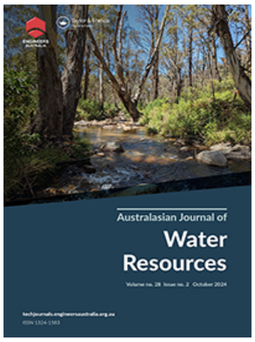

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Evaluating the impact of low intensity farming on alpine river water quality: case study from south Westland, Aotearoa New Zealand

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ABSTRACT
South Westland is a remote part of New Zealand where farming is restricted to a narrow band of coastal plains and mountain bound alluvial flats, and occurs on a mixture of freehold and conservation estate concession leases. The region has the lowest density of stock in the country and stock numbers have remained static since 1996. These communities face continued pressure from regulatory restrictions on heavy stock grazing, yet little is known about the impact that farming has on their waterways. Monitoring of the water quality of 16 large river systems in south Westland shows that nutrient concentrations are near-pristine (i.e. <0.1 mg N L^{-1}), although there is a positive correlation between increasing pastoral land uses and NNN concentrations.

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Water quality; South Westland; riparian farming; river run lease grazing; NNN

1. Introduction

Intensive pastoral land use in Aotearoa New Zealand has resulted in appreciable water quality degradation of lowland streams. New Zealand farming transitioned from principally dryland sheep grazing in the 1970s–1980s to dairy production in the mid-1990s (Scarsbrook and Melland 2015). These shifts in livestock production magnified the effects of diffuse pollutants on New Zealand river water quality, especially those associated with pastoral intensification (nitrogen, phosphorus, *E. coli*, and sedimentation indicators) (Ballantine and Davies-Colley 2014; R. J. Davies-Colley 2013; Larned et al. 2016; J. M. Quinn and Stroud 2002; J. M. Quinn et al. 2009; Snelder et al. 2022; Wilcock 1986). Most of the contaminants within streams draining pastoral land emerge from leaching and runoff as diffuse pollution, although dairy cattle shed waste may also be an important point source contaminant, or contributor to diffuse pollution when discharged to land (Collins et al. 2007; R. Davies-Colley and Nagels 2002; McDowell et al. 2011). Diffuse pollutants emerge from the cumulative effects of extended areas of catchments being intensively farmed exacerbated by the effects of artificial drainage, livestock trampling causing riverbed and bank damage, and effluent leaching into waterways (Davies-Colley et al. 2004; Wilcock 2008).

Streams in dairy-farmed catchments are significant contributors to degraded water quality relative to reference streams in native forest (e.g. R. Davies-Colley and Nagels 2002; McDowell and Wilcock 2008). Rivers draining catchments where dairying is dominant have very poor water quality, with high nutrient concentrations, faecal contaminants and low visual clarity (e.g. Wilcock et al. 1999, 2012). As such, the expansion of dairy farming and reduction in dryland sheep farming presents a major challenge for water use in New Zealand especially for preserving in-stream values and restoring damaged waterways.

A tranche of recent freshwater reforms were legislated in 2020 including an amendment of the effects-based Resource Managements Act, and the Resource Management (National Environmental Standards for Freshwater) Regulations 2020 (see: Larned et al. 2022). These empower regional land and water plans to give effect to the National Policy Statement for Freshwater Management (NPS-FM, Ministry for the Environment [MfE] 2024), alongside permitted and discretionary activities governing land use. Regional water plans must observe the national bottom limits for water quality via the National Objectives Framework (NOF) and set water quality limits (MfE 2024). The NOF are defined as four bands depending on river environment state – either A ('excellent'), B ('good'), C ('fair'), and D ('acute'). Revisions to the NPS-FM in 2020 mandated that heavy livestock be excluded from lakes and rivers (>1 m in width) on low slope land (i.e. <10°) from 1 July 2025. The stock exclusion rules specify a 3 m setback from a lake or river (>2 stream order) for cattle, pigs, and deer, but do not apply to sheep grazing (MfE 2021).

Rules prohibiting heavy stock from entering waterways ensure that banks and riverbeds are less vulnerable to collapse from trampling and damage by cattle (J. M. Quinn and Stroud 2002; Trimble and

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Mendel 1995). Bank collapse is a particular concern as it may be a source of fine-grained sediment that reduces visual clarity (R. J. Davies-Colley et al. 1992), increases water turbidity, or accumulates on riverbeds damaging benthic habitat (J. Quinn et al. 1992; Wright-Stow and Wilcock 2017). Such restrictions are reasonable measures to ensure sustainable land management and the protection of river systems in the intensively farmed agricultural heartland of New Zealand, which operate at levels of much greater stocking compared to the remote parts of the South Island/Te Waipounamu. Implementation of stock exclusion was particularly challenging in areas dependent on riparian grazing and the policy was disestablished in mid-2024 (MPI 2024).

Most farming in south Westland consists of grazing leases on Crown land (often within designated areas of the Conservation estate) within the river valleys and along areas of private freehold land close to the coast. Farming is substantially constrained in south Westland because of the small amount of flat, improved pasture, and carrying capacity limitations within the grazing leases. Being geographically remote there are no resources dedicated to monitoring water quality and little is known about the state of the river water quality in this region, and what effects pastoral agriculture has on water quality. The objective of this study is to evaluate the water quality of south Westland and to determine whether existing farming practice is having a measurable effect on river water quality.

2. Materials and methods

2.1. Study location

Bound as a narrow strip (<50 km wide) between the main divide of the Southern Alps/Ka Tiritiri o te Moana and the Tasman Sea, south Westland (defined between Jackson's Bay and Fox Glacier townships) covers 6467 km^2 of indigenous rainforest, grasslands, and herbfields (Figure 1). The climate is cool temperate and extremely wet with a mean annual rainfall near sea level of 7311 mm and > 11,000 mm on the main divide. The high rainfall affects soil drainage, so fields may be contoured as 'humps and hollows' so that stock grazing can continue in wet conditions (Figure 2c). There are 15 river catchments of stream

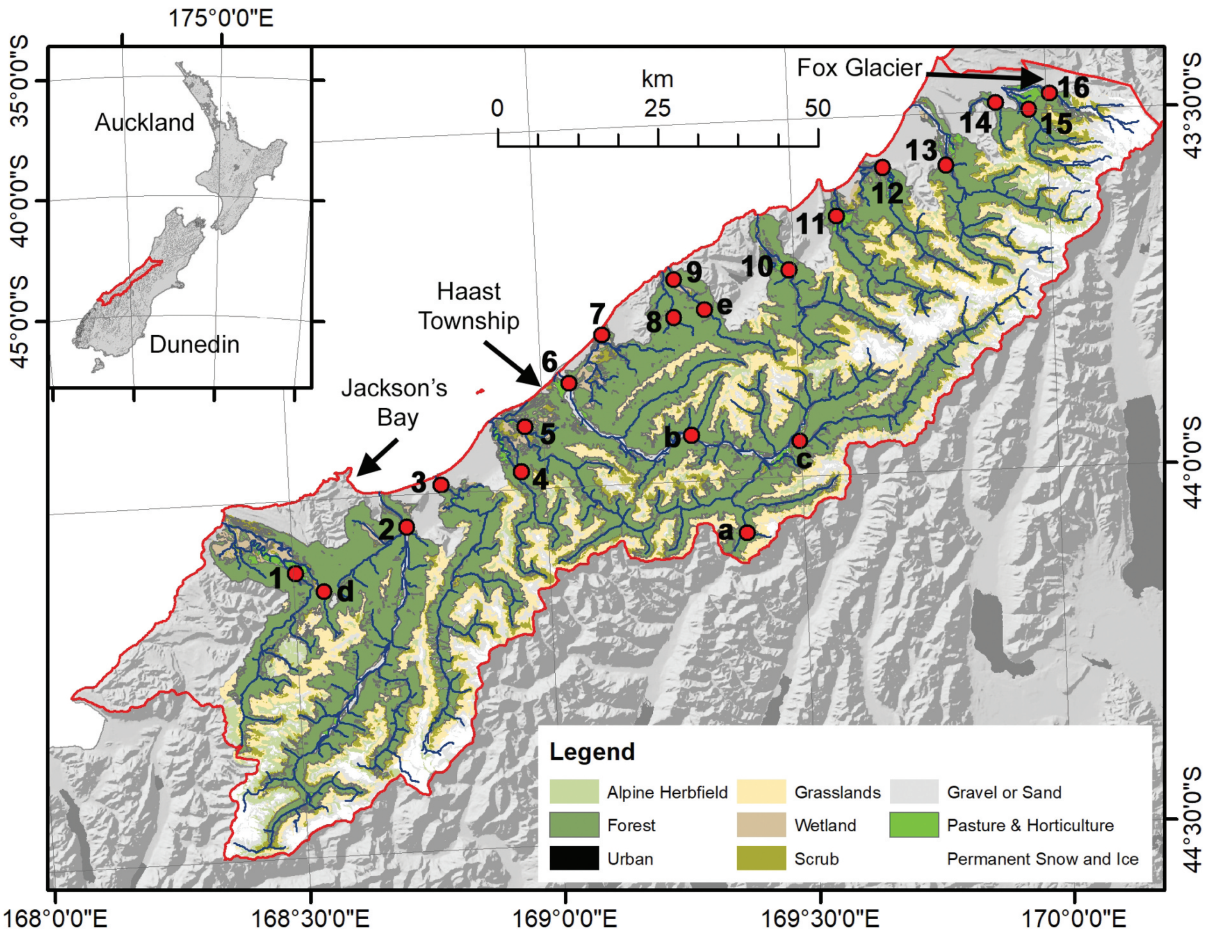

Figure 1. Location of river sampling locations in south Westland, Aotearoa New Zealand. Dark green indicates permanent forest cover, yellow is indigenous grassland cover, and white is permanent snow and ice cover. Land cover derived from satellite imagery captured in 2018 as mapped in the Landcover Database (v. 5) (Source: Manaaki Whenua Landcare Research 2019). Numbers indicate river sampling points as defined in Table 2.

