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Too Many Cows?

An exploration of relationships between livestock density and river water quality in Aotearoa New Zealand

Abstract

Intensive cattle farming is a major driver of freshwater pollution in Aotearoa New Zealand, yet research on the link between cattle intensity and river water quality is limited. This exploratory study investigated relationships between livestock intensity and freshwater indicators – nitrates and macroinvertebrates. We found that higher dairy stocking rates and total cattle numbers are linked to increased nitrate pollution at regional and district levels, with no significant correlations for beef cattle or MCI (macroinvertebrate community index) scores. Our findings underscore an urgent need for further research, particularly at the catchment level, to inform farm management plans and freshwater policy.

Keywords livestock density, river quality, nitrates, macroinvertebrates, input controls

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Over the last 30 years, the health of freshwater environments in Aotearoa New Zealand has significantly declined (Canning and Death, 2021; Julian et al., 2017). The primary contributor to this decline has been the expansion of the agriculture industry, with the cattle population nationwide increasing from 3.4 to 6.3 million since 1990 (Ministry for the Environment and Statistics New Zealand, 2020; Pangborn and Woodford, 2011; Statistics New Zealand, 2021b). Consequently, ecosystem health has been substantially impacted, with over 85% of rivers in pasture catchments degraded by excess nutrients and pathogens (Joy and Canning, 2021; Joy et al., 2022; Statistics New Zealand, 2022). Public pressure to address freshwater pollution has been high, with surveys indicating that for a period of time it was among the top concerns of New Zealanders (Booth et al., 2022; Ministry for the Environment, 2018; Statistics New Zealand, 2019). Additionally, over 80% of New Zealanders wanted the government to do more to prevent freshwater pollution (Cosgrove, 2019).

Table 1: Factors impacting freshwater quality

Factor	Example
Contamination from livestock	Excess nutrients and pathogens from cattle waste (e.g., nitrate leached from soils supplied by urine. Phosphate bound to soils and pathogens enter rivers via surface runoff from excrement).
Contamination from sedimentation	Removal of riparian vegetation, direct stock access to water, and erosive processes in upper catchments.
Contamination from other sources	Industrial discharges and septic tanks.
Fertiliser application	Increased application supports higher livestock intensity, leading to more nitrate leaching and phosphate runoff from cattle waste.
Soil characteristics	Greater nitrate losses in light free draining soils versus heavier textured and poorly drained soils.
Lag times	Lag times vary and may be more than 50 years depending on lithology, location, elevation, and groundwater flows.
Topology and catchment hydrology	Animals spend more time on flatter land so the proportion of urine deposited on low slopes is greater than on sloping landscapes. Sloping landscapes tend to have higher rates of sediment runoff.
Plant life	Amount, type, and arrangement of plant life in catchment and along waterway.
Climate	Temperature and rainfall (amount and intensity) can lead to variations in the flow and leaching rates, alongside the occurrence of eutrophication.

At present, the agriculture industry does not shoulder the environmental costs of its activities. For instance, assuming a cost of $400 to prevent one kilogram of nitrate from entering a waterway, and with 200 million kilograms of nitrate leached from agriculture into lakes, rivers and groundwater in 2017, the annual negative externalities related to freshwater are estimated at $79 billion (Foote, Joy and Death, 2015; Joy, Marriott and Chapple, 2022a). The environment bears the primary costs, but the wider public faces economic burdens from environmental remediation and the loss of ecological and cultural values, all of which will have a heavy impact on future generations.

In response to public concerns, different policy mechanisms have been considered to tackle freshwater pollution. To date, policy has largely focused on output controls which regulate the amount of pollution a system produces, such as through limits on nitrogen and phosphorus loading or point source discharges. This has been the primary mechanism of pollution management under the Resource Management Act 1991 (RMA), which focuses heavily on managing the effects of activities rather than the activities themselves (Environment Foundation, 2018). However, other policy mechanisms are available, including input controls (regulating what enters the system, such as the amount of fertiliser used) and land use controls (controlling what activities can happen where). Currently, the National Policy Statement for Freshwater Management 2020 (NPS-FM), guided by the Māori concept of ‘te mana o te wai’ to ensure that the health and wellbeing of water is put first, directs freshwater management by regional councils. Within the NPS-FM, input and land use controls are referred to as ‘limits on resource use’ (Ministry for the Environment, 2024, p.19). These controls are two types of limits that could be used to manage activities under the NPS-FM framework.

