Factsheet 2: Cost-effectiveness of pine planting for improving water quality, greenhouse gas mitigation and biodiversity. Whatawhata case study

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Background

In 2001, a number of land management changes were implemented within the 260 ha Mangaotama catchment on the then Whatawhata Research Centre. These changes were made under the direction of a multi-stakeholder advisory group, for the purpose of investigating ways of improving the economic and environmental performance of a hill country mixed livestock farm (Dodd et al. 2008).

Planting of *Pinus radiata* for timber production was a major part of the changes implemented. This occurred in three main blocks across the farm:

1. an 88 ha sub-catchment draining to a fourth-order stream (PW2), which previously had been pasture covering easy to steep hill country with some scrub reversion (Fig. 1a). The basin is mainly north to east aspect (63%) and >15° slope (80%) with 7.5 km of total stream reach. In 2001, radiata pine trees were planted in the entire sub-catchment, though a 10 m wide buffer zone around the streams (as per consenting rules) meant that the immediate stream banks themselves were not planted. The establishing trees (79 ha NSA) were fenced around the top of the basin to exclude livestock (Fig. 1b).
2. a 32 ha sub catchment draining to a second-order stream (PR1), which previously had been pasture covering rolling to easy hill country with some scrub reversion (Fig. 1a). The basin is mainly east and west aspect (60%) and 8-25° slope (77%) with 2.6 km of total stream reach. In 2001, radiata pine trees were planted in the steeper slopes adjacent to the streams, though a 10 m wide buffer zone around the streams (as per consenting rules) meant that the immediate stream banks themselves were not planted. The establishing trees (11 ha NSA) were fenced to exclude livestock (Fig. 1b).
3. a 47 ha sub-catchment draining to a second-order stream (PW3), which previously had been pasture covering rolling to steep hill country with some gully bush remnants (Fig. 1a). The basin is mainly north to east aspect (70%) and >8° slope (90%) with 2.9 km of total stream reach. In 2001, radiata pine trees were planted in the steepest west slope of the sub-catchment, with minimal planting adjacent to streams. The establishing trees (16 ha NSA) were fenced to exclude livestock (Fig. 1b).