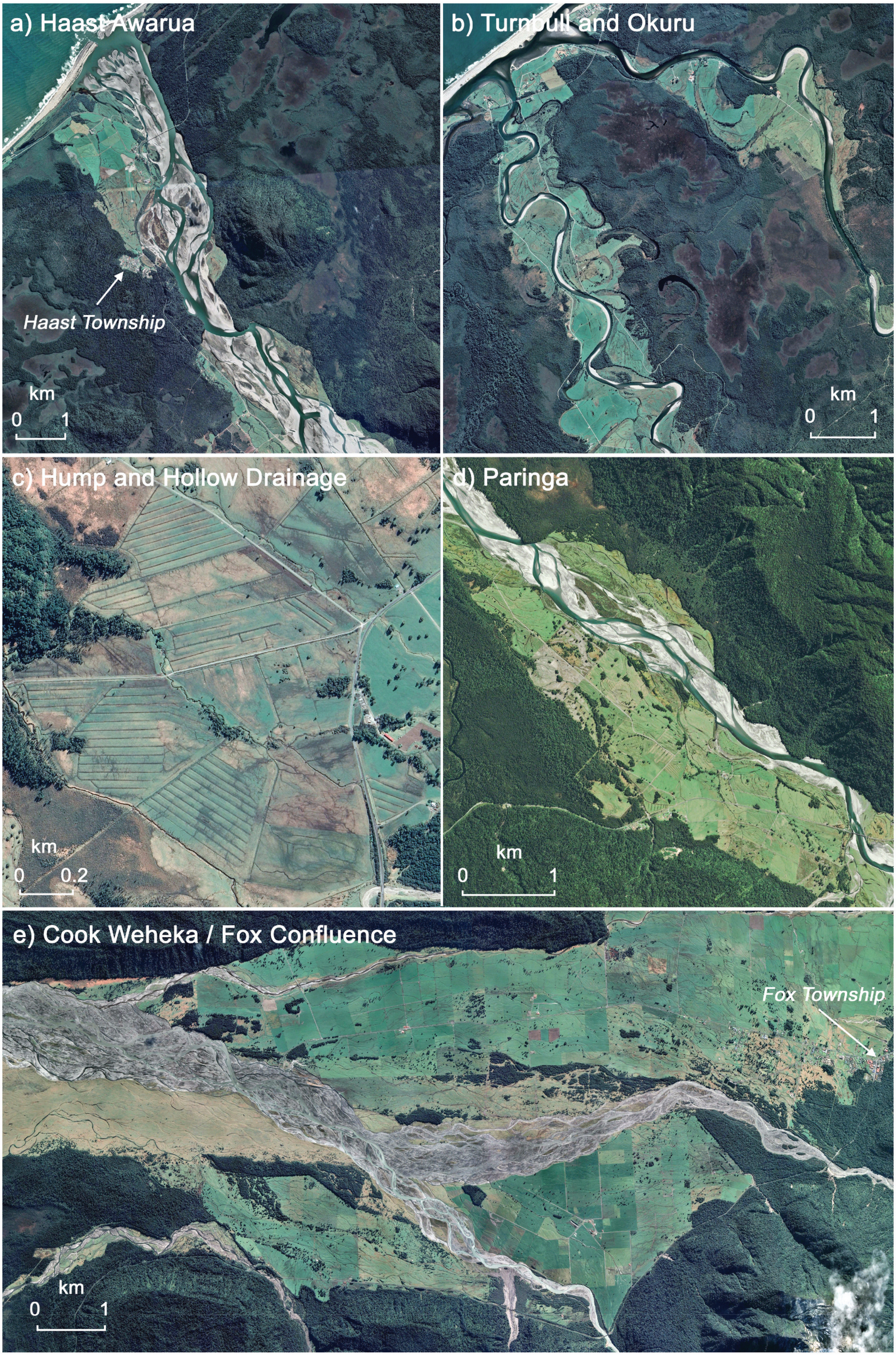

Figure 2. Alluvial pastoral land use in south Westland a) Haast-Awarua at Haast township, b) Turnbull and Okuru rivers, c) example of hump and hollow drainage in Karangarua catchment d) Paringa and e) confluence of Cook Weheka and Fox Rivers at Fox township.

order ≥ 4 that drain the axial mountains of the Southern Alps. The drainage network is steep (mean of 10.8°) with occasional cascades but all lowland channels are gravel bedded and highly mobile (Figure 2). Most catchments have snow and ice in the headwaters, except for the coastal catchments in the foothills (Waita, Whakapohai and Moeraki) where the headwaters are <2000 m asl (Table 1). As of 2023, there are 17 active grazing concessions in the Conservation Estate, principally on alluvial flats (e.g. Figure 2).

The only hydrometric station in the area is at Roaring Billy ('b' in Figure 1) within the Haast Awarua catchment with continuous flow records (1970–). Continuous flow monitoring on the Arawhata ('2' in Figure 1) occurred between 1988 and 2019, and is no longer high flow rated. The remoteness of the area and the unstable shifting gravel beds mean there are no other maintained flow gauging stations or water quality monitoring sites in the area.

2.2. Data sources, collection and analysis

Stocking rates from the Agricultural Production Survey (APS) census data are available from 1971 to 2019 (MfE 2019). Regionally-specific data for Westland is available for 1990–2019 (no data for 1997, 2000, 2001) and stocking intensity rates are amalgamated to 345 km^2 mesh blocks for 1994, 2002, 2007, 2012, and 2019 (MfE 2019). APS metadata notes a methodological change in deer head counts before 2002 so numbers may not be directly comparable across the data set (MfE 2019). Land cover is from the land cover database v.5 (Manaaki Whenua Landcare Research 2019) derived from LandSat imagery for 1996, 2002, 2008. 2012 and 2018 with a 1 ha resolution (Ye et al. 2021).

Sixteen catchments were sampled across south Westland (Figure 1; Table 1), usually under median (or base flow) conditions using discrete grab samples. The experimental design includes catchments that are not actively grazed (i.e. control catchments: Martyr, Whakapohai, Moeraki, Ohinetamatea, Cook Weheka, and Fox); catchments that have traditional pastoral farming on the coastal plain (Cascade, Turnbull, Okuru, Paringa, Makawhio, Mahitahi, and Karangarua); and catchments with riparian grazing leases (Arawhata, Waiatoto, Haast, and Waita). Access above and below grazing areas is restricted due to a lack of access points to the river. Cattle in grazing leases self-organise along the riparian corridor to graze on river bars within the conservation estate. Of the grazing leases only the Haast River has access points above grazing (Landsborough and Upper Haast), at the top of the grazing lease (at Roaring Billy), and below the grazing lease (Haast, in the township).

Water samples were collected every 3 to 6 months from 2012 to 2015, then biennially in 2017, 2019, 2021, and 2023 (Table 2). Samples for nutrient analysis were collected into 10% HCl washed 60 mL LDPE bottles directly from the main channel. Each sample was pre-filtered using a 0.45 µm cellulose acetate filter for analysis of nitrate-nitrite (NO_3^-+NO_2^-), herein referred to as NNN, nitrate-nitrite nitrogen), ammoniacal nitrogen (NH_4^-), and dissolved reactive orthophosphate (PO_4^{3-}). Nutrient concentrations for NNN, NH_4-N and PO_4-P were determined using a Star 5000 Flow Injection Analyser (FIA) with a method

Table 1. Physiography of catchments organised from SW – NE along the main divide of the Southern Alps. Site ID numbers are shown in Figure 1.

