MAANUKA-DOMINATED RIPARIAN PLANTINGS FOR RECOVERING THE MAURI OF LAKE WAIKARE

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ABSTRACT

The Lake Waikare, in the lower Waikato, in its hypertrophic state, is one of the most polluted lakes in Aotearoa. For generations, the lake and surrounding wetlands have been important to local iwi as they provided sustenance to the communities living around them. The lake and wetlands were a source for mahinga kai (food gathering), a source of irrigation for food crops, and a site of cultural and spiritual significance. These uses and people's connection to the lake have been lost due to the current state of degradation. For this reason, there is a significant effort by the local authorities and iwi to restore the mauri (health) of Lake Waikare with a multitude of projects and strategies, riparian and native plantings being one of them.

A 4-ha, 40,000 plant, Experimental Plot was set up in 2017 in Nikau Farm, mostly by volunteers from the local communities and the collaborators in this project, to investigate the role of maanuka-dominated riparian plantings in reducing impacts of farming activities on adjacent freshwater. However, it soon became evident that the benefits of this experiment extended beyond water quality and beyond scientific goals. The "Waikare Learning Community" became an example of working in a transdisciplinary team of scientists, regulators, and iwi, from different worldviews and expectations, but with similar values and visions for the environment.

Run-off collectors, weather station, soil sensors, suction cups, and dip wells were installed to monitor the movement of water through the maanuka-dominated plots. Plant establishment and growth, soil quality, and soil biodiversity were also monitored. Results showed that phosphorus, total nitrogen, total organic carbon, and *Escherichia coli* were the main pollutants in the run-off samples. Nitrate was the main form of nitrogen leaching through the deeper soil horizons. Water management by maanuka (rain interception and evapotranspiration) was probably the most important factor regulating the losses of nitrate through the riparian planting compared with a grassed (unplanted) riparian band. Most areas of the Experimental Plot (planted at 1.9 plants/m^2) reached full canopy cover and up to 3.3 m height within 3.5 years. The improvement of soil health in riparian plantings

(soil quality and soil biodiversity) will likely have a positive effect on further mitigation of water pollution in the future, as well as recovering biodiversity and ecosystem functioning.

KEYWORDS

Water quality, soil quality, biodiversity, ecosystem restoration

PRESENTER PROFILE

Dr. Maria J Gutierrez-Gines is the Lead Scientist of Biowaste in the Institute of Environmental Science and Research (ESR) Ltd. Her research interests focus on the use of native plants to manage environmental problems such as water pollution and organic waste reuse.

Glen Tupuhi is the chair of a cluster of Waikato Tainui marae around the perimeter of Lake Waikare and the corresponding stretch of the Waikato River. Glen has a background in health, justice and active involvement in multi systemic Iwi development. Like many of his generation he has despairingly observed the changes to the lake that have occurred over the last 60 years.

1. INTRODUCTION

The pollution of freshwater bodies is a global problem that affects not only the aquatic and terrestrial ecosystems that depend on them, but also hinders the capacity of people to use that water for drinking, recreation or harvesting food. In Aotearoa, it is estimated that between 67 % and 77 % of the lakes in urban, pastoral or forestry areas are in poor ecological health (MfE and StatsNZ, 2020). Although there are numerous, overlapping and cumulative drivers for this degradation, the pollution caused by nutrients (such as nitrogen and phosphorus), pathogens, and sediments is a fundamental cause that needs priority attention (MfE and StatsNZ, 2020).

Research with laboratory, lysimeter and small field trials demonstrated that bioactive plants such as maanuka and kaanuka affect the cycling of nitrogen in the soil, and consequently reduce the leaching of nitrate compared with other non-native plants (Esperschuetz et al., 2017b, Halford et al., 2021). These plants also enhanced the die-off of pathogenic organisms in wastes that passed through their root systems, indicated by the presence of *Escherichia coli* (*E. coli*) (Gutierrez-Gines et al., 2021, Prosser et al., 2016). We therefore hypothesised that incorporation of maanuka into biodiverse riparian plantings could potentially filter and inactivate pollutants from intensive agriculture leading to greater improvements in water quality.

