There were no significant differences in relation to total sediment or the percentage of organic matter of sediment between upstream and downstream sites.

Discussion

The present study found variability in the response of aquatic macroinvertebrates to cattle access to streams. These results are in line with previous national and international studies, which have reported results ranging from variable results (Conroy *et al.*, 2015), to negative impacts (Harrison

Table 4. A comparison of water chemistry parameters between 39 paired sites up and downstream of CDPs (mean ± standard deviation). *P*-values are calculated from paired *t*-test (normal data) and Wilcoxon signed-rank test (non-normal data). Values in bold indicate significance at $P < 0.05$

	Upstream	Downstream	P-value
Water chemistry			
TP	0.041 ± 0.047	0.048 ± 0.063	0.723
MRP	0.024 ± 0.027	0.023 ± 0.029	0.850
NH_4	0.037 ± 0.048	0.044 ± 0.067	0.980
TN	4.947 ± 3.502	5.009 ± 3.442	0.116
TON	4.158 ± 3.376	4.106 ± 3.361	0.425
NO_3	0.012 ± 0.020	0.012 ± 0.021	0.917
Ca	27.912 ± 25.821	29.069 ± 26.083	**<0.05**
Cl	19.335 ± 5.827	19.332 ± 5.482	0.994
Na	10.262 ± 3.293	10.753 ± 2.982	0.131
K	1.872 ± 1.449	2.069 ± 1.482	**<0.05**
Mg	7.644 ± 3.377	7.778 ± 3.108	0.763
Other water parameters			
Conductivity	273.395 ± 165.395	284.379 ± 184.707	0.205
pH	7.091 ± 0.450	7.146 ± 0.431	0.414
Redox potential	151.469 ± 52.730	156.421 ± 62.040	0.205
DO	87.213 ± 3.751	86.813 ± 4.100	**<0.05**
Sediment			
Total sediment	689.201 ± 612.328	670.012 ± 615.753	0.583
% organic matter	3.673 ± 2.640	3.797 ± 2.275	0.342

Ca = calcium; CDPs = cattle drinking points; Cl = chloride; DO = dissolved oxygen; K = potassium; Mg = magnesium; MRP = molybdate reactive phosphorus; Na = sodium; NH_4 = ammonia, NO_3 = nitrate; TON = total organic nitrogen; TN = total nitrogen; TP = total phosphorus.

Values in bold indicate significance at $P < 0.05$

and Harris, 2002), no significant impact (Ranganath *et al*., 2009; Herbst *et al*., 2012) and a positive impact of cattle access to streams on the abundance and diversity of some semi-aquatic riparian macroinvertebrates (Drake, 1995). It is difficult to draw generalisations from instream and riparian studies due to the multiple stressors (e.g. phosphorus, nitrogen, sediment) involved and the inherent variability in characteristics found between and within catchments (Belsky *et al.,* 1999). Variables such as climate, landscape factors, biophysical characteristics of the stream and land management practices (including stocking rate) all play a role in influencing the impact of cattle access on water parameters, including macroinvertebrates (O'Callaghan *et al*., 2018).

Despite variability in results, measures that prevent cattle access to watercourses are commonly implemented through agri-environment schemes (AESs). The European Court of Auditors (2011) has recommended that AES payments should be targeted to sites with the greatest environmental potential. The results in this study indicate that sites that were more than or equal to good quality upstream of CDPs were more susceptible to cattle access impacts than sites where upstream water quality was less than good (Figure 3). Thus, cattle exclusion measures targeted to these sites are likely to achieve the greatest environmental benefit. GLAS policy addresses this by targeting cattle exclusion measures to high-status waterbodies, i.e. farmers with high-status waterbodies are afforded priority entry into the scheme and must select the cattle exclusion measure.

However, nationally, high-status water sites frequently coincide with designated Special Areas of Conservation or Special Protection Areas (i.e. Natura 2000 sites). Farmers with Natura 2000 sites are also afforded priority entry to GLAS and can select the Natura 2000 measure (which does not necessarily include management in relation to cattle access to watercourses). Thus, the anomaly may arise that a farmer with land that is a designated Natura 2000 site, e.g. for the protection of freshwater pearl mussel (a species that is highly susceptible to excessive sediment and nutrients), does not have to select the cattle exclusion measure or any water quality measure, thereby failing to maximise the potential impact of current targeting.

