Long-term environmental impacts of land use change at Whatawhata: the story continues

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Abstract

The Whatawhata Integrated Catchment Management project is New Zealand's longest-running before-after-control-impact catchment farm system study. The economic and environmental impacts of land use changes have been monitored in the 260-hectare Mangaotama Block over 30 years, before and after land use changes implemented in 2001. Those changes included extensive pine plantation (140 ha), indigenous vegetation restoration (12 ha), poplar planting, livestock exclusion from streams, and shifts in livestock enterprises from breeding to finishing systems. This paper updates earlier presentations of the impacts of these changes. Longer-term monitoring has assessed the impacts on water quality, indigenous biodiversity, and greenhouse gas (GHG) emissions. Results indicate mixed water quality outcomes. Visual clarity improved and stream temperature declined, in contrast with rising nitrate and total nitrogen concentrations, partially due to reduced stream flow. Catchment annual average sediment loads have decreased while annual average nitrate loads have increased. Biodiversity monitoring shows increased tree regeneration and forest structure improvement in fenced and planted areas. The land use changes also significantly reduced GHG emissions, primarily through afforestation and lower livestock numbers, converting the catchment farm from a net emitter to a net sink. Soil carbon stocks overall appear to be in decline, though data are limited. These findings provide insights for hill country farmers and policy developers seeking to understand realistic time frames for meeting environmental management goals in the long-term.

Keywords: biodiversity restoration, environmental impact, farm system, greenhouse gas mitigation, water quality

Introduction

The Whatawhata Integrated Catchment Management (ICM) project is the longest continuously monitored before-after-control-impact (BACI) catchment-scale study in New Zealand (Hughes et al. 2020). The study assessed the impact of land use and management changes on the economic and environmental performance of a 260-hectare steep hill country headwater catchment farm system, referred to as the "Mangaotama Block". The changes, which were implemented in 2001, were made under the direction of a multi-stakeholder advisory group (farmers, foresters, local government, researchers). Long-term monitoring of farm system performance and environmental impacts captured the before-and-after response of the changes. The early results were reported at the 2007 NZGA Conference in Taupo (Quinn et al. 2007). The project to date has generated over 150 research papers and been the subject of numerous field days, stakeholder workshops and graduate student projects, as well as contributing to regional planning submissions.

The original objective of the research, to improve the sustainable performance of North Island hill country farm systems, was guided by the vision of "a well-managed hill country catchment". Six high level goals contributing to this vision were developed by the multi-stakeholder group: 1. Sustainable businesses, 2. Healthy ecosystems, 3. Protected landscape values, 4. Active partnerships, 5. Demonstrable environmental performance, and 6. Adequate rural infrastructure. A broad set of key performance indicators (KPIs) was developed to evaluate system performance against those goals (Dodd et al. 2008a). The project then focused on a case study catchment farm at the (then) Whatawhata Research Centre owned by AgResearch. The multi-stakeholder group went through a process of first evaluating the economic and environmental performance of the existing sheep and cattle breeding land use. Modelling of various future scenarios around land use and enterprise change to determine likely impacts on KPIs was then carried out. This enabled the stakeholder group to develop and implement a land use change plan on the block in 2001-2002 (Dodd et al. 2008b).

The core features of the changes were (see Figure 1):

- Pine forestry plantation on 140 ha (54% of whole catchment and 77% of LUC Class VI and VII land).
- Indigenous vegetation restoration on 12 ha (5% of whole catchment) surrounding and connecting 7 ha of indigenous forest fragments around a first order