Lake Waikare, in the Lower Waikato catchment is one of the most degraded lakes in Aotearoa. Decades of intensive land-use practices including native forest clearance, drainage, pastoral farming, and production forestry have expedited erosion of soil in the wider catchment, resulting in large sediment and nutrient loads entering the lake. In addition, the flood control scheme established in the 1960s modified the natural hydrological regimes of the lake and adjacent wetlands. Intensive dairy farming in the areas adjacent to the lake contributes nitrogen, phosphorus, and pathogens to the lake. As a result of all these impacts, the lake is currently shallow with a mean depth of 1.5 m, and is considered to be hypertrophic, experiencing a high degree of year-round turbidity and prone to regular algal blooms due to elevated nutrient levels and warm water conditions (Lawrence and Ridley, 2018). Loss of biodiversity in the Lake Waikare Catchment includes loss of approx. 67 % of the wetlands (Reeves et al., 2012). For generations, the lake and surrounding wetlands have been important to local iwi as they provided sustenance to the communities living around. The lake and wetlands were a source for mahinga kai (food gathering), a source of irrigation for food crops, and a site of cultural and spiritual significance. For this reason, local authorities and iwi are improving the mauri (health) of Lake Waikare with a multitude of projects and strategies, riparian and native plantings being one of them.

The complexity of this problem guaranteed the need for a different approach, a more holistic, transdisciplinary (Goven et al., 2015) and highly collaborative team with scientists from multiple disciplines, but also with local authorities and mana whenua as kaitiaki of this rohe. In this context, we established a field experiment to investigate if and how maanuka-dominated riparian ecosystems could improve water quality in Lake Waikare. In addition, such an experimental setting also offered the opportunity to investigate further benefits of riparian plantings, such as soil health and biodiversity recovery. Beyond just improvements to water quality, these ecosystems could provide further ecological benefits, such as increasing biodiversity and ecosystems functioning, recycling of nutrients, habitat enhancement, increasing pollination, and biological control of some pests (McKergow et al., 2016, Wade et al., 2008).

A detailed description of the methods and results of this project can be read in Adamson (2021) and Gutiérrez Ginés et al. (2022). The objectives of this paper are a) to give an overview of the methods used to monitor the potential environmental improvements achieved with maanuka-dominated riparian plantings, emphasising the difficulties of doing research in real conditions, b) summarise the main results, highlighting the interconnection between factors and the uncertainties inherent to research in real conditions, c) share some experiences that the authors considered helped achieve transdisciplinary research.

2. RIPARIAN PLANTINGS: HOW TO ESTABLISH A NATIVE BUSH

2.1 METHODOLOGY

Four hectares of dairy pasture in Nikau Farm, south of Lake Waikare, (-37.474036, 175.231869, Figure 1) were planted in winter 2017 with native nursery-grown seedlings, with the help of multiple volunteers from the local and science communities (Figure 2). There was no specific pre-planting site preparation (no herbicide) other than fencing to exclude stock and plants were not staked. The dominant soil type is classified in the New Zealand Soil Classification as an Ultic soil, the Mangatawhiri clay loam. The planted area was divided into two plots adjacent to a slow-flowing drain that enters Lake Waikare about 30 m downstream of the plots. The Experimental Plot was a 272 m x 30 – 50 m riparian band (1.6 ha) in a gentle slope (< 10°) towards the drain. The second plot ('Flat' Plot) is a 2.4 ha plot located on the north-western side of the same drain, at a lower elevation than the Experimental Plot and experiences periodic flooding. The Experimental Plot was divided into 10 subplots (Figure 1): a) three 10 m-wide plots of exclusively swamp maanuka, b) three 10 m-wide unplanted and unmanaged pasture plots (referred to as controls) to represent a scenario of a fenced-off unplanted riparian band, and c) four plots of varying widths with a mixture of 22 native plant species. The Flat Plot was planted with the selected mix of species in a random pattern. The mix of species was selected based on conversations with Waikato Regional Council (WRC), mana whenua - including the species that were planted in the rest of their restoration plantings, and the planting guides published by Department of Conservation (2015). The 40,000 nursery plants were planted at an average 1 plant/m^2, which is the recommended density in restoration plantings in this region (Department of Conservation, 2015) but varied between 0.7/m^2 (Flat Plot) and 1.9/m^2 (Experimental Plot). Due to the scientific and cultural objectives of this project, the variety of maanuka locally known as swamp maanuka comprised 50 % of the total number of plants. All the plants were eco-sourced and purchased from local nurseries.

