Medium-term impacts of grassland and forestry integration on the environmental performance of a New Zealand pastoral system

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Abstract
At the IGC in 2008, we presented a paper outlining a project that aimed to improve the economic and environmental performance of a New Zealand hill country pastoral catchment farm system. This project was undertaken by engaging a wide group of sector stakeholders in visioning, modelling, planning and implementing significant land use change within a 296-hectare pastoral farm. In recognition of developing sectoral views of agricultural sustainability, the major changes involved pine afforestation, livestock production intensification, protection of waterways and indigenous bush restoration. The report in 2008 outlined the positive impacts on key farm systems and water quality performance indicators after 4 years. Additional data on these and other parameters have been collected in the subsequent 20+ years. Some indicators have not followed expectations – in afforested sub-catchments, nitrate-N concentrations in drainage waters have steadily increased and no significant decreases in annual suspended sediment loads have been detected. Other indicators have changed as expected – with the exclusion of livestock access to riparian areas, indigenous bush understory has regenerated and stream ammonium-N concentration spikes have decreased; and stream water temperatures have decreased with headwater afforestation. Improvements in animal productivity have reduced emissions intensity from 25 to 15 kg CO_2-e per kg product. Afforestation and associated carbon sequestration have more than offset livestock and soil emissions to move the system from a net CO_2 source to a projected net CO_2 sink for the next 100+ years.

Introduction
Intensive livestock grazing enterprises cover some 5M hectares of low altitude steep land in the North Island of New Zealand (Mackay 2008). These systems were developed from temperate mesic evergreen forests in the Early 20th century through the introduction of European grassland species. They are typically dominated by family-based, owner-operator sheep and cattle breeding systems, producing meat and wool for export markets. The soft-rock sedimentary soils are highly erodible under intensive grassland systems (>8 ewe equivalents per hectare). They are also of naturally low fertility and phosphatic fertilisers are imported to support legume-based nitrogen fixation. The sector is market-led and producers are reliant on international commodity prices for meat and wool, mediated by corporate processor/wholesalers, with limited ability to influence target markets (McDermott and Scrimgeour 2016). There is increasing pressure from global consumers and local urban-based communities for these systems to reduce environmental impacts in three key areas: losses of sediment and nutrients to water bodies (Larned et al. 2016), greenhouse gas emissions (GHG, Reisinger and Leahy 2019), and indigenous biodiversity (Maseyk et al. 2019). Most of the available options to respond to this pressure are expensive to implement relative to farm system profitability (Daigneault et al. 2018).

In 1995, a long-term sustainable agriculture research project was initiated at the former Whatawhata Research Centre, in the western Waikato region (Dodd et al. 2008a). It started with the formation of a multi-stakeholder oversight group made up of decision-makers in the domains of policy, (government agencies), practice (farmers, foresters, conservationists) and research (agricultural, environmental and social). This group went through a facilitated process of agreeing on a vision and goals for the generic socio-ecological system of interest "well-managed hill country", assembling relevant indicators to assess the state of a specific system relative to those goals and evaluate progress towards them, then applying those indicators to a specific land block ("Mangaotama"). The block in question was a 296-ha catchment within the larger research centre, which at the time was almost entirely vegetated in moderate-high producing pasture (with only c. 8 ha of indigenous forest remnants in small gullies exposed to grazing), contained 20 km of waterways, included beef and sheep breeding enterprises, and represented a system approx. half the size of typical commercial farm systems in this environment. Based on performance data gathered from 1995-2001, the stakeholder group concluded that the Mangaotama block was failing to meet agreed goals, in terms of forage production, soil erosion, weed management, animal production, water quality, indigenous biodiversity, profitability and return on capital.