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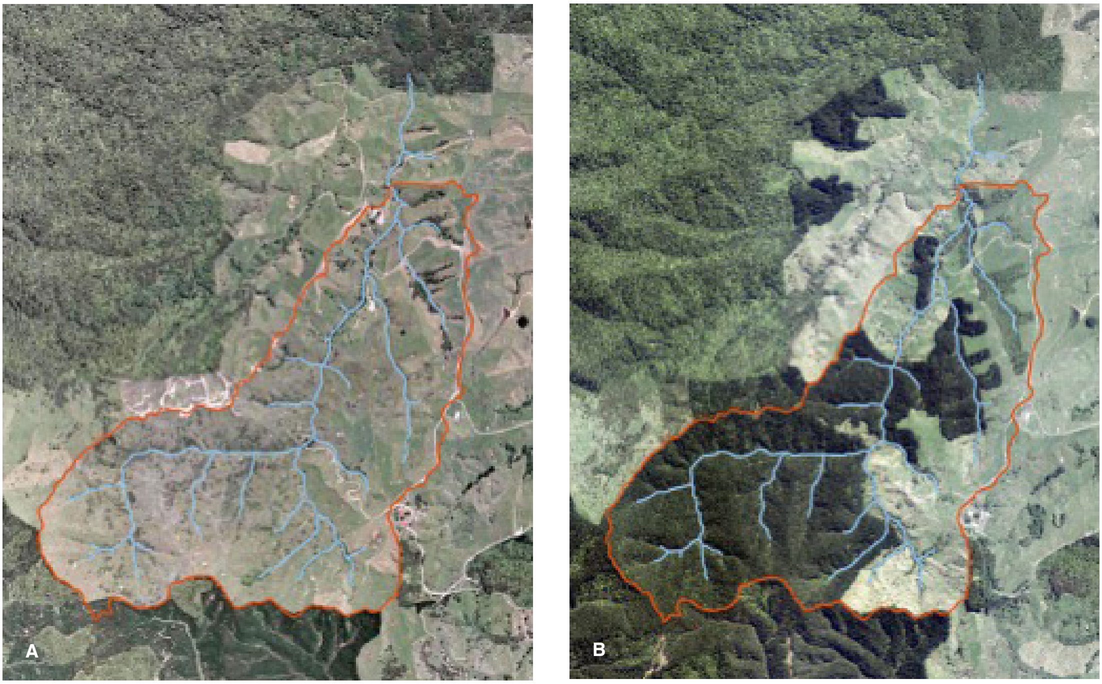

Figure 1 Aerial photo of the 260 ha Mangaotama catchment block in a) 2001 prior to land use changes and b) 2019, with catchment boundary marked in red and streams in blue. Pine plantation areas can be seen as deep green forest cover, native tree planted areas can be seen as expanded riparian forest cover in the top right.

stream. This included planting a range of c. 30 native tree and shrub species incl. tōtara, kauri, karamu, kānuka, puahou, māhoe, kōhūhū, and koromiko.
- Poplar pole spaced planting on erodible land remaining in pasture (1000 stems).
- Exclusion of all livestock from 16.5 km of streams (85% of total stream length) and cattle from all streams.
- The area remaining in pasture (c. 100 ha) was 23% LUC Class IV and 48% Class VI land, on which the key livestock enterprises changed as follows:
    - Transition of the cattle enterprise from beef breeding (Angus) to bull finishing (Holstein-Friesian).
    - Transition of the sheep breeding enterprise (Romney) genetics to a high-fecundity facial eczema resistant flock (Finn × Romney).

In 2016 AgResearch ended their lease of the Whatawhata Research Station land (880 ha) and Tainui Group Holdings Ltd. assumed management of the whole station, including the Mangaotama Block. The animal enterprises across the block have largely remained the same since, with some years carrying dairy grazers in addition to the breeding ewes and bulls. Environmental impact monitoring has continued since the land use changes up to the present day, focusing on three areas: 1. Waterways, 2. Indigenous forest biodiversity, and 3. Greenhouse gas exchange.

The objective of this paper is to provide a further update on progress in these three domains of environmental performance, to assist the hill country stakeholder community in realising expectations from the sorts of management changes widely proposed to improve agricultural sustainability.

Materials and Methods

Waterways

Five stream monitoring sites were established within the Mangaotama block in 1994, including PW5, an end-of-catchment site (Quinn and Stroud 2002). Another key monitoring site was NW5, which is an end-of-catchment site in the adjacent Whakakai catchment. The Whakakai catchment (310 ha) is entirely in native forest, including the Karakariki Scenic Reserve. Catchment flows were modelled with the Soil and Water Assessment Tool (SWAT), calibrated to monthly flow data from the weirs at PW5 and NW5 (Hoang and Hughes 2024). Mean flows were calculated for four area-specific peak flow size categories (<600, 600-1100, 1100-1600, >1600 L/s/km^2) over three multi-year periods: pre-planting (1994-2001); post-planting, pre-canopy closure (2002-2009); and post-planting, post-canopy closure (2010-2024).