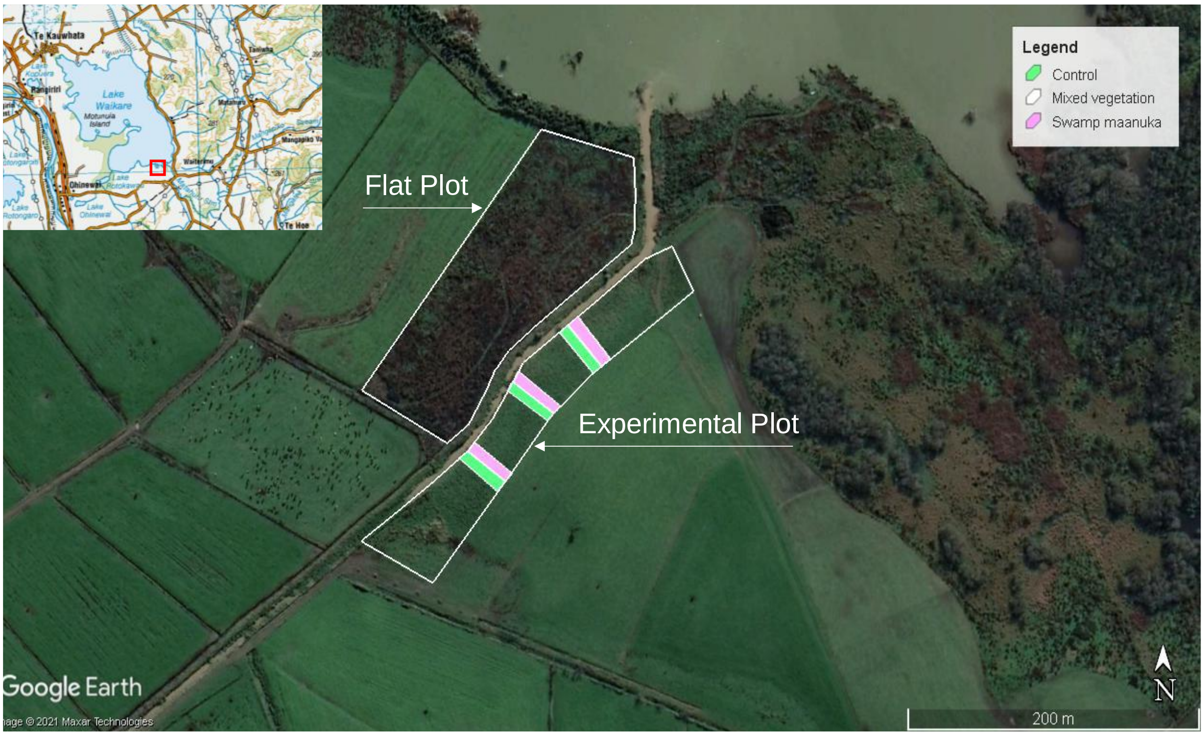

Figure 1: A satellite photo of the two planted plots at Nikau Farm, and delineation of the different treatment plots in the Experimental Plot.

Post-planting plot maintenance consisted of mechanical management of weeds, which was performed with a brush-cutter once per year for the first two years in the Experimental Plot, and once overall in the Flat Plot. Once the native seedlings were higher than the grass, no further management occurred. In the wetter areas of the Experimental Plot, near the drain, the growth of *Convolvulus* sp. was monitored, and in the third year this vine was manually removed. The survival and growth of the planted seedlings was recorded in each of the subplots of the Experimental Plot in a 20 m x 2 m representative transect per plot. Each transect was divided longitudinally in 5 m quadrants (10 m^2 each). In each quadrant the number of plants, the species, height and width were recorded (Figure 3).

Measurements were carried out in April 2018, September 2020, and January 2022. In March 2019, only growth of maanuka, and swamp maanuka was recorded.

Figure 2: A) Opening the plantings with a karakia led by kuia Elsie Davis on 25th June 2017, B) volunteers planting the Experimental Plot in October 2017.