A substantial programme of investment was undertaken in 2001-2002 to reconfigure the system and integrate multiple enterprises for the purpose of improving long-term performance across the relevant indicators. The initial cost of implementing these changes amounted to NZ$425k (Dodd et al. 2014):

- 153 ha of afforestation with *Pinus radiata* in a 28-year rotation to clear-fell, on the areas of the block assessed as the lowest performing from an animal production point of view (52% of land area). This included exclusion of livestock from 17 km of waterways and 3 ha of indigenous forest remnants.
- Planting 3000 wide-spaced poplar poles on erodible slopes remaining in pasture (c. 30 ha).
- Fencing of 5 ha of indigenous forest remnants within areas remaining in pasture and supplementary planting of 9 ha of indigenous tree and shrub species (5% of land area).
- Genetic improvement of the sheep enterprise with high fecundity and facial eczema-resistant sires.
- Replacement of the beef breeding enterprise with bull finishing, taking ex-dairy progeny from weaning to 18 months (slaughter prior to their second winter to avoid heavy stock on erodible slopes).

At the IGC in 2008 we reported on the short-term outcomes of these changes for the key performance indicators (Dodd et al. 2008b). Improvements in soil fertility and forage production related to a shift in the pastoral enterprises to the better-performing land units (43% of land area). Improved animal performance was driven by greater sheep fecundity (109 to 124% lamb weaning) and an increase in the consumption of available forage by young lambs and bulls, resulting in an increase in meat productivity which was only 24% lower than that produced on the original 296-ha block. As a result, the annual surplus of the pastoral enterprises went from a multi-year average of NZ$181 to NZ$285 per grazed hectare. Annual export of sediment and phosphorus from the catchment was reduced by 76% and 60% respectively. Most of the early production, profit and environmental indicators were positive for the 4 years after land use and management changes.

Since 2016 the operational management of the block has reverted to indigenous Māori (Waikato-Tainui) who have largely maintained the systems put in place in 2001 and allowed for ongoing monitoring of outcomes by the research teams. This paper updates medium-term outcomes for key environmental indicators, given the longer-term aspirations of the original multi-stakeholder oversight group for improving system performance.

Methods

System performance has been monitored in the 20+ years since the land use and management changes, within the Mangaotama and the adjacent Whakakai indigenous forest catchment. The Whakakai is a ‘reference’ catchment for water quality covered in largely undisturbed indigenous forest. On-farm, the animal enterprises have been modified by the farm managers in response to economic drivers, such as including the wintering of dairy cows, dairy heifer grazing as these represented the most profitable options in the short term. In addition, the forestry blocks have gone through a standard pruning and thinning regime from 2008-2011 to reach final tree stocking rates (c. 340 stems/ha). Key performance metrics have been monitored as follows:

1. Exotic and indigenous tree and shrub growth and species composition of indigenous forest remnants.
2. GHG emissions from animal enterprises modelled in Overseer® (https://www.overseer.org.nz/).
3. Calculation of carbon sequestration in planted trees and indigenous forest remnants using growth data in #1 and published allometric equations.
4. Estimation of the whole system GHG balance, based on data from #2 and #3.
5. Water quality via monthly sampling of 5 sites for water clarity, concentrations of suspended sediment, dissolved reactive P, nitrate-N, ammonia-N, water temperature and invertebrate fauna.
6. Calculation of the macroinvertebrate community index (QMCI) from #5; intermittent fish surveys.

Results and Discussion

Greenhouse gas balance

Annual livestock biogenic CH_4 and soil N_2O emissions have reduced by 54%, largely proportional to the 55% reduction in grazed area. From an emissions intensity perspective, the increased animal productivity has led to a large reduction, from 25 to 15 kg CO_2-e per kg product. Relative carbon sequestration rates in biomass for the various tree and shrub plantations over 20 years were: space-planted poplars 1.5; native tree afforestation, 5.5; native shrub riparian planting 16.7; pine afforestation 64.5 t C/ha/y. As expected, the rapid growth rates, high survival and thinning management of the pine forest has resulted in the greatest sequestration rates per unit area and overall. Sequestration rates for the poplars and native trees were reduced by low tree survival rates (44% and 40% respectively). In addition, increases in biomass were recorded in forest fragment areas (8 ha) following exclusion of livestock at 5.2 t C/ha/y, a factor not currently accounted for in accreditation schemes, since the areas are considered pre-1990 forest. The total C stocks sequestered in all woody vegetation over 20 years has amounted to c. 186 Mg.