Site ID	Catchment (Sub Catchment)	Area (km^2)	Strahler Stream Order	Est. Runoff (mm yr^{-1})	Mean Elevation (m asl)	Land Area (<10°) (% total area)	Pastoral land use (% total area)
1	Cascade	436	5	5016	615	28.7%	3.2%
d	Cascade (Martyr)	69	4	3056	623		6.5%
2	Arawhata	931	6	6510	859	17.9%	1.4%
3	Waiatoto	470	5	7290	963	16.6%	1.1%
4	Turnbull	182	5	7009	804	22.5%	4.7%
5	Okuru	285	6	5592	645	29.2%	2.0%
6	Haast	1356	6	5676	950	12.5%	2.0%
a	Haast (Upper)	50	4	2681	1142		–
b	Haast (Roaring Billy)	1055	6	5846	1055		1.0%
c	Haast (Landsborough)	613	5	5093	1140		0.8%
7	Waita	130	5	3109	284	55.5%	1.3%
8	Whakapohai	59	5	5016	418	13.4%	–
9	Moeraki	107	4	6130	559	21.4%	0.6%
e	Moeraki (Upper)	74	4	7135	713		0.1%
10	Paringa	277	5	6773	739	18.9%	3.2%
11	Mahitahi	197	5	6976	816	19.7%	5.7%
12	Makawhio	169	5	5407	740	25.3%	3.6%
13	Karangarua	408	6	6228	1039	15.6%	2.8%
14	Ohinetamatea	31	3	5249	632	27.5%	1.3%
15	Cook Weheka	155	5	6415	1141	14.5%	5.3%
16	Fox River*	97	4	5125	1538	20.8%	2.7%

Table 2. Dates of sample collection relative to the austral seasons.

Season	Date	Analytes Measured	Adverse Weather
Summer	28–29 January 2012	All	
	12–13 December 2012	All	
	28 Feb–1 March 2014	All	
	7–8 February 2015	All	
	2 December 2021	In situ obs, N, P	
Autumn	10–11 April 2013	All	High flows and rain
	22–23 May 2014	All	
	13–15 May 2017	All	
	25–27 April 2024	In situ obs, N, P and E. coli	
Winter	11–12 August 2013	All	Snow on Haast Pass
	26–27 August 2014	All	Snow on Haast Pass
	4–5 September 2015	All	
	14 September 2024	In situ obs, E. Coli	
Spring	25–25 October 2012	All	
	8–9 November 2013	All	
	5–6 November 2014	All	
	10 November 2019	N and P	
	1 November 2023	N and P	

detection limit of 0.001 mg L^{-1} for NNN and PO_4-P, and 0.005 mg L^{-1} for NH_4-N. A 1 L HDPE bottle was filled from the main river channel at each site to determine the suspended particulate material (SPM). A 16 mL aliquot was decanted from the SPM bottles and measured for nephelometric turbidity using a Hach 2100P portable turbidimeter (following EPA Method 180.1). The remaining sample volume was then filtered through 1.5 µm Whatman glass fibre filter following standard methods for the determination of suspended sediment concentration (SSC in mg L^{-1}) and particulate organic matter (POM in mg L^{-1}) (see: Bright, Mager, and Horton 2020a). SSC and POM filters were weighed on a 4-point decimal balance with a detection limit of 0.3 mg L^{-1}.

Given the remote location and travel distances involved between sites (and to a suitable laboratory facility) it was not possible to collect or analyse samples for faecal contaminants. Of the faecal contaminants, *E. coli* is a commonly used indicator of potential water quality degradation associated with pastoral farming because it is able to persist in both enteric and aquatic environments. To redress this shortcoming, two additional sampling rounds were undertaken in April and September 2024 by purposely transporting an IDEXX® Colilert quanti-tray method with incubator to Haast to determine *E. coli* concentrations in river water using the most probable number (MPN) method. At each location one 100 mL sample of river water was collected directly from the main channel of the river into a sterile polypropylene container. The samples were stored in a cool and dark chiller box during transportation and then analysed for *E. coli* on the day of collection. Activated samples were incubated at 35°C for 18 h as specified by the manufacturer protocols. Wells that fluoresced under UV light were then used to determine the MPN of *E. coli* in each sample and reported in units of CFU per 100 mL.

A Kaplan Meier (K-M) bootstrapping method was used to generate the median of variables where there was a large number of non-detects (i.e. values at or below the method detection limit). The macro KMBoot was used to calculate the median of left-censored data using Minitab® v17, where censored values were set to the instrument detection limit following the method described in Helsel (2012). All water quality parameters have skewed distributions so all statistics are reported as median values and variance reported using the median absolute deviation (MAD). Statistical testing of the medians was performed in SPSS v. 23 using a Mann–Whitney U-test (on 2 samples) at the 95% confidence threshold, and associations were tested using Spearman's correlation coefficient.

3. Results

3.1. Land use change

Although farming has been present in the region since the mid-1870s (Gordon 1938) the amount of land dedicated to farming has remained static between land cover surveys (1996–2018) with only small areas of grasslands being either retired from grassland, or reclassification from low producing to high exotic producing grasslands. Stock exclusion rules specify that land blocks with a slope < 10° and with waterways >1 m fence off heavy livestock from riverbed and banks. For south Westland this presents a land management challenge because suitable flat land is restricted to alluvial flats on point bars within the deeply incised river valleys (e.g. Arawhata, Waiatoto, Haast Awarua, Turnbull and Okuru, Figure 2), or as a narrow strip of coastal plains (Figure 2; Figure 3). Across south Westland only 23.5% of the area meets the requirement of having a land parcel slope < 10° (Figure 3) with most flat land retained in coastal forests and wetlands. Low producing grassland and high producing exotic grasslands constitutes only 2.4% of the south Westland area. Areas where pastoral expansion may occur remain in the undeveloped

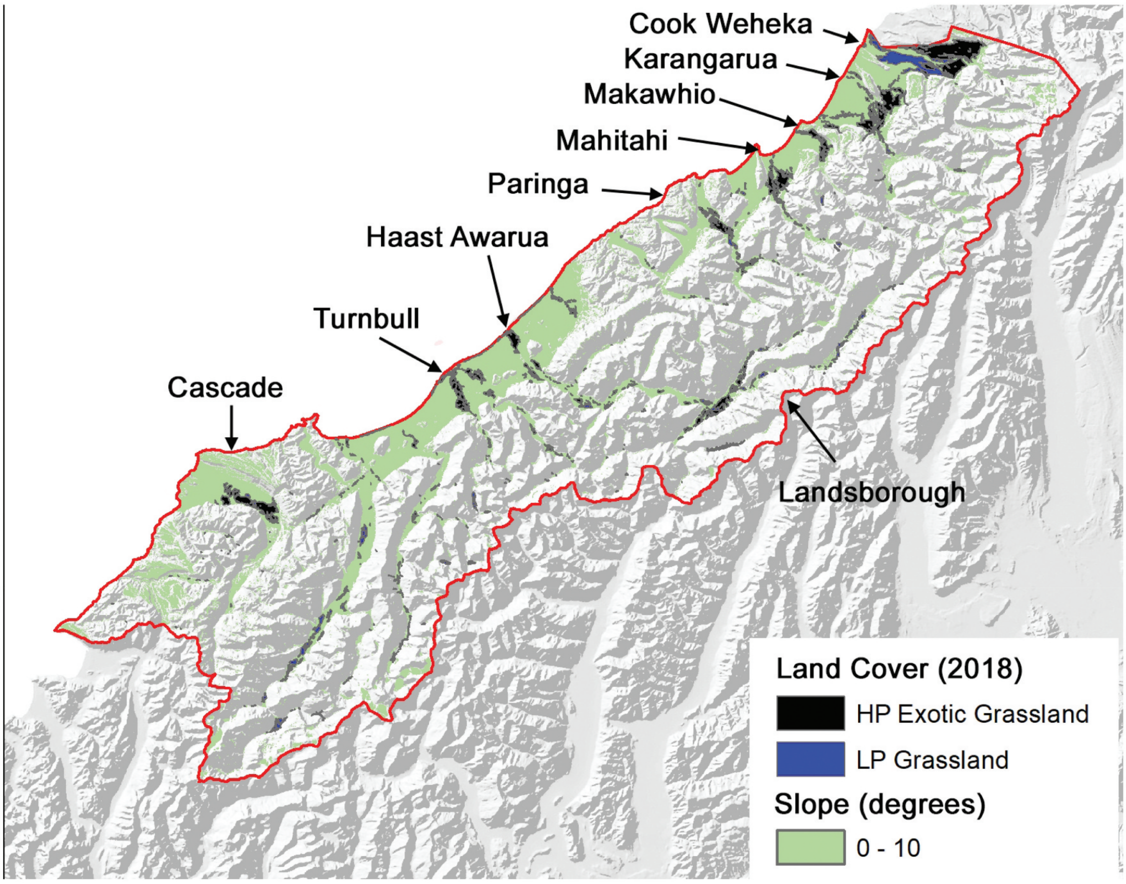

Figure 3. Extent of land with a slope (<10°) (green) accounts for 23.5% of the area, and 2.4% is classified as a pastoral land use (sum of low producing (LP) grassland and high producing (HP) exotic grassland) in south Westland.

pockets of the coastal plains. The greatest intensity of pastoral land is north of Big Bay (e.g. Mahitahi, Makawhio, Paringa, Cook Weheka and Fox catchments) whereas the southern coastal plain between Arawhata and Haast Awarua is mostly forest. Across south Westland pastoral land use is a small portion of total catchment area (<1 to 6%) (Table 2).