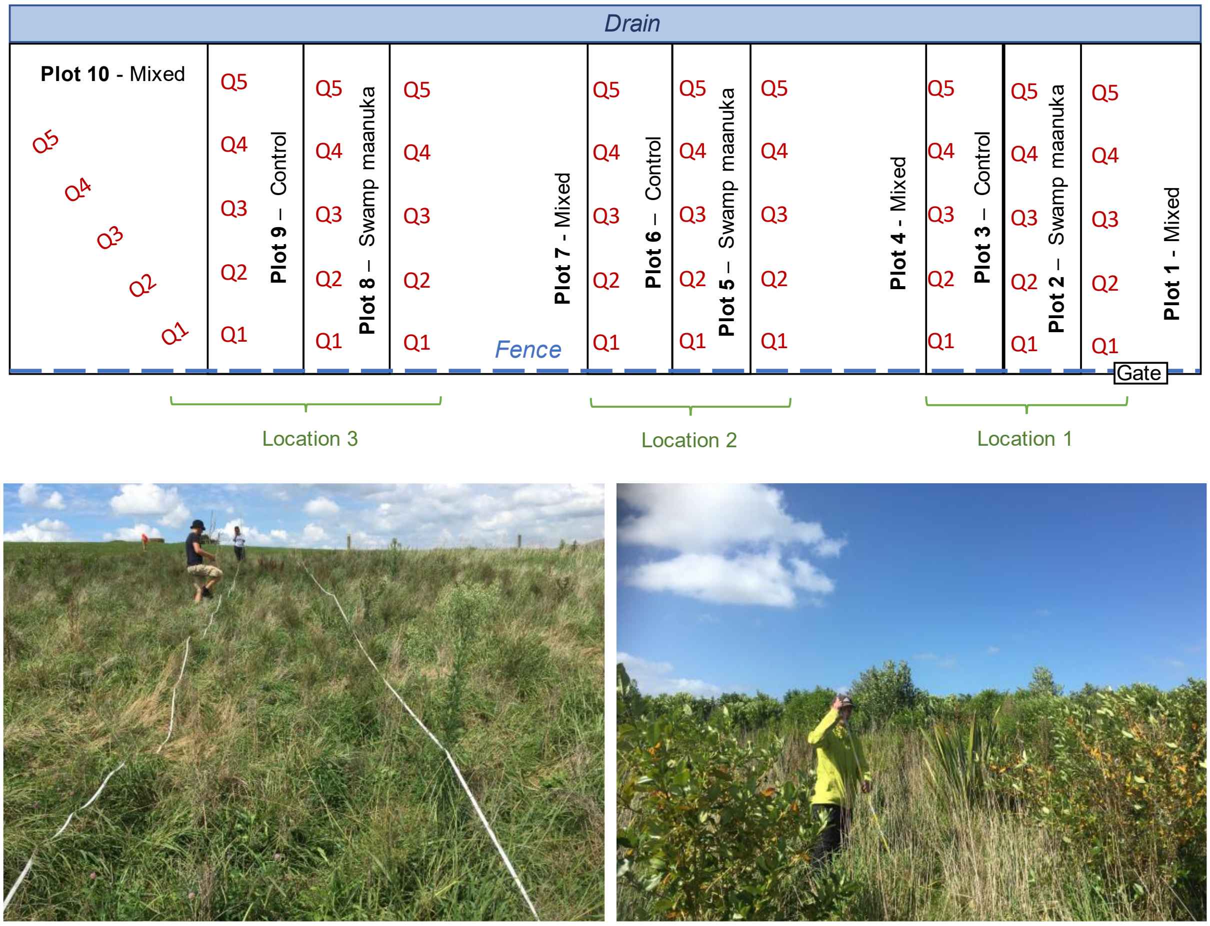

Figure 3: Top: Diagram representing approximate areas of sampling with Plot's identification numbers, distribution of quadrants (Q), and grouping of results in Locations for statistical analysis. Note that the distribution of Q is different in Plot 10 to follow the main direction of the slope. Bottom: Photos of the team measuring plant growth in the 20 x 2 m transects in 2018 (left) and 2020 (right).

2.2 RESULTS

The two plots planted with NZ-native seedlings developed a heterogenous cover (Figure 4). Most of the mortality in the occurred within the first four months, being 20 % and 28 % (Figure 5C) in the Experimental Plot; in the subsequent four years plant density has gradually reduced (Figure 5C). These results are consistent with the first months after planting being the most important for the survival of the plants (Bergin and Gea, 2007). The subsequent mortality in early years in our experience was mostly due to competition with weeds or plants being cut during mechanical weeding. In later years some mortality has been self-thinning as a response to have been planted so densely, which is common in even-aged plantings, where increased biomass production results in higher mortality (Forrester et al., 2021).

Figure 4: Drone picture taken in January 2022 from the southwest end of the two plots. The Flat Plot is situated at left of the drain, and the Experimental Plot at right of the drain.

The average native plant density in the monitored area of the Flat Plot in January 2022 decreased from 0.7 to 0.3 plants/m^2, although plant distribution was clumped reaching a maximum of 10 plants in a 10 m^2 quadrant. Despite the swamp maanuka initially comprising 50 % of the plants, the predominant species in the monitored transects after 5 years were karamuu > mingimingi > puurei/swamp sedge > ti koouka > harakeke > *Coprosma rigida* > swamp maanuka > swamp coprosma > toetoe. This indicates that all the Coprosma species selected (karamuu, mingimigni, swamp coprosma), as well as tii koouka and harakeke, not only thrived in these variable seasonal conditions of moist and waterlogged soils, but also were not negatively impacted by the competition with the prevailing weeds (mostly fleabane – *Conyza sumatrensis* during the initial years). These weeds were mechanically managed only once in 2018. Most of the swamp maanukas planted in this experiment were very small seedlings provided as root trainers and had high mortality in the first 4 months. Small root trainers did not provide enough resilience for the plants to be held unwatered in the plots for a few days until they were planted. Seedlings that are grown in planter bags or bigger pots could be used, as these typically show a better survival rate after transplanting than seedlings grown in root trainers (Bergin and Gea, 2007). It is likely that most of the swamp maanukas that we measured in January 2022 were the bigger plants delivered in 0.5 L pots.