One mechanism for implementing an input control is a limit on stocking rates. Previous guidance from the Ministry for the Environment suggested that introducing a stocking rate limit may be appropriate across a catchment or on specific soil types at certain times of the year (Ministry for the Environment, 2023). In line with this guidance, Otago Regional Council proposed a 2.5 cow/ha stocking rate limit in the Manuherekia rohe (area) in its draft land and water regional plan (Otago Regional Council, n.d.), while Greater Wellington Regional Council proposed 12 stocking units (~1.4–3.4 cows, depending on the type) per hectare for small farms (4–20 ha) in planned changes to its natural resources plan (Greater Wellington – Te Pane Matua Taiao, 2023). Activities above these thresholds would require either a resource consent (Otago Regional Council, n.d.) or certain standards to be met to operate as a permitted activity (Greater Wellington – Te Pane Matua Taiao, 2023). It is unclear how each council decided on these stocking rate limits, as the calculations and explanations are not provided in public documents or on council websites.

The NPS-FM requires councils to use the ‘best information available’ when setting limits for output, input or land use controls (Ministry for the Environment, 2023, p.29). Ministry guidance states that ‘the first time limits … are set, they may be based on very general estimates and assumptions that methods will be a move in the right direction toward [targets]’, and ‘when more information becomes available from monitoring, councils can adjust their limits’ (ibid., p.84). In the context of setting limits on stocking rates, councils would ideally use data on (past and existing) stocking rates across their regions, districts and catchments (or even sub-catchments). They would then assess these stocking rates against water quality indicators across the same periods, preferably incorporating other factors that influence freshwater outcomes, such as fertiliser application, lag times for nutrient leaching, and slope variation (see Table 1). However, significant data limitations exist in some of these areas (discussed in the methods section below), and there has been limited research on the associations between these factors and outcomes. This makes setting such limits under the NPS-FM direction challenging.

Our research aims to provide an initial exploration of relationships between cattle density and two freshwater indicators for rivers – nitrates and macroinvertebrates – at regional and district scales. We recognise that research into the complex interactions of factors other than livestock density is also limited. While this article does not cover all factors affecting freshwater quality and their interactions, our analysis is an important first step in understanding the relationships between cattle intensity and freshwater quality. It also highlights several limitations, including data availability, that must be addressed for future research and effective policy development in this area.

Methods

Spearman's correlation coefficient was used to examine the strength and direction of relationships between cattle intensity and two water quality indicators: nitrates and the macroinvertebrate community index (MCI). This method was chosen because it is suitable for small, non-normally distributed samples, and does not rely on the assumptions of a parametric test (Field, 2017). All statistical analyses were conducted in IBM SPSS Statistics for Mac, version 29.

The country's 16 regions and all 61 districts (where possible) were included in the analysis. For the regional analysis, the Chatham Islands were excluded due to the lack of data for cattle intensity and freshwater indicators. Additionally, the Nelson and Tasman regions were combined because Nelson is relatively small (422km^2) and the two regions are commonly combined for other purposes, such as emergency management and tourism.

While a finer-scale analysis was desirable, it was not possible due to data limitations. Despite multiple Official Information Act (OIA) requests sent to various agencies, access to catchment-level and farm-level cattle density datasets could not be obtained. Requests were also made for nitrogen fertiliser use on dairy farms, as reported under the national environmental standards for freshwater, as well as for farm intensity data across catchments from farm plans held by Environment Canterbury. These OIA requests were declined due to fragmented datasets, lack of data recorded by councils, and the refusal to provide data on the grounds that it would need to be 'created' (Williams, 2023; M. Prickett, personal communication).[1]

Data sources

Cattle stocking rates at the regional level were calculated using farm livestock and land use data from the agricultural production survey conducted by Statistics New Zealand and the Ministry for Primary Industries (Statistics New Zealand, 2021a, 2021b). The latest census of all farms was used (52,300 farms in 2017). Cattle stocking rates were separately calculated for dairy cattle and beef cattle, as well as for dairy and beef cattle combined. Stocking rates were calculated by dividing the total number of cattle by the total land area under that land use – for example:

$$\frac{1{,}308{,}058 \textit{ dairy cattle}}{359{,}081 \textit{ hectares of land used for dairy farming}} = 3.6$$

As Statistics New Zealand does not hold livestock data at the district level, data for cattle stocking rates from the *New Zealand Dairy Statistics 2020–21* report was used (DairyNZ and Livestock Improvement Corporation Limited, 2021). This limited the district level analysis to dairy cows only.