Monthly measurements of water quality were made at PW5 and NW5 from April 1995 to September 2020. These measurements included pH, electrical conductivity, turbidity, total suspended solids (TSS), volatile suspended solids (VSS), temperature, dissolved reactive phosphorus (DRP), total phosphorus (TP), nitrate-N (NO_3-N), ammonium-N (NH_4-N), organic carbon and visual clarity (VC). Samples of the faecal indicator bacterium, *E. coli*, were taken from four sites in the upper catchment in 2001-2 and 2004-5 and from the PW5 site in 2018-19. Spring and autumn surveys of water width and depth, macrophytes, benthic sediment, bed sediment and algae were conducted. Fish population surveys were conducted on seven occasions between 2000 and 2021.

An averaging estimator approach was used to calculate sediment, NO_3-N and DRP loads. This used the concentration at the start of the interval (monthly) to estimates flux across intervals. Load is estimated as the sum of loads for each sampled interval weighted by the number of samples taken across the whole period.

The student's t-test was used to determine significant differences ($\alpha = 0.05$) in the mean number of events and sediment yields between multi-year analysis periods.

Indigenous forest biodiversity

In 2000, 17 permanent vegetation sample plots (each 50 m^2) were established in three forest fragments within the Mangaotama Block, with a further 30 plots established in larger native forest areas in the Whakakai catchment (Smale et al. 2008). Measurements in 2000, 2002, 2004, 2008, 2012 and 2019 included plant species identification, vegetation cover across five height tiers, sapling and seedling numbers, tree stem densities, diameters and heights, and woody debris on the forest floor. A further 19 permanent vegetation sample plots (each 50 m^2) were established in 2002 in the native shrub riparian planted areas around the largest bush fragment in the Mangaotama Block. Tree identity, survival and canopy dimensions were measured in 2019.

Greenhouse gas exchange

Biological emissions of CO_2 and N_2O related to the pastoral system were modelled by building a FARMAX model of the pastoral enterprises, and transferring the animal numbers and fertiliser inputs into OVERSEER (Wheeler et al. 2003) v6.3.0. Annual emission factors for excreta and fertiliser use in OVERSEER were thus used to calculate N_2O emissions. OVERSEER does not account for soil methane emissions from the various land cover types, so annual assimilation rates of 0.02 – 0.26 kg CH_4/ha were assumed (Kirschbaum et al. 2012). Emissions of CO_2 from fuel and fertiliser use were also derived from OVERSEER.

Tainui Group Holdings entered the whole Whatawhata Station into the Emissions Trading Scheme in 2017. Eighteen circular mensuration plots (28 m diameter) have been established in the pine forestry area of the Mangaotama Block and were most recently measured in 2022 for stem density, diameter and tree height.

Carbon stocks of non-pine woody vegetation were calculated based on measurements of tree density and dimensions in 2019. For indigenous riparian shrub plantings this included root collar diameters, and tree heights. For indigenous forest fragments this included stem diameters and tree heights. Published allometric relationships between shrub and tree measurements of stem diameter and height were used to calculate tree biomass and carbon stocks (Beets et al. 2012). For spaced plantings of poplars, measurements of survival, stem diameters and tree heights were made in 2018 and biomass calculated with the allometric equations of Lodhiyal et al. (1995) and root:shoot ratios of Guevara-Escobar et al. (2002).

Estimation of soil carbon stock changes were limited by the lack of data across the farm at the beginning of the land use changes. Thirty-four soil sampling sites were established in the native riparian planted areas in 2001 and re-measured in 2019 (0 – 300 mm). A further thirteen soil sampling sites were established in native fragment forest, pasture, and native planted areas in 2001 and re-measured in 2011 (0 – 200 mm). Measurements included dry bulk density and total soil organic carbon content (combustion method) in three soil layers (0 – 300 mm sites) or two soil layers (0 – 200 mm sites) respectively. These small data sets were analysed in an unbalanced ANOVA with measurement year and vegetation type as main effects.