The average maanuka height gain during the project was 48 cm/y, ranging from 33 cm/y to 59 cm/y. Plant growth of maanuka as well as the rest of species was heterogenous along the Experimental Plot, with lower growth rates in the areas closer to the drain (Q4 and Q5, Figure 5A & B). This is likely due to these areas being usually waterlogged for several months from late autumn until early spring, resulting in higher gleying of the soil, while in the higher areas of the slope the permeable Mangatawhiri clay loam topsoil is deeper (Adamson, 2021). There may also have been an impact from drain cleanings placed along the drain. In the mixed plots, the species composition likely affected the average plant growth as well, because the higher parts of the slope were dominated by bigger trees such as maanuka, karamu, koromiko, akeake and tarata. The vegetation in lower parts of the slope was, on the other hand, dominated by maanuka, flax, and small leaved coprosmas, which are smaller species.

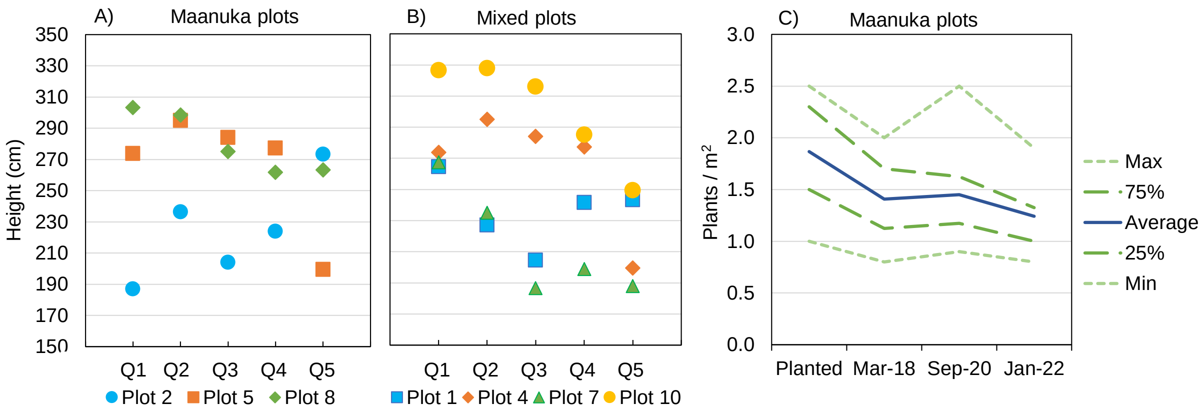

Figure 5: A) & B) Average tree height in each plot of the experimental area and in each sampled quadrant (10 m^2). Q1 is the closest to the fence, Q5 is the closest to the drain. C) Changes in plant density of maanuka plots monitored along the experiment.

Interestingly, the maanukas in Plot 2 near the fence on highest ground (Q1) were much smaller than in other plots or in other areas of the same plot (Figure 5A), and also showed signs of stress with sparce chlorotic foliage. An explanation for this lack of health is the extraordinarily high concentration of nutrients (N, P, Ca), Cation Exchange Capacity, salinity, and pH in the soil at this specific spot, as presented in Section 4 - Soil Health (Figure 11), and which are considerably higher than the WRC monitored pH and Olsen P for indigenous (native plants) sites (Taylor, 2021). Although a better growth of maanuka with increasing fertility has been previously demonstrated (Esperschuetz et al., 2017a, Gutiérrez-Ginés et al., 2019, Seyedalikhani et al., 2019), there is also evidence of a decrease in plant health and even mortality at high concentrations of N, P and electrical conductivity (Gutiérrez-Ginés et al., 2019, Seyedalikhani et al., 2019).