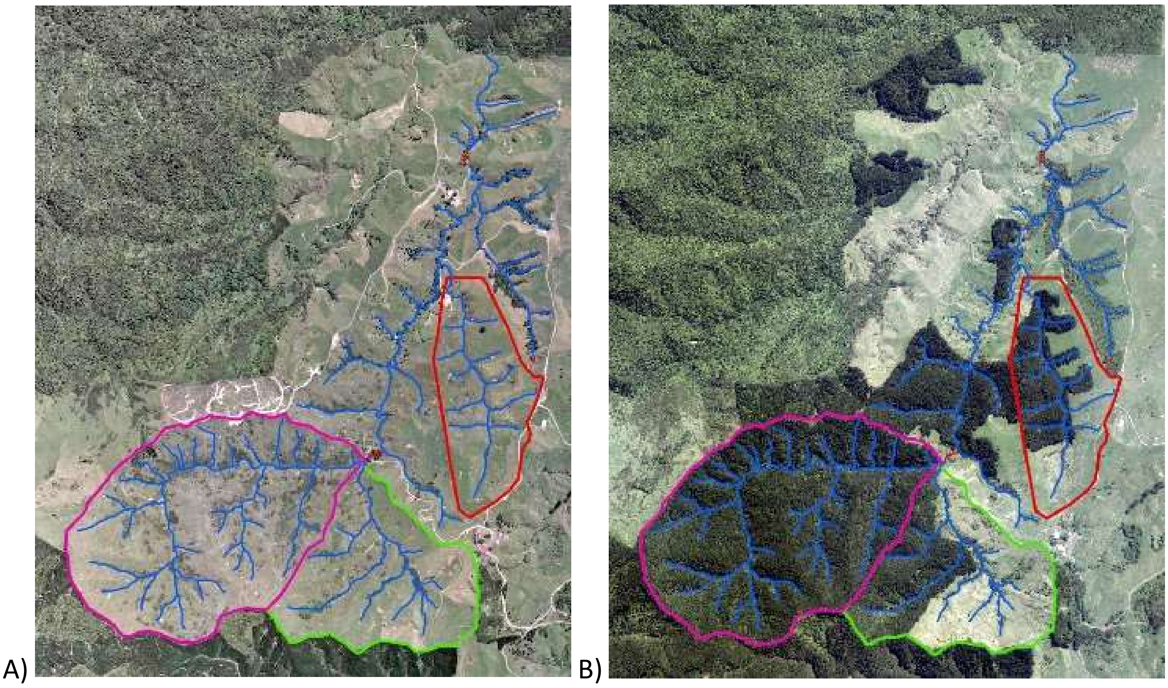

Figure 1: Case study pine-planted sub-catchments in a) 1995 prior to the management change and b) 2016 after pine planting. Sub-catchment boundaries with pines are shown in purple (PW2), red (PR1) and green (PW3) and streams for the whole catchment block are shown in blue.

Measurements

At the stream outlet of the three blocks NIWA had established a stream monitoring site in 1995 (PW2, PW3) and 2000 (PR1) and monthly measurements of water quality continued from then until 2020. These measurements included the concentrations of nitrate-N, ammonium-N, dissolved reactive phosphorus (P) and water clarity (described in Hughes & Quinn 2014). Additional measurements included stream flow, channel shade, water temperature, macroinvertebrate communities and fish. The Pre-change period ran from 1 Jan 1995 to 31 Dec 2001 (7 years) while the post-change period ran from 1 Jan 02 to 31 Dec 20 (19 years). An additional stream site in a third-order stream draining adjacent native bush catchment (NW5, 100 ha) was also measured over the same period as a reference site.

Tree growth has been measured by the original forestry management company (NZForestry Ltd) for which block average data are available. In 2022, individual PSP data from 20 plots were available from PFOlsen (used to comply with the reporting requirements of the Emissions Trading Scheme).

Management

The radiata pine tree management regime was as follows (Woortman 2010):

Planting	1000 stems/ha in 2001
First prune	May-November 2006
Second prune	June 2007-January 2008
Third prune	May-July 2008, pruned height 6.7-7.0 m
First Thin	December 2007, stocking ~700 sph
Second thin	November 2009, final stocking mean 340 sph

Mean DBH was 23.8 cm and mean height was 10.8 m in 2010 (Woortman 2010). Mean DBH was 22.6 cm and mean height was 14.5 m in 2017 (C. Branch, *pers. comm*). In 2022, mean DBH was 47.2 cm and mean height was 27.2 m (H. Foxwell, *pers. comm*) and there were no significant effects of slope or aspect on either measure of tree size.

Costs

Costs of establishment and management of the planted area over 20 years are shown in Table 1, which to this point sum to approx. $10 000/ha. As of 2014, the predicted harvest value of the forest for 2029 within these three sub-catchment areas was $2.03M.

Table 1: Actual costs of pine establishment in three sub-catchments at Whatawhata. PW2 = 100% pines, PR1 = 42% pines, PW3 = 36% pines

Item	**Detail**	**Period (Years)**	**PW2 ($)**	**PR1 ($)**	**PW3 ($)**
Planning	Management	Y1	7900	1100	1600
New fencing	7-wire post and batten	Y1	0	3200	2000
Planting	1000 stems/ha	Y1	94 500	13 200	19 100
Maintenance	Weed, pest, disease, access	Y2-20	184 100	25 600	37 300
Silviculture	Pruning, Thinning	Y7,9	272 100	37 900	55 100
Lost grazing	Livestock GM $150 ha^{-1}	Y1-20	267 000	36 000	48 000
Total		Y1-20	**825 600**	**117 000**	**163 100**

NB. Not included are the costs of measuring the changes in water quality and vegetation.

Benefits: water quality

Four water quality attributes relevant to these streams are covered by the National Objectives Framework (NOF, MfE 2020): nitrate concentration, ammonium concentration, dissolved reactive phosphorus concentration and suspended fine sediment (measured by visual clarity). The effects of pine plantation on these are shown in Table 2, based on monthly sampling for the 7-year period prior to planting and the 19-year period after planting.