3.2. Trends in livestock numbers

Westland has had a reduction in total livestock since 1990 (Figure 4) with a shift away from sheep grazing towards increased dairy cattle, consistent with national trends (Data from MfE, 2019). The Westland district dairy cattle population peaked in 2014 at 188,417 but had declined to 152,552 by 2019 (Figure 4a). When plotted as animal unit (AU) equivalents (assuming 6 sheep = 1 cattle, 2 deer = 1 cattle) the stocking rates of Westland remained relatively stable around 200,000 AU equivalents, although there was a surge in AU between 2011 and 2016, peaking at 256,682 in 2014 (Figure 4b). These data show that despite a shift in livestock production there has been little change in livestock stocking density across the Westland region.

In south Westland, there has been a decline in livestock, from a peak of 132,428 in 1994 to 27,818 in 2017 (Figure 5a). Sheep numbers have reduced by 86% and deer by 74%. Beef cattle numbers fluctuated through the census data but by 2017 had reduced by 24% from 1994. There was an increase in dairy cow numbers from 225 (in 1994) to 1741 (in 2017). The increase in dairy cows is, however, insignificant because the total head of cattle between 1994 and 2017 has decreased by 9.4% so that the loss in head of beef cattle has been greater than the head count increase in dairy cattle. As of 2017, the stock density is strongly skewed across Westland, with the largest herds occurring in the upper part of the region (Figure 6). The stocking density of south Westland is < 1 AU km^{-2} for the areas under grazing leases (e.g. Waiatoto and Haast) and generally < 2 AU km^{-2} for the pastoral farming areas south of Fox Glacier. The coastal plain of the Turnbull-Okuru has 1400 cattle and 375 sheep over 1000 km^2 for a stocking rate ~ 1.8 AU km^{-2}. The highest stocking densities in south Westland occur on the outwash plain of the Fox/CookWeheka (12.5 AU km^{-2}), comprised of 5000 cattle, 2000 sheep, and 300 deer (Figure 6). Unlike the rest of Westland, however, animal unit equivalents have also declined significantly in south Westland since the 1990s (Figure 5b) from a peak of 32,067 AU (1994) to 13,229 (2017).

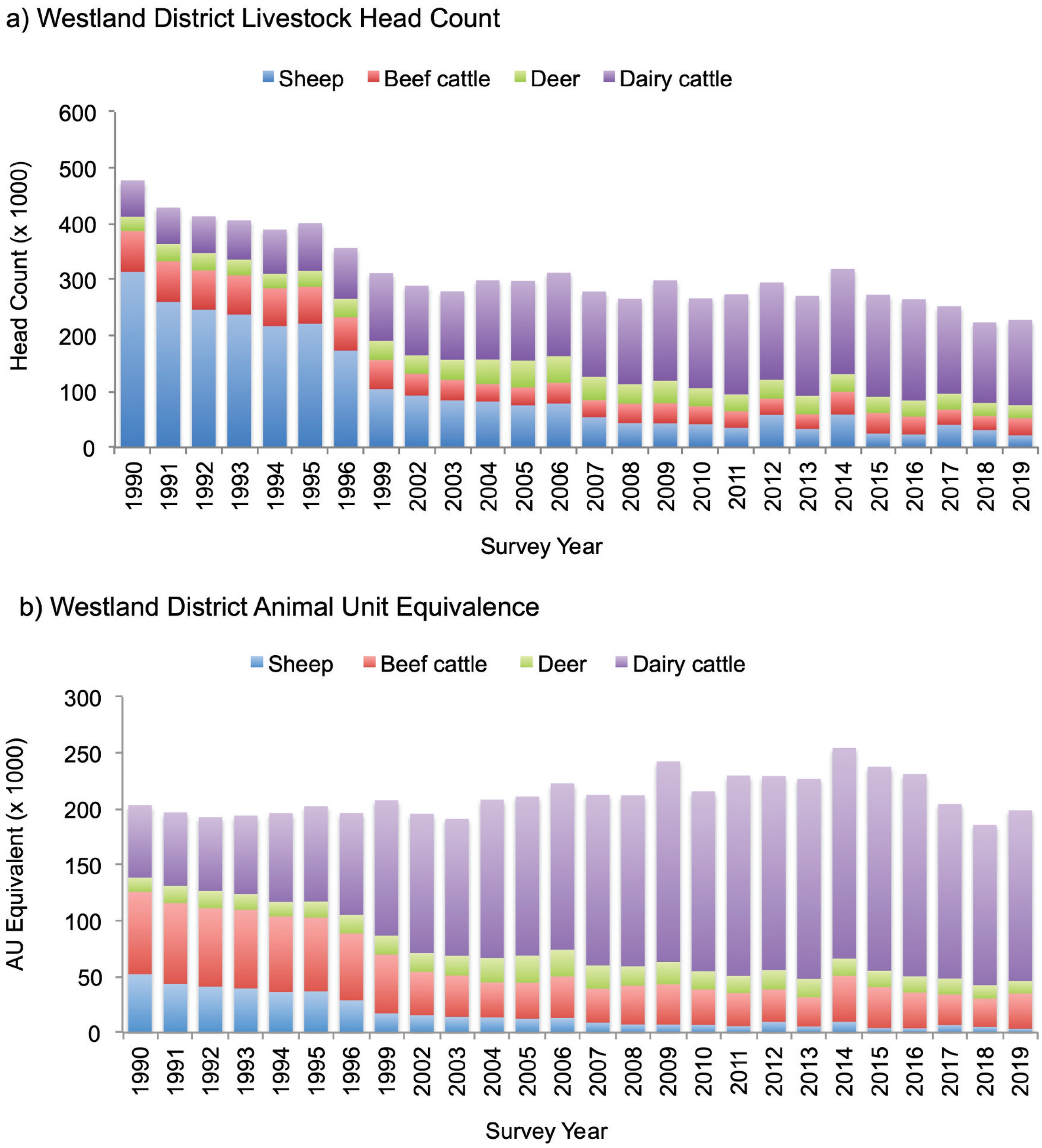

Figure 4. Change in livestock composition since 1990 Westland District. Total head count has decreased over last 30 years. Animal unit equivalence: cattle (1), domestic sheep (6), red deer (2).

3.3. Water quality

Measures of the general water quality are indicative of near-pristine standards (Table 3). Water temperatures are cool, with median temperatures ranging from 2.9 ± 1.2 °C (Fox Glacier) to 14.8 ± 2.3°C (Moeraki). There are only small temperature deviations between the extremes of winter (8.1 ± 0.8 °C) and summer (12.4 ± 1.5°C). The ionic load is low with median-specific electrical conductance of less than 80 µS/cm, with the exceptions of the Fox Glacier River (107 ± 23 µS/cm), Cook Weheka River (84 ± 6 µS/cm) and the Landsborough tributary of the Haast (94.6 µS/cm). The catchments with high electrical conductance are associated with river systems with significant glaciated headwaters (e.g. Fox and Cook Weheka), or lowland river mouths where there can be occasional upstream migration of salt during high tide (e.g. Waiatoto, which has a high measure of variance as a result of tidal influence). The pH of all rivers samples was neutral to slightly alkaline, ranging from 7.0 to 7.7 and are within the ANZG values for cool, extremely wet river systems. Total Alkalinity is generally at the lower range of freshwater systems, and ranged from 10 to 32 mg/L as bicarbonate (Table 3). The alkalinity values indicate soft water, and are concordant with the low ionic load as indicated by electrical conductance.