In summary, the main factors influencing successful establishment of native planted seedlings at this trial are a) the size of the plants to be planted (bigger pots – if well-watered before planting – provide more resilience than small root trainers in the event of a long period of lack of rain or delayed planting after plant delivery), b) competition post-planting (taller plants can outcompete weeds), or, alternatively, weeds will need to be maintained at a size not much higher than the plants, c) visibility of plants when doing manual weed control (either by being taller than pasture or having a distinctive leaf compared to pasture – although staking vulnerable plants such as kahikatea or small maanuka could have also aided visibility, as would regular spacing) and finally d) favour the establishment of plants in the first few months by making sure the plants are properly planted in the soil, and planting in a season with high probability of frequent rain in the following months. Given little maintenance was needed, the cost of native plantings was largely determined by the cost to purchase native seedlings. It would have therefore been cheaper to plant at a lower density. Planting density will therefore depend on the size of the plants and their crown volume. For example, small leaved *Coprosma* spp., sedges or ti kouka need to be planted closer together (≥ 1 plant/m^2) than large leaved species with larger crowns such as karamu, akeake, black matipo or tarata (~ 0.6 plants/m^2). Areas that previously received high fertiliser inputs can have nutrient concentrations that are too high for some native plants to thrive. Plants that are susceptible to high nutrient environments might not do well at such locations.

3. MAANUKA-DOMINATED RIPARIAN PLANTINGS TO IMPROVE (JUST?) WATER QUALITY – A HOLISTIC APPROACH

The four hectares of our experiments are insignificant compared with the total catchment of Lake Waikare (~21,000 ha). For that reason, it was unrealistic to measure an improvement of water quality in the Lake or in the drain that passed through the plots. Instead, we aimed to monitor water as it passed along the Experimental Plot by measuring the volume and quality of water of runoff - the water that flows on the surface of the soil, and subsurface flow - the water that flows laterally through the soil. At the same time, we measured other environmental factors, such as plant and soil health, which are linked with water quality, which would also allow for a mechanistic insight on how the riparian planting system is working.

3.1 METHODOLOGY

3.1.1 MEASURING RUN-OFF

We designed, manufactured and installed fit-for-purpose runoff collectors, which were installed in duplicates in each of the subplots. The development and optimization of the devices has taken almost four years to be functional, and multiple iterations of the metal frame installation, collectors and connectors were necessary (Figure 6). The main challenges were related with the watertightness of the connections and the collecting container, as well as the balance between leaving some sediments to get into the sample (to measure potential sediment contamination) and avoid big particles, leaves and invertebrates accessing the container and contaminating the sample. The final set up was installed in July 2021, and monthly samples collected since then. Further challenges we were facing were due to sporadic flooding of the area which damages the system, which tends to float, and the velocity at which the containers fill when there are big rainfall events.

Samples from the runoff collectors were sent overnight in chilly bins to ESR and analysed for *E. coli* numbers on reception, using the Colilert method (IDEXX Laboratories). The Colilert method provides the Most Probable Number (MPN) of *E. coli* enumeration per 100 mL of sample. pH and electrical conductivity (EC) were also analysed with a pH and EC probes (Eutech Instruments). The samples were stored at −20 °C until further analysis for turbidity, N and P, total organic carbon (TOC) and elements by Analytica Laboratories. NO_3^--N, NO_2^--N, NH_4^+-N and dissolved reactive phosphorus (DRP) were analysed by a Lachat Flow Injection Analyser (APHA 4500). Total Kjeldahl Nitrogen (TKN) and total P (TP) were analysed colourimerically by a SEAL AQ400 Discrete Analyser following acid digestion (APHA 4500). Turbidity was analysed by a Hach turbidimeter (APHA 2130 B), TOC was analysed by an Elementar Analyser by combustion at 850 °C (APHA 5310 B). Elements were analysed by a Perkin Elmer NexION 300/350D ICP-MS.

Figure 6: Set up of the runoff collectors. A) Frames of the collectors as they were built. The frames were dug 5cm into the soil, with the triangular end leading to the sample inlet oriented downhill. B) Original collection system did not allow for maintaining a "clean" sample. C) New system prototype, which is better sealed and included a filter to impede the intrusion of litter and animals. D) Set up of the new collectors in the field. E) The new system established in the field.

3.1.2 MEASURING SUBSURFACE FLOW

The subsurface flow was monitored by installing suction cups and dip wells in early 2021 and monitored regularly over winter 2021, as described in Adamson (2021). Suction cups were installed in two control plots and two swamp maanuka plots at depths of 10 cm, 30 cm and 50 cm. For each set of depths, and plots, the suction cups were installed at 1 m, 4 m and 7 m from the fence of the Experimental Plot. A total of 36 suction cups were installed and sampled seven times between May and July 2021. The samples from the suction cups were analysed for N speciation by Analytica Laboratories with the same methods described for run-off samples.

Dip wells were 4 cm wide PVC pipes with slotted sides and sealed bottom, which allowed to monitor the depth of the water table. The depth of the water was measured using a "bubbler" in the same days than the suction cups were sampled. In addition, a data logger was installed in one of the wells to continuously measure the water depth. A better description of this setup and the results will be presented in the Water NZ Conference 2022 paper and presentation by Olivia Adamson.