Results and discussion

Waterways

Afforestation of over 60% of the catchment had a marked impact on the hydrology of the Mangaotama stream (Hughes et al. 2020). The impact on stream hydrology was gradual as it was related to the development of forest canopy. Canopy closure increases rainfall interception (mainly through evapotranspiration) and slows the progress of water movement to streams. Canopy closure of the pine forest areas was achieved after approximately eight years of growth (c. 2009). At this point the total flow from the Mangaotama catchment had reduced by around 32%. The afforestation had the most significant impact on floods, with peak flows following heavy rainfall reducing by more than 50% (Table 1).The frequency of larger events (i.e., >3000 l s^{-1}) has also declined, from 3.9 events per year during 1994-2009 (pre-canopy closure) to 0.4 events per year between 2010-2024 (post-canopy closure, A. Hughes, *unpublished data*). No significant difference was detected in the mean number of events during the same periods within the Whakakai catchment (8.3 events per

Table 1 Changes in mean area specific peak flows (L s-1 km-2) from the Mangaotama catchment during eight years before and from 8-16 years after land use changes, relative to concurrent flow size classes in the Whakakai native forest catchment.

Whakakai catchment stream area-specific flow size class	**Mean area-specific peak flow (l s^{-1} km^{-2}) "+/- 1**		
	Whakakai (1994-2016)	**Mangaotama (1994-2001)**	**Mangaotama (2009-2016)**
Low (<600 l s^{-1} km^{-2})	318 ± 124	357 ± 151	148 ± 87
Medium (600-1100 l s^{-1} km^{-2})	780 ± 178	708± 261	349 ± 141
High (1100-1600 l s^{-1} km^{-2})	1427 ± 130	1312 ± 227	758 ± 235
Very high (>1600 l s^{-1} km^{-2})	2293 ± 760	2323 ± 1526	980 ± 389

year from 1994-2009), and 7.4 events per year from 2010-2024). This indicates the reduction in number events is not related to climatic variability.

Analysis of suspended sediment data from 1999 to 2010 did not detect any change in trend in sediment loads (Hughes et al. 2012). A re-assessment using a different load estimation approach and a longer time period compared to the 2012 paper (A. Hughes, *unpublished data*) has found that mean annual specific sediment yield (SSY) during the pre-planting period (1994-2001) was 603±180 t/km^2/y (mean±SE). This decreased to 387±88 t/km^2/y during the post-planting and pre-canopy closure period (2002-2009). In the post-planting and post-canopy closure period (2010-2024) the average annual SSY had decreased to 200±32 t/km^2/y. The differences between the two post-planting periods (2002-2009 and 2010-2024) were significant and the differences between the pre-planting period (1995-2001) and the post-planting, post canopy closure period (2010-2024) was also significant. The mean annual SSY values for the Whakakai catchment for these same three analysis periods were not significantly different between periods. The reduction in SSY in the Mangaotama catchment can be attributed primarily to the reduction in the size and number of flood events in the catchment. The reduction in the number of large erosive events is likely to have lessened the contribution of sediment from bank erosion processes. Furthermore, the protective nature of the forest cover is also likely to have reduced sediment delivery from hillslope erosion processes (e.g., sheetwash and mass movement).

Changes in water quality in the fourth-order stream draining the Mangaotama Block are shown in Table 2, alongside classification according to the relevant standards from the National Objectives Framework (NOF; MfE 2023). Water quality has improved at the catchment outlet in terms of visual clarity and temperature. Statistical analysis of the nutrient concentration data indicated that the small decrease in ammonium-N concentration was significant, but that the increases in concentrations of DRP, nitrate-N and total N were also significant. Note that nitrate-N is approaching the 1000 μgL threshold for band B of the NOF framework. The *E. coli* data from before and after land use change do not align spatially but do suggest that there has been little overall improvement in this measure.