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Nitrates were chosen as an indicator of freshwater pollution, as elevated nitrate levels promote rapid algal growth, leading to eutrophication (Canning and Death, 2021; Joy et al., 2022; Snelder et al., 2020). Two nitrate indicators were included: nitrate-nitrogen (NO_3-N) and total nitrogen (TN). NO_3-N represents the proportion of nitrogen in the form of the nitrate ion, which typically enters rivers through leaching, primarily from cattle urine (Land, Air, Water Aotearoa, 2023a). In contrast, TN includes the sum of NO_3-N, nitrite nitrogen, ammoniacal nitrogen and organic nitrogen (Ausseil et al., 2024). Although TN and NO_3-N are different forms of nitrogen, the values are similar in most rivers in the absence of point source discharges. When ammoniacal nitrogen is present, it is usually from point source discharges since it is highly immobile in soils (Land, Air, Water Aotearoa, 2023a); then measurement of TN and NO_3-N can differ.

While the National Policy Statement for Freshwater Management gives councils the flexibility to choose which form of nitrogen they wish to manage, Table 6 (Appendix 2A) of the statement specifies the measurement of NO_3-N. However, data for NO_3-N is not available through the LAWA (Land, Air, Water Aotearoa) database for all regions and districts (and thus individualised data requests to specific councils would have been required). TN data, on the other hand, was accessible for all regions and districts. Therefore, both NO_3-N and TN data was included in this analysis. As LAWA river water quality datasets do not include district assignments for sites, they were manually assigned using Local Government New Zealand maps.

For both NO_3-N and TN, median values and the percentage of samples over 1 mg/L were calculated for the period 2017–21. A 1 mg/L threshold was used to align with the dissolved inorganic nitrogen (DIN) limit recommended by the Science Technical Advisory Group (Science Technical Advisory Group, 2019; 2020). While DIN, NO_3-N and TN are all different measures, a maximum limit of 1 mg/L is generally accepted as an optimal limit for ecosystem and human health (Australian and New Zealand Governments, 2000; Death, 2020; Joy and Canning, 2021; Richards et al., 2022; Science Technical Advisory Group, 2020; Schullehner et al., 2018). This is because, at levels above 1 mg/L, waterway health declines, and eutrophication (algal bloom) sets in if other factors also favour eutrophication (Koolen-Bourke and Peart, 2022; Science

Table 2: Degree of correlation

Weak -	Very weak -	Very weak +	Weak +	Moderate +	Strong +
-0.20 to -0.39	-0.19 to -0.01	0.00 to 0.19	0.20 to 0.39	0.40 to 0.59	0.60 to 0.79

Table 3: Correlations between different measures of cattle intensity and nitrates (NO3-N and TN)

	Median NO3-N	% NO3-N samples >1 mg/L	Median TN	% TN samples >1 mg/L
Dairy SR	0.553*	0.665*	0.536*	0.750**
Beef SR	0.127	0.126	0.464	0.354
Dairy & Beef SR	0.696**	0.753**	0.642**	0.789**
Total cattle head (dairy and beef)	0.360	0.379	0.586*	0.682**

* = correlation significant at 0.05 ** correlation significant at 0.01
SR = stocking rate, NO3-N = nitrate nitrogen, TN = total nitrogen

Table 4: Correlations between MCI and different measures of cattle intensity

	% MCI samples < 90
Dairy SR	-0.121
Beef SR	-0.232
Dairy & Beef SR	-0.232
Total head cattle (dairy & beef)	0.032

MCI = macroinvertebrate community index.

Technical Advisory Group, 2020). Furthermore, levels above 1 mg/L in drinking water have been associated with an increased risk of colorectal cancer (Schullehner et al., 2018). This threshold is higher than the 0.44 mg/L trigger level of NO_3-N recommended by the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC and ARMCANZ, 2000; ANZECC, 2018), but lower than the national bottom line of 2.4 mg/L of NO_3-N set in the NPS-FM. The NPS-FM limit was not used in this study, as it has been heavily criticised by freshwater scientists for being irrelevant and inappropriate outside laboratory conditions. This is because it is the level at which nitrate would directly kill fish if they had not already died from lack of oxygen (Death et al., as cited in Science Media Centre, 2013; Joy and Canning, 2021).