NNN in south Westland were very low with a median concentration of 0.028 mg N L^{-1} (Table 4) and fall well within the regulatory National Objectives Framework (NOF) guidelines as Band A, which specifies a median annual concentration of <1.0 mg N L^{-1}. Current concentrations of NNN in south

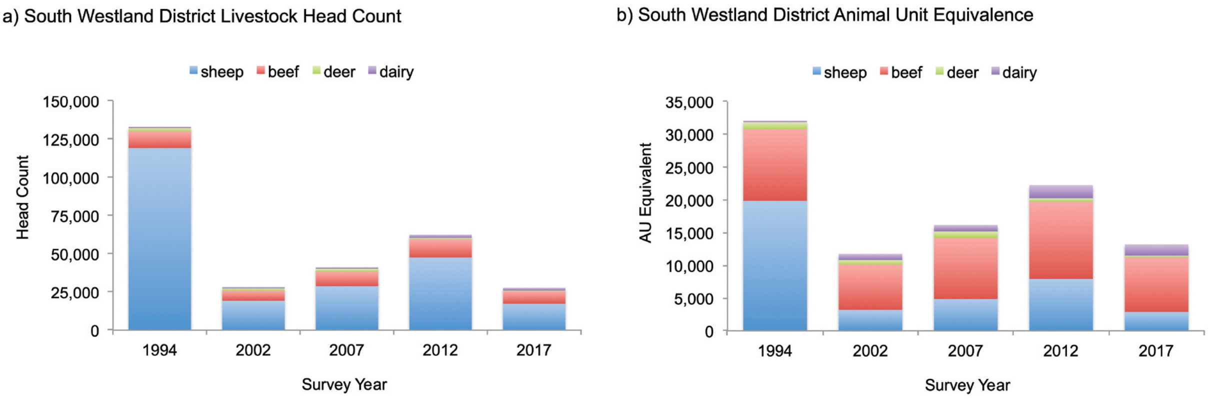

Figure 5. Change in livestock composition for south Westland. Total head count and animal equivalence units have decreased since survey in 1994. Animal unit equivalence: cattle (1), domestic sheep (6), red deer (2).

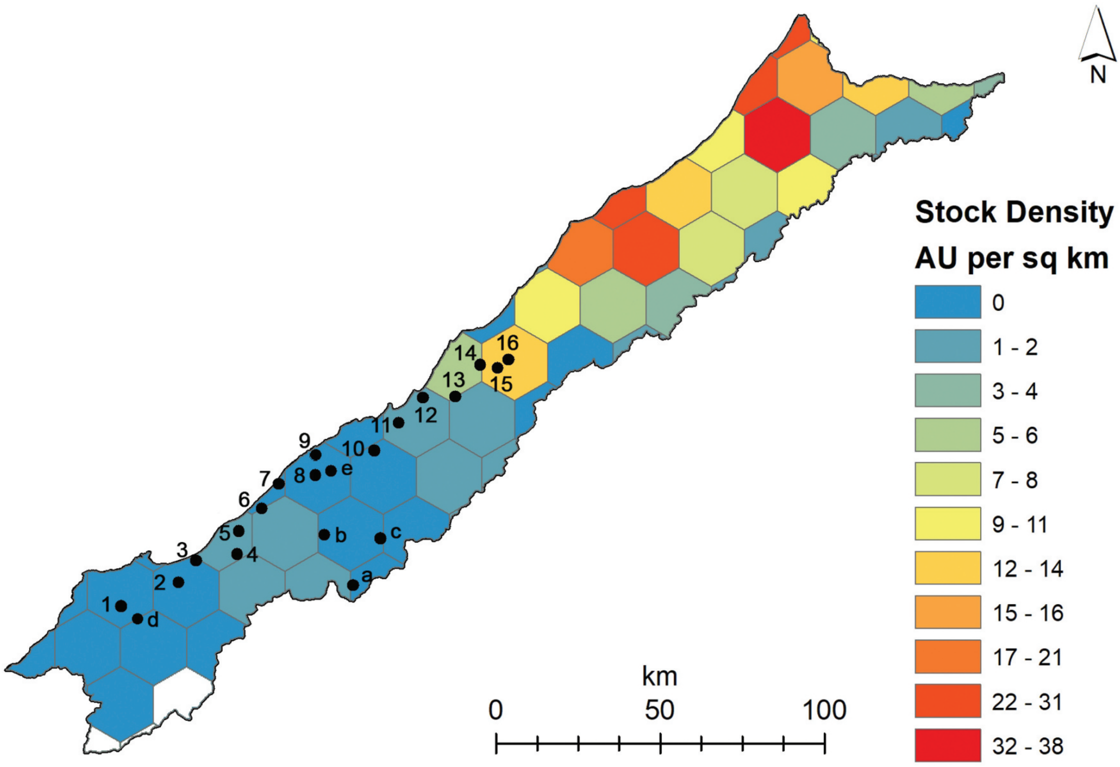

Figure 6. Stock density in animal unit (Au)_equivalents for Westland using the APS data for 2017. Numbers indicate the sampling locations of Table 1.

Westland were over an order of magnitude below the threshold of 'excellent' as prescribed by the NOF in the NPS-FM and are also well below the ANZG (2018) values for cool extremely wet rivers (0.092 mg N L^{-1} for low elevation and 0.048 for mountains) (Figure 7). There was some variability in NNN concentrations but all samples were less than 0.092 mg N L^{-1} (Figure 7). The location of the highest NNN concentrations was the Mahitahi River (0.053 mg L^{-1}), which was also the catchment with the greatest percentage area of high producing grassland. Compared to adjacent catchments, there was a small increase in NNN recorded at this location. The glacial catchments also had higher NNN concentrations (e.g. Cook Weheka and Fox Glacier Rivers) with 0.047 and 0.048 mg N L^{-1} respectively (Table 4) and these were likely higher because of different hydrochemistry that occurs between glaciated and non-glaciated catchments, either from microbial mediation in glacial ice (Foght et al. 2004), or scavenging of nitrate ions from snowfall (Kurzyca and Frankowski 2019).

Ammoniacal nitrogen concentrations were also low, with median concentrations usually below 0.006 mg N L^{-1} (Table 4), below the NOF band A limit and consistent with ANZG values for cool extremely wet mountain rivers. Previous reports of ammoniacal nitrogen concentrations in streams draining NZ native forests have NH_4-N concentrations less than 0.010

Table 3. General indicators of water quality showing in situ temperature (in ºC), specific electrical conductance (µs/cm) and pH and ex situ alkalinity as determined by titration in units of bicarbonate concentration (mg/l). Measurements are calculated from 17 discrete grab samples, apart from Martyr, Landsborough and Whakapohai, which have 3 grab samples. Asterix indicates control catchments that do not currently have active grazing above the sampling location.

	Temp (ºC)		EC (µS/cm)		pH		Bicarbonate Alkalinity	
Catchment (Tributary)	Median	MAD	Median	MAD	Median	MAD	Median	MAD
Cascade	9.2	0.9	57.6	2.4	7.7	0.2	24.4	1.0
Cascade (Martyr)*	8.8	–	73.0	–	7.7	–	28.4	–
Arawhata	10.6	1.7	56.4	5.0	7.2	0.2	18.8	1.5
Waiatoto	9.4	1.1	73.3	29.0	**7.2**	0.3	20.8	2.5
Turnbull	10.3	0.9	31.7	0.3	7.0	0.3	10.2	1.0
Okuru	12.3	1.7	38.1	5.7	7.1	0.3	13.7	1.5
Haast	11.7	2.7	72.1	5.1			25.4	2.0
Haast (Upper)*	6.9	0.9	44.3	1.3	7.2	0.1	17.3	1.5
Haast (Roaring Billy)	8.5	0.6	73.6	8.5	7.7	0.1	26.9	2.0
Haast (Landsborough)	9.7		94.6	–	7.5	–	24.9	–
Waita	12.6	1.7	44.9	5.3	7.0	0.5	12.7	1.0
Moeraki*	14.8	2.3	28.0	1.5	7.0	0.3	10.2	1.0
Moeraki (Upper)*	9.8	1.4	31.0	4.8	7.1	0.1	12.2	1.0
Whakapohai*	9.9		31.7	–	7.0	–	12.7	
Paringa	11.1	1.9	54.2	2.8	7.2	0.1	18.3	3.6
Mahitahi	10.9	2.2	60.5	10.4	7.1	0.1	18.3	6.6
Makawhio	11.3	2.1	43.6	8.0	7.1	0.1	16.3	1.0
Karangarua	10.1	1.5	62.2	5.1	7.3	0.2	20.8	4.1
Ohinetamatea*	11.0	1.6	44.3	6.5	7.4	0.3	13.7	1.5
Cook Weheka*	8.1	0.9	87.4	6.4	7.4	0.4	30.5	4.6
Fox River*	2.9	1.2	107.4	22.8	7.7	0.4	32.0	13.2
ANZG (2018)			**98^H^**		**7.3–7.9^H^**			
			107^L^		**7.0–7.7^L^**			

Table 4. Median and the median absolute deviation (MAD) for nutrient water quality indicators of south Westland main rivers (in mg L^{-1}. ANZG (2018) values are derived for cool extremely wet mountain (H) or lowland (L) rivers. Medians of PO_4-P are reported using the Kaplan–Meier method for censored data and no MAD is reported. Dash indicates insufficient data points (i.e. <5 for reporting a MAD). The local regulatory authority, the West Coast Regional Council (WCRC) water quality limits as specified in the land and water plan are also included for analytes where limits have been specified. Medians for NNN, NH_4-N and PO_4-P are calculated from 19 samples but DOC is calculated on 15 samples (up to 2017). Medians reported for the sites Martyr, Landsborough and Whakapohai are calculated from 3 discrete grab samples. Values in bold indicate an exceedance above the ANZG (2018) values. Asterix indicates control catchments that do not currently have active grazing above the sampling location.