Median nitrate concentrations have significantly increased since pine planting (Hughes & Quinn 2019) but have only crossed the NOF threshold into the B Band in the PW2 fully planted stream (Fig. 3a). By contrast, median ammonium concentrations have significantly decreased in the PW2 and PW3 streams and significantly increased in the PR1 pine riparian stream (Fig. 3b). While median DRP concentrations have also significantly increased in the fully planted PW2 stream, they have not changed in the other two streams, and it is notable that all levels remain below that measured in the adjacent native bush catchment (Fig. 3c). Visual clarity has improved in the fully planted PW2 and partially planted PW3 streams but reduced substantially from an initially high level in the PR1 pine riparian stream (Fig. 3d). Total nitrogen and total phosphorus have also been measured in these streams, with the results broadly similar in direction to those seen for nitrate and DRP.

Table 2. Changes in median measures of stream water quality at three pine planted sub-catchments, before fencing and planting (1995-2001) vs. after fencing and planting (2002-2020). The percentage of upstream area in pine is indicated for each site. National Objectives Framework (NOF) bands and national bottom lines (NBL) for rivers are noted where relevant (MfE 2023).

Item	Units	NBL	Site (% pines)	1995-2001	NOF band	2002-2020	NOF band
Visual clarity	Black disc (m)	0.61[1]	PW2 (100%)	0.54	D	0.60	D
			PR1 (42%)	1.67	A	1.21	A
			PW3 (36%)	0.63	C	0.91	B
Dissolved reactive P	µg L^{-1}	n.a.	PW2 (100%)	20	D	40	D
			PR1 (42%)	5	A	5	A
			PW3 (36%)	29	D	30	D
Nitrate-N	µg L^{-1}	2400	PW2 (100%)	450	A	1350	B
			PR1 (42%)	54	A	258	A
			PW3 (36%)	753	A	919	A
Ammonium-N	µg L^{-1}	240	PW2 (100%)	13	B	10	B
			PR1 (42%)	8	B	13	B
			PW3 (36%)	16	B	11	B
Temperature	°C	n.a.	PW2 (100%)	15.5		14.0	
			PR1 (42%)	16.6		14.5	
			PW3 (36%)	15.4		14.8	
Macroinvertebrates	QMCI	4.5	PW2 (100%)	3.9	D	6.6	A
			PR1 (42%)	-		-	
			PW3 (36%)	4.0	D	6.6	A

[1] Suspended sediment class 2 for river environment classification group Warm Wet Hill

The reasons for the inconsistent responses in stream water quality after pine plantation remain unclear. Reductions in ammonium-N would be consistent with livestock reductions as the main source of N in urine. However, other dynamics appear to be influential (Hughes & Quinn 2014, 1019). These include reductions in flow rates (a reverse dilution effect), drying out of upland seepage wetlands which may have previously transformed soil N to gaseous emissions, and a reduction in aquatic plants through shading, which may have previously taken up dissolved N in streams. Visual clarity improvements would be consistent with a reduction in sediment derived from hillslope erosion under trees. The minimal improvement in the PW2 fully planted stream may be due to a loss in bank stability as herbaceous plants on these areas are shaded out (Davies-Colley & Hughes 2020). The significant reduction in clarity at the PR1 riparian pine stream may be related to forage cropping activities in the upper part of this basin during 2005-2010.

Where pine trees were planted and indigenous shrubs developed in riparian margins, shade levels increased over time from <20% to >90% by 2018. Water temperature has declined in all three planted basins (Fig. 4). These reductions in water temperature have been most marked in PW2 fully planted and PR1 pine riparian, where most stream banks are shaded. This is expected to be beneficial for aquatic life, particularly sensitive macroinvertebrates. In PW2 and PW3 the QMCI scores increased from ~4.0 to 6.6 as a result of pine planting.

Benefits: greenhouse gas mitigation

Increases in carbon stocks of the pine planted area over 21 years are shown in Table 3. Measured data relates to biomass carbon stocks for tree stems calculated with allometric equations (Moore 2010) using measured aboveground stocking rate, diameter and height. The equivalent aboveground stocks have been derived from the CenW model (Dodd et al. 2020). This model also produces a figure for total forest stocks, which can be compared with the relevant quantity that would be credited in the ETS using lookup tables. Measured growth at this site appears to have been about 42% greater than the MPI regional lookup table estimates for pine forest.