For the regional-level analysis, we also examined relationships between stock intensity and the MCI. The MCI was chosen as another indicator of ecosystem health because macroinvertebrates are relatively sedentary and long-lived, and respond to multiple stressors or changes in their habitat (Clapcott et al., 2017). We used the percentage of MCI samples with scores lower than 90, as scores below this are indicative of severe organic pollution or nutrient enrichment. It is important to note that there are limitations to using the MCI in these sorts of analyses, as there is no standardised sampling regime and different councils use different methodologies, and therefore the quality of data can vary (Canning and Death, 2023). The data for this analysis was accessed through the LAWA database (Land, Air, Water Aotearoa, 2023b, 2023c, 2023d, 2023e: see 'Supplementary files 1 – datasets used').

Results

Regional-level relationships

Correlations were examined for stocking rates and freshwater quality indicators. The degree of correlation (Table 2) was interpreted and recorded following the procedures outlined in Field (2017). A range of moderate to strong positive correlations were observed between dairy stocking rates, beef and dairy stocking rates, total cattle head and both NO_3-N and TN (Table 3). This indicates that increased dairy cattle stocking rates, combined dairy and beef cattle stocking rates, and the total number of dairy and beef cattle are associated with increased nitrate pollution in rivers at the regional level.

There were no statistically significant correlations between beef stocking rates and NO_3-N, or between beef stocking rates and TN (Table 3). There were also no statistically significant correlations between MCI scores and NO_3-N or TN (Table 4).

District-level relationships

There are moderate positive correlations between the percentage of NO_3-N samples greater than 1 mg/L and both dairy cattle stocking rates and total head of dairy cattle (Table 5). All other correlations are weak positive. These findings indicate that an increase in both dairy stocking rates and total head of dairy cattle is associated with an increase in nitrate pollution in rivers at the district level.

Discussion

The aim of this study was to assess relationships between cattle density and two freshwater indicators (nitrates and macroinvertebrates) at regional- and district-level scales. The research is exploratory in nature, but provides an initial step for assessing appropriate stocking rates to protect ecosystem health, which may assist regional councils in considering and setting appropriate limits on resource use. Our findings highlight the urgent need for further research in this area to guide potential policy on implementing limits on stock intensity.

At the regional level, we found strong positive correlations between dairy cattle stocking rates and nitrate levels, as well as between beef and dairy stocking rates and nitrate levels. Additionally, there were strong positive correlations between total head of cattle and TN. What is particularly interesting is there were no statistically significant correlations between beef

Table 5: Correlations between dairy cattle stocking rates, total head of dairy cattle and nitrates (NO3-N and TN)

	Median NO3-N	% NO3-N samples >1 mg/L	Median TN	% TN samples >1 mg/L
Dairy SR	0.367*	0.484**	0.211	0.311*
Total head dairy cattle	0.384**	0.457**	0.372**	0.357*

* = correlation significant at 0.05 ** correlation significant at 0.01
SR = stocking rate, NO3-N = nitrate-nitrogen, TN = total nitrogen

stocking rates and either NO_3-N or TN. This may be due to differences in cattle density, landscape, topography and fertiliser use between each farming type. Beef farms in New Zealand typically occupy hilly terrain with limited irrigation systems and fertilisation, resulting in lower stocking rates (Beef + Lamb New Zealand, 2020). In contrast, dairy farms are generally located on flat to gently rolling land with extensive irrigation and fertilisation to support higher stocking rates (Schipper et al., 2010). As a consequence, this intensive pasture management and irrigation can accelerate nitrate leaching into rivers, compromising ecosystem health (Manaaki Whenua Landcare Research, 2020; Vogeler et al., 2019). Physiological differences may also play a role, as dairy cattle typically produce more urine and waste nitrogen than beef cattle (Misselbrook et al., 2016).