	NNN		NH_4-N		DOC		PO_4-P
Catchment (Tributary)	Median	MAD	Median	MAD	Median	MAD	Median
Cascade	0.029	0.002	**0.010**	0.002	1.3	0.4	<0.001
Cascade (Martyr)*	0.030	–	0.006	–	1.2	–	<0.001
Arawhata	0.021	0.004	0.005	0.001	1.9	0.7	<0.001
Waiatoto	0.037	0.009	0.006	0.002	1.9	0.6	<0.001
Turnbull	0.035		0.006		0.9	0.3	<0.001
Okuru	0.026	0.008	0.006	0.004	2.0	0.4	<0.001
Haast	0.025	0.005	0.006	0.005	1.7	0.7	<0.001
Haast (Upper)*	0.016	0.006	0.002	0.006	1.8	0.3	<0.001
Haast (Roaring Billy)	0.030	0.004	0.005	0.003	1.6	0.5	<0.001
Haast (Landsborough)	0.033	–	0.003	–	1.9	–	<0.001
Waita	0.009	0.005	0.005	0.002	3.7	1.3	<0.001
Moeraki*	0.005	0.005	0.005	0.004	1.8	0.1	<0.001
Moeraki (Upper)*	0.017	0.006	0.006	0.004	1.2	0.4	<0.001
Whakapohai*	0.018	–	0.009	–	1.1	–	<0.001
Paringa	0.036	0.012	0.005	0.001	1.5	0.4	<0.001
Mahitahi	**0.055**	0.009	0.002	0.002	1.9	0.2	0.001
Makawhio	0.035	0.012	0.005	0.002	1.5	0.5	<0.001
Karangarua	0.033	0.007	0.002	0.004	1.6	0.3	<0.001
Ohinetamatea*	0.011	0.006	0.005	0.001	1.4	0.4	<0.001
Cook Weheka*	0.047	0.012	0.005	0.003	1.9	0.4	0.001
Fox River*	0.048	0.012	**0.009**	0.003	1.9	0.6	0.002
ANZG (2018)	**0.048^H^**		**0.006^H^**		–		**0.005^H^**
	0.092^L^		**0.008^L^**				**0.009^L^**
NOF (Band A)	**1.100**		**0.030**		–		**0.006**
WCRC (2014)	**0.700**		**0.900**		–		**0.030**

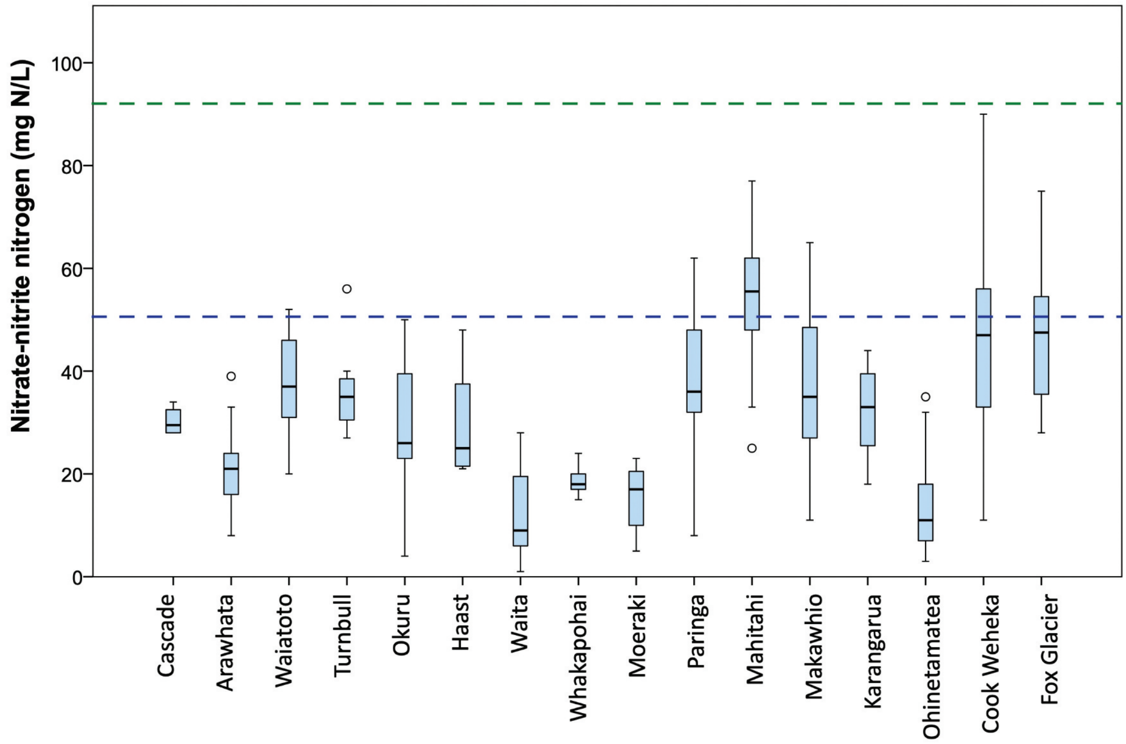

Figure 7. Box plots of NNN concentration in the main south Westland rivers relative to the ANZG (2018) values for cool extremely wet mountains (blue dashed line at 48 µg N L^{-1}) and lowland (green dashed line at 98 µg N L^{-1}).

mg/L (Duggan et al. 2002; Mosley and Rowe 1981). In our study, NH_4-N concentrations were highly variable between sampling rounds, as indicated by their MAD relative to the median. These rivers are characterised by dense cool temperate rainforests in their headwaters, which likely produce NH_4-N from microbial decomposition of forest litter (Parfitt et al. 2003). Thus, we are not able to distinguish between NH_4-N produced by organic decomposition and that of urea associated with stock grazing. For example, Whakapohai that has no pastoral land-use had a median NH_4-N concentration of 0.009 mg/L compared to that of 0.002 mg/L in the Mahitahi catchment, the latter of which has the most pastoral grazing in this case study.

Dissolved reactive phosphorus concentrations were very low (Table 4), and often below the method detection limit (i.e. <0.001 mg P L^{-1}), which is consistent with local terranes that are naturally very low in phosphorus-bearing minerals (Mager and Horton 2023). Local farming practice is to apply lime-based fertilisers to amend soil pH, and based on the water quality sampling, there is no evidence that excess phosphorus from agricultural practice is present in these catchments.

Nephelometric turbidity (Table 5) was used as a surrogate measure for SPM and in most catchments turbidity met the ANZG values for cool extremely wet mountain rivers (i.e. <3.6 NTU). Turbidity exceeded the ANZG values in rivers with glaciated headwaters (e.g. Arawhata, Waiatoto, Landsborough, Karangarua, Cook Weheka, and Fox). All catchments in south Westland have naturally high concentrations of suspended sediment, with annual yields ranging from 1236 (Waita) to 10,245 (Fox) t km^{-2} a^{-1} (Hicks et al. 2019). Suspended particulate matter (SPM) was principally as inorganic suspended sediment (SS) and under base flow conditions POM was typically < 50% of SPM (Table 5). Previous studies (e.g. Bright, Mager, and Horton 2020a) have quantified the ratio and mobilisation of SS and POM under high flow conditions in the Haast Awarua River, as this is the only gauged river in the region, and POM varies between 20% and 30% under quiescent conditions but drops to < 2% of SPM during storm events. It is assumed that these trends are similar for the other high order catchments in south Westland because of their similar land use, slope, and runoff (Table 1).

There was a strong positive correlation between turbidity and dissolved organic carbon (DOC) (Spearman's $p = 0.65$, $p = 0.001$) as well as other measures of particulate load (SSC $r = 0.62$, $p = 0.003$). Brownwater streams are common in Westland and are formed by high concentrations of leached organic acids and range from 1.6 to 43.2 mg L^{-1} (Winterbourn, Collier, and Graesser 1988). The DOC concentrations were highly variable, with medians ranging from 0.9 to 3.7 mg C L^{-1} and similar to reported concentrations in southern New Zealand (Bright, Mager, and Horton 2020b), but lower than

Table 5. Median and the median absolute deviation (MAD) for particulate water quality indicators of south Westland main rivers (in mg L^{-1}. ANZG (2018) values are derived for cool, extremely wet mountain (H) or lowland (L) rivers. Dash indicates insufficient data points (i.e. <5) for reporting a MAD. Medians calculate from 13 samples (up to 2017), apart from Martyr, Landsborough and Whakapohai, which have 3 samples. Values in bold indicate an exceedance above the ANZG values. Asterix indicates control catchments that do not currently have active grazing above the sampling location. E. coli were measured twice in 2024 and are reported in units of CFU/100 mL and † indicates sample was collected a day after significant rain.