3.1.3 REAL TIME MONITORING OF WATER IN THE SOIL, PRECIPITATION AND RUN-OFF

Soil moisture, electrical conductivity and temperature are continuously monitored with 12 TEROS12 (METER Group) soil sensors installed in the swamp maanuka and control plots at depths of 15 cm and 30 cm (Figure 7). The University of Auckland's purpose-built devices are transmitting the data to a cloud via a Sigfox network. A weather station Aercus WeatherRanger records weather data continuously. Rain gauges placed under the maanuka canopy and out of the canopy are also continuously monitoring rainfall. With a WiFi connection, it sends that data to the same cloud storage. Currently, we are experimenting a smart-bucket system to add to the run-off collectors to be able to measure real-time high-resolution data of volume, which could be linked with precipitation and soil moisture.

Figure 7: Photos showing, from left to right, the installation of the remote monitoring rain gauge, soil sensor at 30 cm deep, the weather station in the shed powered by solar panels, the interior of the shed with the data receiving and sending devices.

3.1.4 MEASURING SOIL QUALITY

Soil quality can directly affect the nutrient retention potential of riparian zones. Understanding soil properties as affected by the vegetation will allow the maximisation potential of the riparian zones to mitigate pollution and improve water quality. In December 2018, four sample points in each plot were located at increasing distances from the fence, and which approximately corresponded with the vegetation transects described in Figure 3. For each sampling point, soil was collected at 0 – 10 cm, 10 – 30 cm, 30 – 45 cm, and 45 – 60 cm depth, using a soil corer. In December 2020, when there was canopy closure in the swamp maanuka plots, we collected soil samples at approximately 5 – 10 m from the fence to compare changes in soil quality between maanuka and control plots. In this case, we collected five topsoil samples (10 cm) from each of the maanuka and control plots.

The soil samples were transported in chilly bins to ESR and frozen within 24 h of collection until further analysis by Manaaki Whenua Landcare Research. Total organic carbon (TOC) and total nitrogen TN were analysed using a Leco TruMac instrument, which uses the Dumas dry combustion principle. pH and Electrical Conductivity (EC) were analysed in a 1:5 soil water mixture and measured with a pH and EC probe, respectively (Blakemore et al., 1987). NO_3^--N and NH_4^+-N were extracted from the soil with a 2M KCl solution (Blakemore et al., 1987) and analysed using a QuikChem 8500 Flow Injection Analyser (FIA). Olsen extractable phosphorus (Olsen P) was extracted from the soil with 0.5M $NaHCO_3$ (Olsen et al., 1954) and analysed using a FIA. Exchangeable Ca, Mg, K and Na were extracted with 1M ammonium acetate ($C_2H_4O_2.H_3N$) (Blakemore et al., 1987) and analysed in an ICP-OES. Cation Exchange Capacity (CEC) was analysed from resulting extracted soil after being washed with alcohol. The adsorbed ammonium ions are then displaced from the exchange sites by a 1M NaCl solution. The NH_4^+-N in the NaCl solution was analysed by FIA (Blakemore et al., 1987).

Physical soil quality was studied in March 2021. Three 15 cm deep and 15 cm diameter undisturbed soil cores were collected from two swamp maanuka and two control plots. The cores were wrapped in plastic and transported to Manaaki Whenua Landcare Research laboratories for bulk density and macroporosity determinations with the methods described by Gradwell (1972).

3.1.5 MEASURING SOIL BIODIVERISTY

Invertebrates play an important role in ecosystems contributing to nutrient recycling, food webs, pollination and soil quality (Bach et al., 2020). Although they are good indicators of habitat quality and biodiversity in restoration ecology (Wade et al., 2008), they are rarely monitored in ecological surveys. Invertebrate biodiversity in the Experimental Plot was monitored in April in 2017 (before planting), 2018 and 2019 by the students of EcoQuest Education Foundation programme. Before the planting (April 2017), five soil samples of 25 x 25 cm and 10 cm deep were collected randomly using a spade and trowel within the fenced area. In 2018 and 2019, one soil sample of the same dimensions and volume was collected in each of the plots (nine samples per year) about 10 m from the fence. Samples were transported to AgResearch (Ruakura, Hamilton) in cotton pillowcases to ensure sufficient aeration for the invertebrates. Samples were placed into heat extractors for three days and invertebrates were collected at the base of the extractor funnels in a 100 mL sample vial containing ethylene glycol to kill and preserve the specimens.