Table 3: Comparative CO_2-e sequestration rates over 21 years

Item	**Source**	**CO_2-e (t ha^{-1}) @21y**
Whatawhata pine tree carbon	Measured aboveground	660
Whatawhata pine tree carbon	Modelled aboveground (CenW)	766
Whatawhata pine tree carbon	Modelled total tree (CenW)	883
Pine ETS carbon	MPI lookup tables (Waikato region)	536

Sources: https://www.legislation.govt.nz/regulation/public/2022/0266/latest/LMS709973.html

Additional GHG mitigation benefits accrue from the reduction in livestock and soil emissions associated with the area now excluded from grazing in each of the sub-catchments (Table 4).

Table 4: Measured carbon stock changes and modelled emissions reductions (OverSEER) from pine planting in three sub-catchments at Whatawhata.

Item	**Detail**	**Net CO_2-e (t) 2022**		
		PW2	**PR1**	**PW2**
Pine forest carbon	11.5 tC $ha^{-1}y^{-1}$	69 950	12 400	14 170
Livestock CH_4 emissions	-3.2 tCO^2_e $ha^{-1}y^{-1}$	5910	1080	1210
Soil N_2O emissions	-0.7 tCO^2_e $ha^{-1}y^{-1}$	1240	240	260
Total	Y1-21	**77 100**	**13 720**	**15 640**

Considering the GHG mitigations accumulation alone, the cost:benefit of the forest restoration and planting works out to $10-12 per tonne of CO_2-e.

Carbon is also stored in soil. Within the catchment block there have been limited assessments of change in soil carbon stocks within the pine planted areas. Waikato Regional Council have monitored carbon concentration and bulk density of the top 100 mm at three sites since 2000 as part of a national soil quality programme: a native forest, long-term pine and pine planted site (Table 5). While the soil carbon stocks at the long-term native and pine site show an increase there does appear to have been a decline at the pasture-to-pine site. However, these data are subject to two major caveats – the fact that they represent only three sites, and the observed changes in soil bulk density at all sites, which indicates that the mass of mineral soil being sampled at the 10 mm depth differs between sampling times.

Table 5: Soil carbon stocks under areas of permanent pasture and pine trees planted into pasture.

Study	**Vegetation**	**Initial (tC ha^{-1})**	**Final (tC ha^{-1})**	**Rate of change (tC ha^{-1} y^{-1})**	**Bulk density change (%)**
2000-2022 (0-100 mm)	Native	48.1	58.3	0.46	-36
	Pasture-Pine	55.6	49.1	-0.30	-23
	Pine-Pine	39.3	49.8	0.48	13

Benefits: biodiversity

The third major category of benefit is the potential gain in biodiversity as a result of pine planting, stock exclusion and pest control. In terms of native forest vegetation, approx. 1 ha in PW2 and 2 ha in PW3 were identified as gully remnants that would have been protected from livestock browse and surrounded by pines. As such, improvements in native understorey growth and cover are likely to have been similar to those fragments in the wider catchment under full native restoration (see factsheet #1). In addition, approx. 9 ha of riparian area left unplanted within pine forestry across the PW2, PW3 and PR1 sub-catchments represents an opportunity for native regeneration and indications are that tree ferns are now abundant in these areas. While there has also been substantial growth of native shrubs and trees under the pine canopy, it is inevitable that these will be removed upon pine harvesting.

In terms of aquatic fauna, the variation in macroinvertebrate species richness prior to 2001 was large, obscuring clear effects of the pine planting. From a low base in 2001, species richness appears to have increased in the PW2 fully planted and PW3 partially planted streams. But in the PR1 partially planted stream, richness appears to have decreased from a high base in 2001. Six fish species have been recorded within the catchment area over seven surveys from 2000-2021. At the sites below pine planted areas, species richness has remained consistent. PW2 has only ever recorded both long- and short-fin eels. PW3 has consistently recorded long-fin eels and sometimes short-fin eels. PR1 has only ever recorded short-fin eels. The total fish density of all three sites has declined over time.

References

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Images

Figure 2. PW2 Weir and shed in July 2003

Figure 3. View of pasture, gully poplars and pines from the southern end of PR1 in July 2023.