In terms of the whole farm system GHG balance, based on IPCC methane and nitrous oxide CO_2-e equivalent GWP values (IPCC 2007), the levels of afforestation and associated carbon sequestration have more than offset livestock and soil emissions to move the system from a net CO_2-e source to a projected net CO_2-e sink for the next 100+ years, assuming the current levels of afforestation are maintained. Given that a split gas approach will be implemented in national policy, the system has also achieved biogenic methane reductions well above the target range of 25-47% (Reisinger and Leahy 2019).

Indigenous Biodiversity

The two main components of indigenous biodiversity of interest were related to the vegetative restoration of indigenous forest remnants through livestock exclusion, feral pest control and supplementary tree and shrub planting, and the aquatic faunal communities, consisting of invertebrates and fish. Forest recovery has been dominated by sapling proliferation, such that understory tree densities have significantly increased from 270 to 1700 stems/ha and vegetative cover in the 0-2 m height tier has increased from 8 to 30%. These changes were not observed in forest fragments left open to livestock browsing. Native plant species richness has not changed substantially, although the number of exotic adventive plant species on the forest floor has declined.

In the streams, macroinvertebrate species richness initially declined at two sites in the 10-year period following land use change, possibly due to both unfavourable climatic conditions (a similar effect was seen in the undisturbed Whakakai indigenous forest catchment) and disturbance associated with afforestation activities. However, the most recent 10-year period has seen those richness numbers recover. At the Mangaotama catchment outlet, fish densities have significantly improved from 1 per m^2 to between 2-3 per m^2, though without any indication of increased species richness. This is likely related to downstream dispersal limitations.

Water quality

The impact of land use changes on water quality have been mixed in terms of the sought-after improvements. Table 1 shows the results measured at the catchment outlet for the 7-year pre-change period (1995-2001) and the 18-year post-change period (2002-2019), in comparison to the adjacent Whakakai catchment.

Table 1. Effects of land use change on water flows and quality attributes in the adjacent Mangaotama (pasture and pine) and Whakakai (indigenous forest) catchments. Medians of monthly sampling during the pre-change (1995-2001) and longer post-change (2002-2019) periods. Significant changes are indicated in bold text.

Water flows and quality attributes at the catchment outlet site	**Mangaotama**		**Whakakai**	
	Pre	Post	Pre	Post
Mean flow for events of 0.1 annual exceedance probability	3991	**2171**	2554	3031
Temperature (°C)	15.8	**13.2**	12.3	12.0
Clarity (m)	0.75	0.90	1.00	1.34
Total suspended sediment (mg/L)	7.1	6.4	2.8	2.4
Dissolved reactive P (µg/L)	14	**17**	41	43
Nitrate-N (µg/L)	399	**793**	102	**94**
Ammonium-N (µg/L)	11	**10**	3	3
Total organic N (µg/L)	195	**135**	70	**52**

The afforestation within the Mangaotama catchment has resulted in reduced stream flows, averaging 38% per annum. The reduction in flow is likely to be largely the result of interception of rainfall by the dense forest canopy. Stream temperatures have reduced significantly, consistent with expectations based on an increase in the proportion of stream length shaded by woody vegetation, from 14% to 75% of the total reach. This will have been beneficial for stream macroinvertebrates that are sensitive to high temperatures, and the QMCI has increased at all sites by 0.3 to 1.7 units. While large-scale erosion has visibly reduced, specific sediment yield (flow × suspended sediment concentration) from the Mangaotama has not declined, being 94 t/km^2/y pre-change and 101 t/km^2/y post-change, in contrast to the short-term indications of a reduction (Dodd et al. 2008b). While clarity shows an improving trend, this was not significant and occurred in both catchments.