	Turbidity		SSC		POM		E. Coli
Catchment (Tributary)	Median	MAD	Median	MAD	Median	MAD	
Cascade	1.2	0.3	2.2	0.8	1.5	0.2	–
Cascade (Martyr)*	0.3	–	0.3	–	0.5	–	–
Arawhata	**4.0**	1.7	**6.8**	1.7	0.7	0.3	18†, 1
Waiatoto	**7.1**	5.0	**15.4**	6.4	2.1	0.9	24†, 7
Turnbull	1.0	0.3	2.4	1.9	0.5	0.3	9, 5
Okuru	1.2	0.5	**4.2**	1.8	1.9	1.0	6, 6
Haast	2.7	1.7	**11.7**	2.2	1.6	0.2	2, 2
Haast (Upper)*	3.2	0.3	4.0	1.3	1.7	0.2	<1, 1
Haast (Roaring Billy)	3.3	2.6	**12.9**	5.7	1.6	0.8	1, 2
Haast (Landsborough)	**8.5**	–	**21.0**	–	<0.3	–	–
Waita	1.8	0.9	**8.4**	2.6	1.7	0.2	93†, 21
Moeraki*	1.1	0.3	2.8	1.3	1.1	0.7	–
Moeraki (Upper)*	0.7	0.3	3.6	1.8	1.4	0.3	4, 1
Whakapohai*	0.3	–	0.4	–	0.3	–	4, 1
Paringa	1.7	0.9	**8.5**	6.5	1.5	0.2	2, 2
Mahitahi	1.4	0.4	4.0	2.3	1.5	0.4	14, 14
Makawhio	1.7	0.6	3.1	1.2	1.8	0.6	11, 18
Karangarua	**7.8**	4.8	**14.2**	8.8	3.3	0.9	3, 40†
Ohinetamatea*	0.8	0.3	**5.3**	2.4	2.3	0.1	1, 6†
Cook Weheka*	**30.3**	25.6	**55.5**	40.5	5.2	2.5	3, 8†
Fox River*	**109.0**	62.0	**292.5**	142.5	4.6	2.1	1, 2†
ANZG (2018)	**3.5^H^** **2.6^L^**		**4.2^H^** **1.7^L^**				

concentrations reported for other parts of the world (e.g. Huang et al. 2012), likely due to dilution because of the locally high rainfall. The highest DOC concentrations were observed in the Waita catchment, which has ~ 10% of its low-lying catchment as wetlands that are prone to soil leaching and the production of coloured dissolved organic matter (CDOM), of which DOC is a component (Davies-Colley et al. 2011). Soil leaching of organic acids in wetlands also likely explains the slightly higher turbidity (1.8 NTU) detected in the Waita catchment as the EPA 180.1 method used for turbidity is sensitive to water colouration (Bright and Mager 2016).

A longitudinal comparison of water quality above, at, and below areas of lease grazing was only available on the Haast River, which has good road access along the main channel. Two major tributaries drain the Haast: the Landsborough and eponymous upper Haast, which drain near-pristine indigenous forest. Grazing is permitted in the lower catchment on the riparian margins up to the Roaring Billy hydrometric station; and the lowest site is 2 km from the river mouth below the Haast township. A comparison of these data (Table 4) showed no significant difference in median nutrient concentrations (NNN, NH_4-N, DOC or PO_4-P) or particulate indicators (SSC and POM) between Roaring Billy and the Haast near the river mouth (Mann Whitney U test, $p < 0.05$). The median concentration in the upper headwaters of the Haast (0.015 ± 0.006 mg N/L) was lower than that observed in the Landsborough (0.033 mg N/L) suggesting that NNN varies with drainage area, but likely reaches a natural upper limit (~0.03 ± 0.005 at Roaring Billy and Haast mouth) whereby increasing catchment area does not significantly alter NNN concentrations (Table 4). There were downstream changes in other water quality indicators (e.g. electrical conductance and bicarbonate alkalinity), which are related to variations in flow accumulation and chemical weathering processes (see: Mager and Horton 2023)(Table 3).

Preliminary analysis of the *E. coli* concentration in the south Westland rivers (Table 5) showed generally low concentrations below 10 CFU/100 mL under base flow conditions. There was some evidence of higher *E. coli* in the rivers with pastoral farming (e.g. Mahitahi and Makawhio) where concentrations were consistently above 10 CFU/100 mL. Grazed riparian lease catchments varied from 1 to 7 CFU/100 mL under baseflow conditions and were not notably different to the background levels of *E. coli* observed in the control catchments (e.g. Whakapohai, Moeraki, Cook Weheka and Fox). It should be noted that *E. coli* counts > 10 CFU/100 mL occurred when samples were collected a day after significant rain and are not directly comparable to base flow *E. coli* counts. More monitoring of bacterial contaminants was needed to ascertain seasonal and/or spatial trends in the *E. coli* data, especially any effects that may be detected in smaller tributaries possibly more affected by pastoral activities.

Table 6. Nitrogen concentrations (in mg N L^{-1}) in streams from New Zealand native forests. South Island forests are mixed beech, podocarp and hardwood species. Modified from: Davis (2014)..

	Rainfall (mm)	*NO_3^-*	*NH_4^+*	*Reference*
Maimai	2600	0.05	0.02	Neary et al. (1978); Mosley and Rowe (1981)
Mawheraiti	2450	0.01	0.01	Mosley and Rowe (1981)
Big Bush	1550	0.03	0.04	Neary et al. (1978); Fahey and Jackson (1997)
Dunlop Creek		0.02	<0.01	Duggan et al. (2002)
North or West SI		0.02		Stenzel and Herrmann (1990)
South Westland Indigenous Forest	>2500	0.03	<0.01	This Study reported as NNN

4. Discussion

Agriculture is an important part of the economic livelihoods of the communities of south Westland. Being geographically remote, its economic development has not followed the same trajectory as more accessible parts of Westland. The land dedicated to pastoral agriculture has largely remained static since the mid-1990s. Total livestock and animal unit equivalent numbers have similarly reduced in south Westland. Operating on the riverine fringe and in restricted pockets of coastal plains there is no evidence of a decline in the water quality data from the main rivers of nutrient contaminants from pastoral land uses. The water quality of indigenous forest-covered catchments, that is, those with no agriculture areas (e.g. Upper Haast, Whakapohai, Upper Moeraki, Roaring Billy), have median NNN concentrations from 0.016 to 0.032 mg N L^{-1}, which is similar to the range of indigenous forest catchments reported in the South Island (Table 6). It should be noted, however, that these comparison catchments may have a similar land cover, but are generally smaller order catchments compared to those presented in this study.

The south Westland catchments that have 1–6% of their areas in pastoral land use ranged from 0.01 to 0.055 mg NL^{-1}, with an average NNN concentration of 0.028 mg N L^{-1} and falling well within the range of NNN observed in pristine catchments. There is, however, a positive correlation between increasing percentage of catchment area in pasture and NNN conditions ($n = 21$, Spearman's $p = 0.72$ $p = 0.000$), suggesting that if pastoral land increases there would be a commensurate response in nitrate concentrations (Figure 8). NNN is also positively correlated to mean catchment elevation, suggesting that the larger catchments with glaciated headwaters also impart an influence on median nitrate concentrations in these catchments (Figure 8). Overall, the concentrations of nutrient contaminants (NNN, NH_4-N, and PO_4-P) are well below the NOF 'Band A' requirements and are concordant with the ANZG (2018) values for the protection of species in upland rivers. In this regard, the presence of pastoral farming in these catchments at the present stocking rates and low percentage of land cover dedicated to pastoralism when combined with the high dilution potential, results in a water quality akin to that of pristine catchments.

Unlike other parts of Westland there is also no evidence of phosphorus discharges that may present a risk to sensitive receiving environments (e.g. Lake Moana/Brunner, McDowell 2008, 2010; Wright-Stow and Wilcock 2017). Phosphorus concentrations were often at, or below, the method detection limit of 0.001 mg P L^{-1} and do not present a risk to the oligotrophic lakes in the region. Furthermore, at

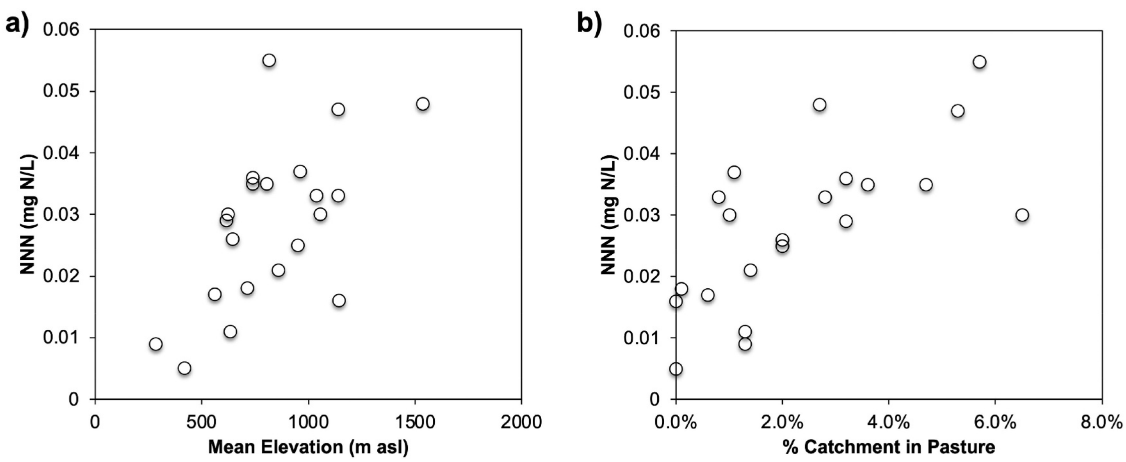

Figure 8. Bivariate plots of catchment characteristics and NNN showing a) mean catchment elevation and b) percentage of catchment area in pastoral land use.