The absence of statistically significant correlations between cattle intensity and macroinvertebrates in this analysis was unexpected, given the well-documented impacts of pollution on ecosystem health and a waterbody's capacity to sustain a diverse macroinvertebrate population (Wright-Stow and Wilcock, 2017). The absence of a relationship between stocking rates and macroinvertebrates likely stems from the inherent limitations of single indices like the MCI, which aggregate the response of multiple invertebrate species into a singular score. Therefore, when calculating the MCI score there is a loss of crucial information, such as the relationships between individual species and their stressors, and it may not be sensitive enough to reflect the impacts of nitrate pollution in this context. Recent research examining the link between nitrate concentrations in Aotearoa New Zealand rivers and invertebrate indices found that while the MCI score exhibits a weak correlation with nitrate levels, modelling individual invertebrate taxa reveals strong relationships (Canning and Death, 2023).

The lack of correlation between cattle intensity and macroinvertebrates may also be related to the way an individual score within the MCI record was calculated. This is because sensitivity scores have been changed since the MCI was developed. To illustrate, new tolerance scores proposed by Greenwood et al. (2015), meant that MCI scores increased by ~5 points; thus, scores previously indicative of stress are now classified as healthy (Joy and Canning, 2021). As a result, any correlation between macroinvertebrates and nitrate pollution in this study may have been obscured, as methodological choices in calculating MCI scores could misrepresent the true environmental impact. Furthermore, a smaller sample size and the selective sampling strategies employed by regional councils may also explain the absence of correlations. Responsibility for freshwater monitoring falls mostly on regional councils, each with different priorities and funding constraints. This can lead to a focus on problem areas or uneven coverage of pristine sites, rather than a balanced distribution of monitoring locations (Stevens, 2024).

Figure 1: Regional heat map of stocking rates (cows/ha) and TN pollution (using LAWA data for the five-year period 2017–21)

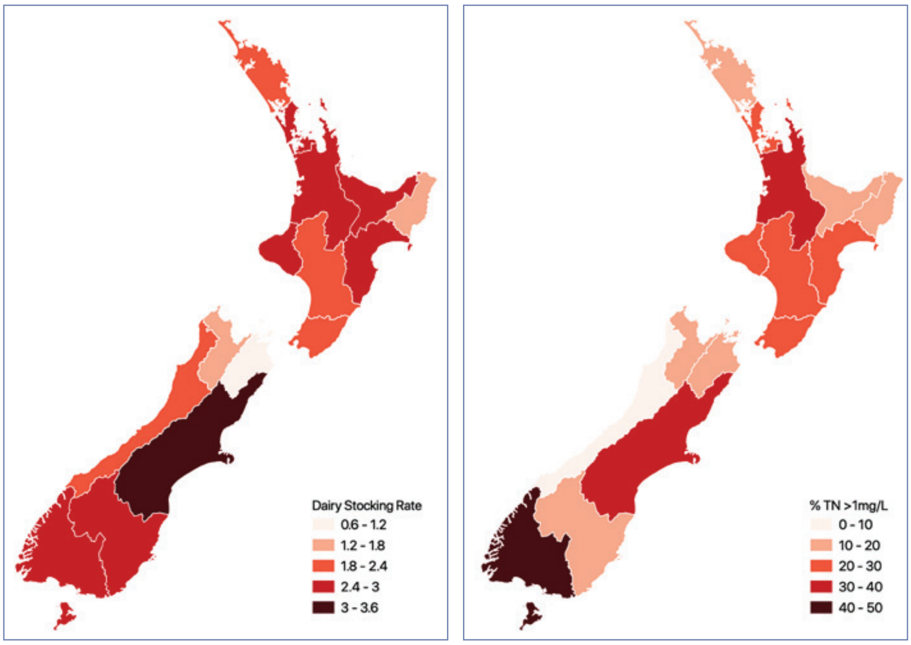

Table 6: Regions and districts with highest rates of TN pollution (using LAWA data for the 5 year time period 2017 to 2021).

District	TN % samples >1mg/L	Number of samples > 1mg/L	Total number of sites
Franklin	94.87	111	117
Hamilton City	84.35	97	115
Invercargill	76.50	179	234
Selwyn	74.55	416	558
Gore	72.79	214	294
Matamata-Piako	68.72	312	454
Carterton	61.01	169	277
Waipa	55.34	254	459
Waimate	54.29	418	770
Waikato	53.48	837	1565

Our district-level analysis was restricted to correlations between dairy cattle and nitrates, as there was no accessible data for beef cattle densities. Moderate positive correlations were found between dairy stocking rates and all measures of NO_3-N and TN. Additionally, moderate positive correlations were identified between the total head of dairy cattle and both nitrate indicators. These findings highlight a positive relationship between nitrate pollution and both dairy cattle stocking rates and the total head of cattle, and underline the value of further investigation of the potential effectiveness of stocking rate limits as input controls within a district to protect ecosystem health.