High temporal variability in QMCI, suspended sediment and clarity has been a feature of the record and obscured clear signals. Concentrations of DRP (reactive phosphorus) and nitrogen species in water have increased significantly, while they remained about the same in the Whakakai catchment. The increase in DRP is not substantive. The main pattern of interest for ammonium-N was a large decrease in variability, such that concentration spikes now rarely occur, attributed to the exclusion of cattle from streams. The reasons for the large increases in nitrate-N may relate to decreasing flow, or the reduction in denitrification activity as wetlands have reduced in area in response to afforestation (Hughes and Quinn 2019).

Conclusions and Implications

Indigenous terrestrial forest plant biodiversity is showing early signs of recovery with livestock exclusion, but aquatic faunal diversity appears to have changed little to date. Water quality has not improved across the board, as some may have expected with the changes in land use that were aimed at achieving such impacts. It seems likely that the legacy effects of c. 80 years of agricultural development in this landscape will take much longer than a generation to be mitigated. However, the overall impact on the GHG balance of the system has been strongly positive, whether from an emissions intensity or a total emissions perspective. The key issue for this system as an example of a (small) owner-operator farm system, is the substantial cost of transition relative to profitability and the sufficiency of farm profit in the years prior to significant forestry income.

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References

Daigneault, A., Greenhalgh, S. and Samarasinghe, O. 2018. Economic impacts of multiple agro-environmental policies on New Zealand land use. *Environmental and Resource Economics*, 69: 763-785.

Dodd, M.B., Carlson, W., and Silcock, P. 2014. The economics of transformation toward sustainable hill country land us: Whatawhata case study. *Proceedings of the New Zealand Grassland Association*, 76: 163-168.

Dodd, M.B., Wedderburn, M.E., Parminter, T.G., Thorrold, B.S. and Quinn, J.M. 2008a. Transformation toward agricultural sustainability in New Zealand hill country pastoral landscapes. *Agricultural Systems*, 98: 95-107.

Dodd, M.B., Wedderburn, M.E., Parminter, T.G., Thorrold, B.S. and Quinn, J.M. 2008b. Improving the economic and environmental performance of a New Zealand hill country pastoral catchment. *Proceedings of the XXI International Grasslands Congress*.

Hughes, A.O., and Quinn, J.M. 2019. The effect of forestry management activities on stream water quality within a headwater plantation *Pinus radiata* forest. *Forest Ecology and Management*, 439(1): 41-54.

Inter-governmental Panel on Climate Change. 2007. *Climate change 2007: the physical basis*. Cambridge University Press, Cambridge.

Larned, S.T, Snelder, T. Unwin, M.J., and McBride, G.B. 2016. Water quality in New Zealand rivers: current state and trends. *New Zealand Journal of Marine and Freshwater Research*, 50(3): 389-417.

Mackay, A.D. 2008. Impacts of intensification of pastoral agriculture on soils: Current and emerging challenges and implications for future land uses. *New Zealand Veterinary Journal*, 56(6): 281-288.

Maseyk, F.J.F., Dominati, E.J. and Mackay, A.D. 2019. More than a 'nice to have': integrating indigenous biodiversity into agroecosystems in New Zealand. *New Zealand Journal of Ecology*, 43(2): 3372.

McDermott, A.K., and Scrimgeour, F.G. 2016. Consumers, farmers and the future of New Zealand Hill country farming. In: *Hill Country Symposium*. Research and Practice Series No.16. New Zealand Grassland Association, Dunedin.

Reisinger A, and Leahy S. 2019. *Scientific aspects of New Zealand's 2050 emissions targets.* New Zealand Agricultural Greenhouse Gas Research Centre, Palmerston North. 20 pp. https://www.nzagrc.org.nz/user/file/Scientific aspects of 2050 methane targets.

Vogeler, I., Cichota, R., and Beautrais, J. 2016. Linking land use capability classes and APSIM to estimate pasture growth potential for land use planning. *Soil Research*, 54(1): 94-110.