The concentrations of DRP, nitrate-N and Total N have all increased significantly since the implementation of the land use changes. These increases are, in part attributable to the change in stream hydrology mentioned above, whereby lower flows have a concentrating effect on contaminants. Flow modelling to account for this effect indicates that the total amount of nitrate-N discharged from the Mangaotama stream approximately doubled in the period after 2001. Possible reasons for this include a reduction in in-stream plant (macrophyte) nutrient uptake as these plants are shaded out, an increase in catchment-wide nitrogen fixation associated with gorse proliferation in the transition years, and the loss in denitrification capacity associated with small seepage wetlands that have diminished as a result of hydrological changes noted (Hughes and Quinn 2014).

The implications of the increases in nutrient concentrations and decreases in flows for annual catchment loads are that average annual NO_3-N and DRP loads during the pre-planting period (1994-2001) were 1452 and 40 kg/y respectively. During the post-planting, pre-canopy closure period (2002-2009) they were 1493 and 26 kg/y, and in the post-planting, post-canopy closure period (2009-2019) the average annual NO_3-N load had increased to 2029 kg/y while the average annual DRP load was similar to the pre-planting period at 34 kg/y. It is worth noting that these loads are based on monthly monitoring, which tends

Table 2 Changes in median measures of stream water quality at PW5 (Mangaotama near the end-of-catchment site) and NW5 (Whakakai native forest catchment) monitoring sites, for the 6-year period prior to land use changes and the 19-year period after. Underlined data indicates significant differences between the periods. National Objectives Framework (NOF) bands for rivers are noted where relevant (MfE 2023).

Item	Units	NBL	Site	1995-2001	NOF band	2002-2020	NOF band
Visual clarity	Black disc (m)	0.61[1]	PW5	0.71	C	0.90	B
			NW5	1.00	A	1.34	A
Dissolved reactive P	µg/L	n.a.	PW5	14	C	17	C
			NW5	41	D	43	D
Total P	µg/L	n.a.	PW5	38		44	
			NW5	52		54	
Nitrate-N	µg/L	2400	PW5	399	A	793	A
			NW5	102	A	94	A
Ammonium-N	µg/L	240	PW5	11	A	10	A
			NW5	3	A	3	A
Total N	µg/L	n.a.	PW5	584		958	
			NW5	188		149	
Temperature	°C	n.a.	PW5	15.8		13.2	
			NW5	12.4		12.1	
Macroinvertebrates	QMCI	4.5	PW5	4.7	D	5.0	C
			NW5	7.2	A	7.4	A
E. coli	MPN/100 ml	n.a.	PW5	398[2]	E	496[3]	E

[1] Suspended sediment class 2 for river environment classification group Warm Wet Hill
[2] MPN = most probable number, measured over two years at multiple pastoral sites (Donnison et al. 2004) [3] measured at PW5 for one year from July 2018.

to under-represent higher flow rates and thus underestimate the true loads (Elwan et al. 2018) – important given the shift in overall flow patterns (Table 1).

In terms of aquatic fauna, two key groups are of interest in reflecting the status of aquatic habitat, namely macroinvertebrates (i.e, aquatic insects, snails, worms, etc.) and fish (mainly eels). There was no clear trend in the fish density or species richness data at any of the sampled sites. There was some evidence that there was a shift from shortfin to longfin eel species dominance at some sites. This may be attributed to the transition from pasture conditions to forested conditions (preferred by longfin eels). The Mangaotama catchment also has a series of natural and artificial barriers to fish passage that may reduce connectivity and inhibit fish passage. The macroinvertebrate community index has been highly variable at the PW5 site, with no clear trend following the land use changes.