There are practical reasons why a farmer with a choice of agri-environment measures may not select cattle exclusion measures. Facilitating animal access to watercourses allows farmers a cheap, low-maintenance source of water for their livestock. Current GLAS incentives are likely be insufficient to cover the costs of land removed from production, fencing costs, and costs of provision of an alternative water supply (e.g. piped water or nose pump). When presented with a range of options, farmers in high-status sites may select less restrictive and/or more financially rewarding measures to ensure entry into GLAS rather than a less financially rewarding measure such as cattle exclusion.

The European Court of Auditors (2011) recommended that there should be clear distinction between simple and more demanding AE measures, with a higher rate of EU contribution for measures with a higher environmental potential. Thus, it would seem prudent that if farmers are not selecting cattle exclusion measures in high-status sites, where such measures are more likely to have a positive environmental impact, efforts should be made to encourage and incentivise their selection.

Conversely, it is likely that a large proportion of farmers who select cattle exclusion measures are located on waterbodies

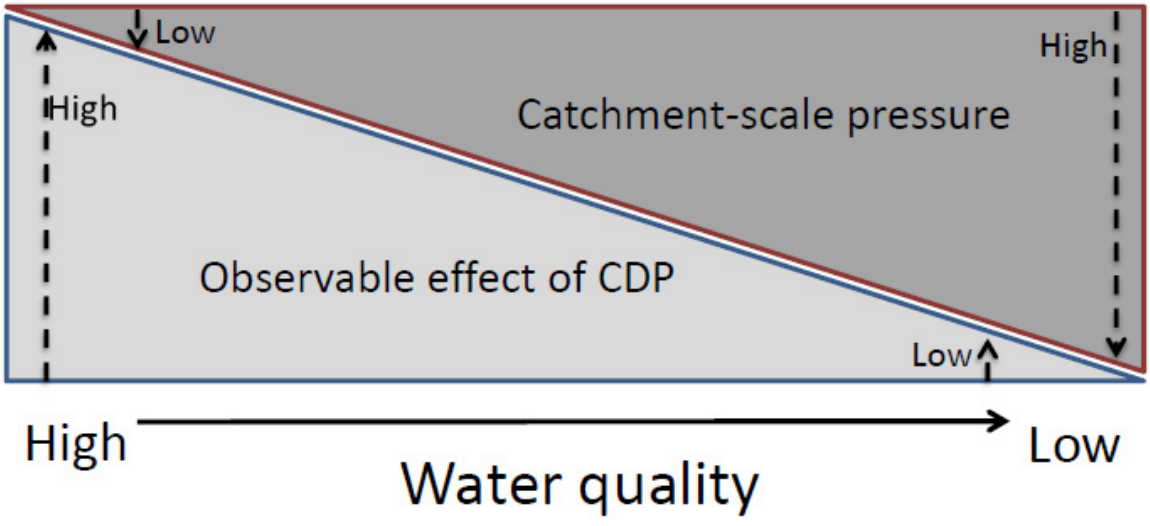

Figure 3. Conceptualisation of the impact of CDPs on water quality relative to background catchment-scale pressure. The length of arrow indicates degree of impact. CDP = cattle drinking points.

where upstream sites are of less than good quality. Conroy *et al*. (2015) stated that the reduction of cattle access at such less than good quality sites may help sites to achieve good status. However, alternatively, presence of a CDP may not result in further apparent deterioration in water quality status (Figure 3), i.e. Ranganath *et al.* (2009) indicated that in-stream ecology is impacted more by background catchment-scale conditions than by localised, reach-scale issues such as cattle access. Where nutrients and other inputs enter streams through mechanisms other than direct cattle access (e.g. diffuse nutrient inputs from agriculture or multiple domestic point source inputs), localised cattle exclusion measures may not be the most cost-effective measure to achieve initial improvements in water quality status.

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