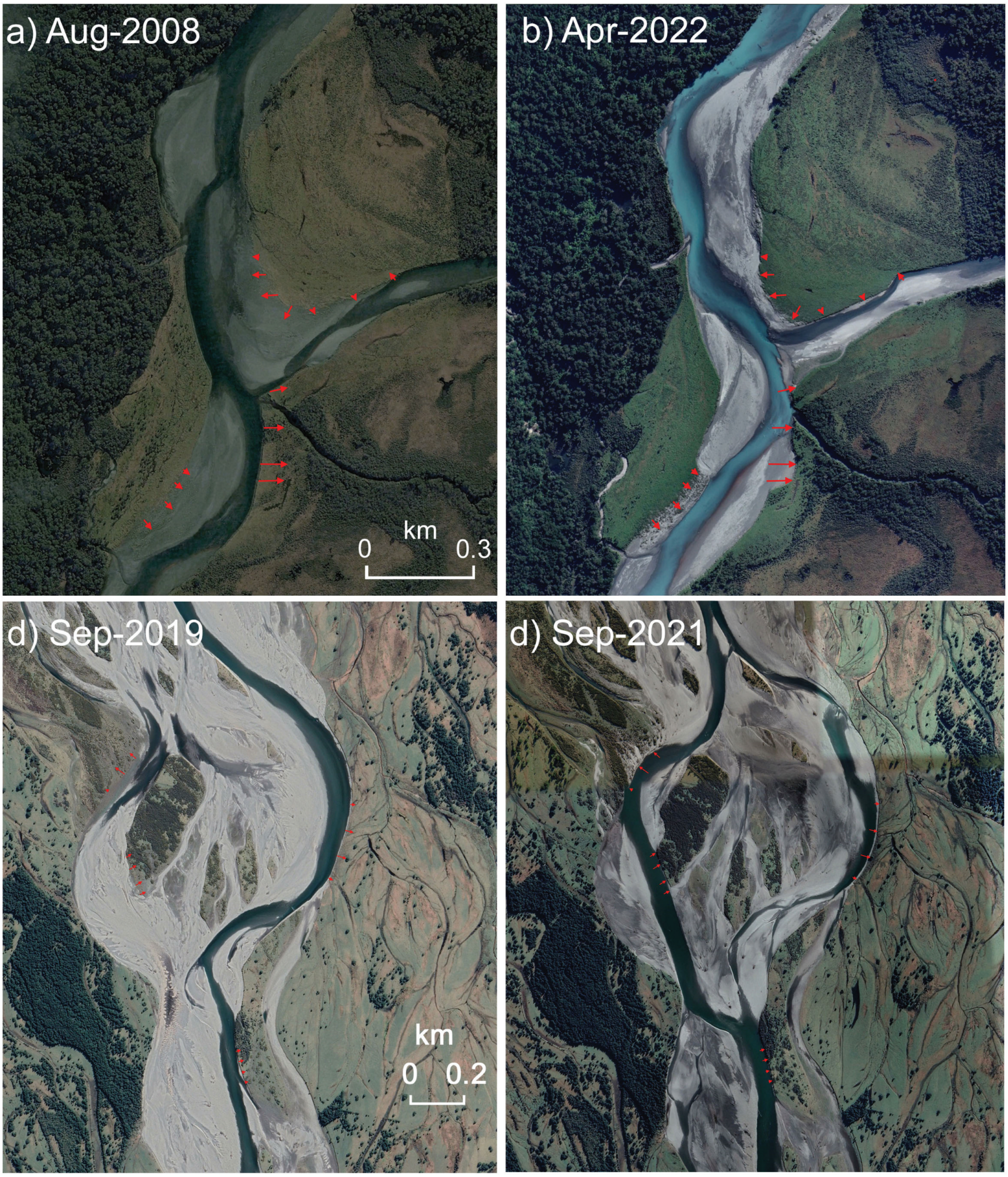

Figure 9. Channel migration, avulsion and bank erosion are challenges to maintaining permanent river runs in south Westland. a) Waiatoto River in Aug-2008; b) Waiatoto River in Apr-2022; c) Karangarua River in Sep-2019; and d) Karangarua River in Sep-2021.

baseflow the turbidity, suspended sediment, and POM show that these rivers have low particulate concentrations, and by inference, naturally high visual clarity. There is no evidence that existing land management practices are causing elevated turbidity that may adversely affect river habitat. Thus, the sustainability of existing farming practice is one of scale (Buck, Niyogi, and Townsend 2004): the scale of animal density is low; the scale of pastoral land relative to catchment area is low; and the scale of dilution and flushing of the hydrological system is very high. Thus, the footprint of pastoral grazing is negligible in this environment. Collectively, these factors combine to create conditions where there are currently no adverse effects to water quality by the presence of farming in the large stream order catchments of south Westland. However, it should be noted that grazing animals, especially cattle, can impact the environment in other ways, potentially altering habitat quality through bank and sediment disturbance during river crossings (Davies-Colley et al. 2004; Duggan et al. 2002). One management strategy to reduce these effects is to exclude stock directly from waterways, however, the addition of fences in the narrow riparian strips in south Westland also presents other concerns, that is, the river runs are grazed on vegetated point bars that are subject to frequent erosion and migration so that any setbacks may be reduced or damaged by channel migration. Bank incision and collapse, or channel avulsions, are common in these rivers (e.g. Figure 9) and the highly dynamic nature of the river channel may make grazing these areas increasingly difficult to maintain setbacks.

This study has not, however, considered the effects of pastoralism on smaller, low order streams, which should be considered in any future monitoring programme. Previous studies into the water quality of central and north Westland rivers have shown that in smaller catchments there was a degradation in water quality closely linked to dairy expansion and intensification (e.g. R. Davies-Colley and Nagels 2002; Wilcock et al. 2007, 2013). In this regard, farm management and consenting conditions will require regular water quality monitoring of vulnerable waterways; especially low order streams and those that discharge to sensitive receiving environments like wetlands (Hughes et al. 2016). Given the geographic isolation of the south Westland farming communities there are significant challenges to development and investment into farming expansion – especially meeting regulatory requirements to show that current management practices are not adversely affecting water quality. The remoteness of the area and few hydrometric stations reveal a generally data-poor region and implementation of monitoring programmes will have to be farmer-led using citizen-science methodologies, ideally supplemented with regular independent auditing, so that social capital and trust can be developed between the farming communities and the environmental regulators (McIntyre, Mager, and Connelly 2022). These gaps in knowledge building are currently being met by farming communities through the establishment of catchment groups as a collective organisation to engage with environmental regulators.

5. Conclusions

Water quality monitoring of rivers in south Westland showed that there is no evidence of elevated nitrate or phosphorus concentrations as a result of small-scale pastoral farming. South Westland is an isolated region that lacks the data of a regular monitoring regime, and this presents challenges in understanding any future changes to water quality. The data that are available to understand the trends and trajectories of water quality in this region are from the Haast Awarua River, which is the only regularly monitored river in the region. At present there is no concern for the water quality of south Westland and it meets all current national-level guidelines. The data show there may be slightly higher NNN present in areas with agricultural farming, but the intensity of these activities has not significantly altered the nutrient chemistry of the main rivers. Bacterial contaminants are also present in all catchments, but at very low levels (i.e. *E. coli* usually < 10 CFU/100 mL), although there does appear to be higher *E. coli* in catchments with pastoral farming, and further work is needed to quantify the *E. coli* concentrations in tributaries and the main rivers. No data are available that consider to what effect, if any, agricultural runoff has on smaller tributaries and habitat quality and future monitoring may be warranted to determine if the water quality of these small water courses is being maintained. The challenge for local farmers is overcoming economic barriers associated with the remoteness of the area and the dearth of regional monitoring that is available for providing an evidence-based mandate of the sustainability of farming in south Westland.

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