Indigenous forest biodiversity

Some aspects of forest fragment condition have improved as a result of fencing, pest control and native tree planting. Before and after differences are shown in Table 3, along with a comparison against un-restored fragments in never-grazed areas within the nearby Karakariki Scenic Reserve. While native plant species richness in the restored on-farm fragments has not changed over 19 years, other indicators of structure have improved towards the levels seen in ungrazed forest. These include a reduction in bare ground surface in favour of an increase in ground surface litter cover, an indication of less livestock disturbance, and an increase in woody biomass through both mature tree growth and the development of saplings into the size range that defines individually measured trees (DBH>3 cm). Most striking is the increase in sapling regeneration and vegetation cover in the 0.3–2.0 m forest tier, as these fragments are no longer browsed by cattle. Many of these saplings will ultimately be subject to competitive suppression via shading by other canopy tiers. This effect is indicated by the fewer and more stable sapling numbers in the reserve.

While these measurements were made in a 3-ha area in the lower catchment, a further 5 ha of forest

Table 3 Changes in native bush fragment structure from 2000-2019 following fencing and pest control.

Item	Units	2000	2019	Reserve forest
Species richness	Species per 50 m^2 plot	24	24	33
Sapling regeneration	stems/ha	20	10 600	6800
Foliage cover 0.3-2.0 m	%	11	24	32
Foliage cover 2.0-5.0 m	%	34	31	37
Bare ground surface	%	15	3	4
Litter ground cover	%	46	69	78
Tree basal area	m^2/ha	51	64	61
Woody debris	m^2/ha	8	10	22

fragments within the pine plantations and approx. 13 ha of riparian area left unplanted among pine forestry represents additional opportunity for natural native regeneration in ungrazed situations. Observations from sequential photo points are that tree ferns have become particularly abundant in these unplanted areas. While there has also been substantial growth of native shrubs and trees under the pine canopy, it is inevitable that these will be damaged upon pine harvesting.

Greenhouse gas exchange

There are a number of impacts on GHG emissions and mitigations as a result of the land use changes, including C sequestration in tree plantings (native, poplar and pine) and in recovering native bush fragments, as well as the reduction in biogenic methane and nitrous oxide emissions associated with the changes in livestock enterprises (Table 3).

The pine plantation has clearly dominated the reductions in net emissions, bearing in mind that at this point the trees are 25 years of age and likely to be maximising annual growth increments. Over multiple future planting cycles the long-term average sequestration rates will reduce, as reflected in the 'averaging' approach recently implemented in the NZ Emissions Trading Scheme (ETS). For example, in this situation over three rotations the average net sequestration rate was modelled to be c. 5 t CO_2-e/ha/y (Dodd et al. 2020).

Survival of native shrubs and trees in the planted areas was approx. 75% after 18 years. While most plants established well in the first 3 years, the increase in canopy cover has suppressed some, along with natural death of short-lived shrub species and some early losses of kauri due to frost, which were not replaced at the time. The increase in forest fragment biomass indicated by the basal area change (Table 3) is also reflected in the carbon stock change of 1.4 t C/ha/y in Table 4. By comparison, the carbon stock change in nearby grazed bush fragments over this period was much lower, at 0.85 t C/ha/y (Dodd et al. 2020).

In terms of the biogenic CH_4 emissions, the change in livestock enterprises led to a 45% reduction in the breeding ewe flock and a 55% reduction in wintered cattle numbers, broadly in line with the reduction in pastoral land area. This was reflected in the 56% reduction in livestock emissions, compared to an estimated 52% reduction in pasture intake as a result of retaining the higher productivity land classes within the pastoral area (Dodd et al. 2008b). This level of emissions reduction more than meets recent policy indications of the need for a 25–47% reduction from livestock systems (Reisinger and Leahy 2019), but was predominantly as a result of reduced stocking rates. However, emissions intensity has improved dramatically, from 25.0 to 15.1 kg CO_2-e/kg product, because of greater lamb and beef liveweight production per hectare.

Overall, the land use and management changes have transformed the catchment farm system from a net source to a net sink over the 19-year period (Table 4). Long-term modelling projections indicate that this will remain so beyond a 100-year time frame, until ongoing livestock emissions catch up to the long-term average C stocks contained in the tree vegetation (Dodd et al. 2020).