In this analysis, we have focused on the impacts of livestock density on above-ground (river) systems at the regional and district scale. Ideally, we would have also included analysis at the catchment and farm level. However, analysis at this scale was not possible because of data limitations. If data could be accessed, future research should investigate relationships between livestock density and water quality indicators at this scale. It may also be possible to determine potential stocking rate density thresholds above which water quality issues are observed. We note that data is also lacking for other important inputs that can be controlled through regulation, such as fertiliser use. For fertiliser application, where a national cap of 190 kg/ha exists, access to good-quality data could enable a reassessment of this cap and guide policy development on fertiliser caps for different catchments (Ministry for the Environment, 2021).

Future research could investigate relationships between livestock density and groundwater contamination. Another potential area of research is an investigation of time series data to better understand any trends or underlying patterns. This would be particularly important for regions and districts with significant nitrate pollution (and higher stock intensity), such as the Waikato, Canterbury and Southland regions, alongside Franklin and Carterton districts (Figure 1 and Table 6).

The association between cattle farming and fresh water is well established in science and policy, and this is why it has been a focus of this analysis. It is important to acknowledge that factors beyond livestock intensity – such as fertiliser application, soil characteristics, plant life, topology and catchment hydrology – also have an impact on freshwater quality. However, there is limited understanding of the complex interactions between these factors for different catchments across Aotearoa New Zealand and further research would be useful.

Despite multiple OIA requests being sent to various agencies for access to catchment-level datasets on cattle density, such datasets could not be obtained. This highlights a severe lack of information on farm intensity across Aotearoa New Zealand, particularly within regulator databases. Even where councils have had farm plan frameworks in place for many years, data on farming intensity could not be, or was not, provided. This also underscores the challenge for anyone beyond individual landowners or industry bodies to understand the intensity of freshwater pollution drivers in their community or catchment. The limited data available on farm intensity also represents a significant failure of the resource management system and regional council monitoring systems. It also highlights the lack of transparency from industry bodies in communicating with communities about the activities that might be polluting their local area.

While the RMA and Resource Management (Freshwater Farm Plans) Regulations 2023 require farm plans to be developed for many farms, these provisions do not mandate providing information on land use pressures (e.g., stocking rates, land cover, fertiliser use) to regional councils as part of the farm planning process. As it stands, regulators will continue to operate with limited information unless farmers are mandated through regional plans to provide their data. If councils do not require the provision of this data, they might be unable to accurately assess the effectiveness of their plans or appropriately determine or adjust any input controls or limits on resource use in the future. Without access to catchment-level or farm-level data, drawing conclusions beyond those presented in this study or determining potential per-hectare stocking area limits is challenging. However, in the absence of more detailed data, and having determined a relationship between stocking density and freshwater nitrate pollution, the question arises: should initial stocking rate limits be implemented based on general estimates using currently available data?

The current coalition government, which took office in late 2023, has stated that it is committed to improving freshwater quality for the benefit of all New Zealanders and wants to improve farm plans (McClay, Simmonds and Hoggard, 2023). Industry bodies have also stated they want to encourage the use of farm plans and improve freshwater outcomes (DairyNZ, n.d.; Fonterra, 2024). The current government has indicated that it intends to repeal and replace the National Policy Statement for Freshwater Management (New Zealand National Party and ACT New Zealand, 2023; Bishop, 2024) – an announcement which has drawn criticism from freshwater ecologists, public health experts and other specialists (Joy et al., 2023). With the repeal of key freshwater regulations, it remains uncertain how these improvements will be achieved. Despite this, the need to consider input controls, including regulating stocking rates, to address freshwater pollution in catchments remains unchanged. If government and industry's commitment to improving freshwater outcomes is genuine, farm management plans will need to be developed with limits on inputs in mind. There is an opportunity for industry to demonstrate their commitment to freshwater improvement and transparency by openly sharing farm- and catchment-level data on stock intensity. These datasets could help establish thresholds necessary to protect ecosystem health and set appropriate caps to improve freshwater outcomes, thereby reducing or avoiding remediation costs, now and in the future.

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1 See https://osf.io/qfd54/files/osfstorage, 'Supplementary file 5 – OIAs and data requests' for a summary of requests.

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