Carbon stocks also occur in soil, with a depth of 300 mm being the conventional benchmark for measurement (IPCC 2003). Although these are not currently accounted for in the ETS, there is much interest in the potential for soil C sequestration in agricultural systems. Table 5 shows the changes in soil carbon stocks for the two small studies using repeat measurements at the same sites, across a range of vegetation types. The year effect of a mean decline in C stocks was significant in both the 0 – 300 mm data set (-0.80 t C/ha/y, $p<0.01$) and the 0 – 200 mm data set (-1.3 t C/ha/y, $p<0.01$), with no significant vegetation by year interaction and no vegetation or year effect on soil bulk density. It should be emphasised that these data are insufficient to establish a trend with any real confidence

Table 4 Measured vegetation carbon stock changes and modelled farm system emissions.

Item	Rates of vegetation C stock change (t C/ha/y)	Net emissions in 2000 (t CO_2-e)	Net emissions in 2019 (t CO_2-e)
Tree planting – pines	+17.6	-62	-9505
Tree planting – native shrubs	+4.8		-100
Scrub regeneration	+4.4		-88
Tree planting – native trees	+2.1		-17
Forest fragment regeneration	+1.4	-26	-42
Tree planting – poplars	+0.4		-15
Livestock CH_4 emissions		+891	+398
Soil N_2O emissions		+230	+91
Energy use emissions		+47	+22
Total		+1080	-9256

Table 5 Soil carbon (C) stock changes under areas of permanent pasture, permanent native bush, pine forest and native shrub planted into pasture. Different letters denote significant differences between values within a study.

Study	Initial vegetation (# sites)	Initial C (t C/ha)	Current vegetation	Final C (t C/ha)	LSD (0.05)
2002-2021 (0 – 300 mm)	Pasture (4)	121.9 ab	Pasture	94.1 b	28.8
	Pasture (4)	113.0 ab	Gorse	95.1 b	
	Pasture (19)	107.6 b	Planted native shrub	99.4 b	
	Pine (6)	139.8 a	Planted native shrub	114.4 ab	
2001-2011 (0 – 200 mm)	Pasture (2)	110.4 a	Pasture	83.1 ab	32.1
	Pasture (5)	114.1 a	Planted native shrub	102.4 ab	
	Grazed native bush (6)	81.0 ab	Fenced native bush	72.1 b	

(note the large LSD values), but long-term increases and decreases in soil carbon across fertiliser input rates on pasture have been observed at Whatawhata (Schipper et al. 2011). A more comprehensive sampling of c. 70 sites balanced across vegetation, soil types and topography has been recently undertaken in anticipation of future re-sampling to investigate land use change impacts.

Overall, many of the environmental outcomes were consistent with the expectations of the advisory group, such as improved water quality in terms of reduced temperature and ammonium concentrations (brought about through shading and animal exclusion); reduced streamflow and event size from pine tree planting; and improved native plant regeneration through stock exclusion from bush fragments. Some anticipated effects were difficult to detect. For example, no reduction in sediment load was initially detected, which was attributed to high inter-annual variability in loads, but subsequent longer-term analysis has shown a sediment load reduction. In addition, no change in aquatic fauna populations were detected, although natural barriers to fish passage may be a significant limiting factor. Other effects were contrary to expectations, such as the increased nitrogen concentrations in streams and total nitrogen export – for which the reasons remain unclear. If the soil organic C stock changes in Table 5 reflect a wider catchment farm pattern, the resultant loss of soil organic N to mineralisation could be a futher contributor.

Greenhouse gas emissions did not feature strongly in the deliberation and planning of the original multi-stakeholder group, but tree planting and the reduction in animal numbers have had predictable effects on the net GHG exchange.

Conclusions and Practical Implications

Improvements in the various indicators of environmental performance occur at very different time scales – from months to decades. Long-term impact monitoring is critical for understanding lag times in environmental indicators, in order to inform decision makers (both farm practice and policy) about realistic expectations for environmental improvement from land use and management change.

The changes in land use and management that were made are still considered to be appropriate for improving the environmental and economic performance of hill country pastoral landscapes, because of the multiple benefits demonstrated. However, care must be exercised in setting time-bound targets for improvement. We are still learning about the long-term dynamics of these biological systems, lessons which were not able to be identified from the simple point-in-time land use comparisons that have featured in earlier research and policy development.

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