In 2019, when canopy closure occurred, we included pitfall traps to assess ground dwelling invertebrates, and beating trays to collect invertebrates from the trees, in addition to the previous soil sampling regime. The pitfall traps consisted of a 700 mL plastic container dug to ground level and filled with 70 mL of ethylene glycol to preserve invertebrates collected. For the beating tray collection method, we hit one tree five times with a wooden pole, while holding a collecting tray underneath. The invertebrates were then transferred from the tray to a vial containing ethylene glycol for preservation. In each site, 10 plants were randomly sampled. All these methods were also used in the Flat Plot, and in an old kahikatea remnant located in the north side of the Lake Waikare, to compare the community structure in the Experimental Plot with that of an ecosystem similar to the original of the region.

The specimens were individually counted and classified to recognisable taxonomic units (RTU) by the EcoQuest students using Leica stereobinocular microscopes. Invertebrates were subsequently identified to species level where possible by an expert entomologist on site. About 40,000 invertebrates of ~ 150 distinct taxa and 30 classes or orders were counted and identified. This shows how labour intensive this research is.

3.2 SUMMARY OF THE RESULTS

Runoff volume and chemical analysis were highly variable and not related with the type of vegetation (control, maanuka or mixture of species). *E. coli* numbers in the run-off remained high after dairy farming in the adjacent land ceased. These results demonstrate that high numbers of *E. coli* can be found in environmental samples that are not necessarily related with animal farming, and further research is needed to better establish the risk to human health related with those high numbers of *E. coli* (Devane et al., 2020, Moriarty and Gilpin, 2009). Comparison of chemical analyses (Figure 8) with the national bottom line freshwater quality (NPS-FM, 2020), indicated that the parameters that mostly affect water quality via runoff are those more bound to soil particles (organic nitrogen, NH_4^+ and P), compared with NO_3^-, which mostly affects water quality through leaching and groundwater contamination (Neilen et al., 2017).

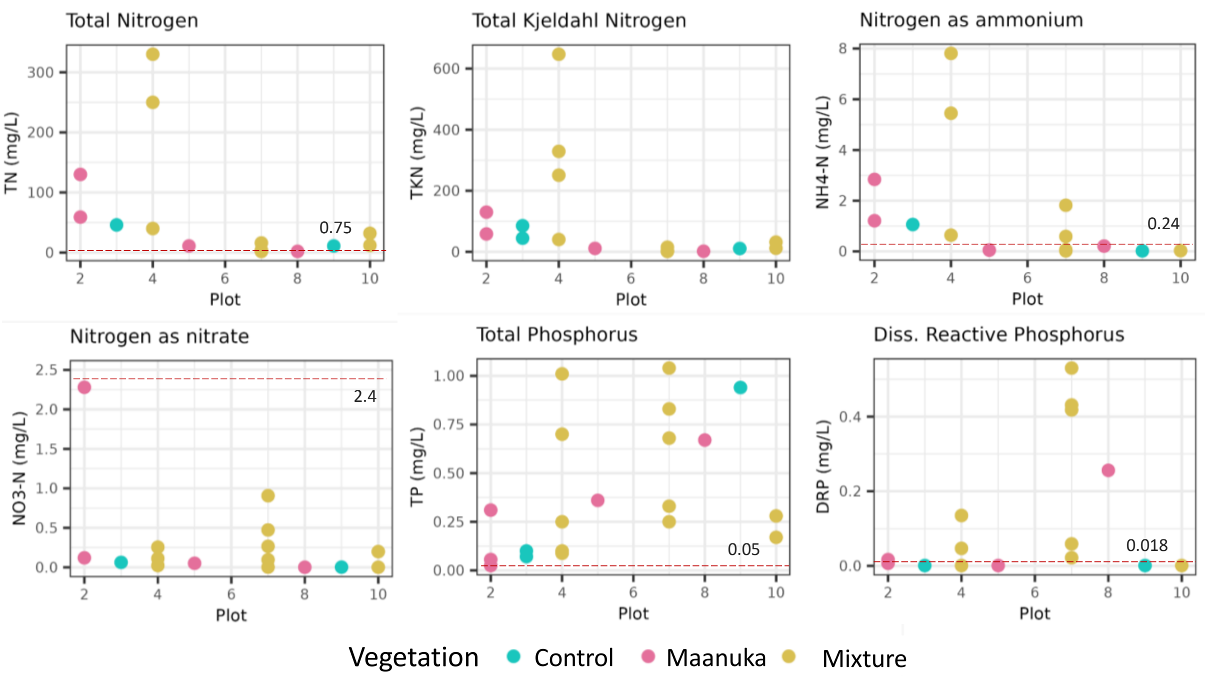

Figure 8: Chemical parameters of runoff water in each of the experimental plots (X axis). The red horizontal lines represent freshwater values according to National Policy Statement for Freshwater Management 2020 (NPS-FM, 2020).

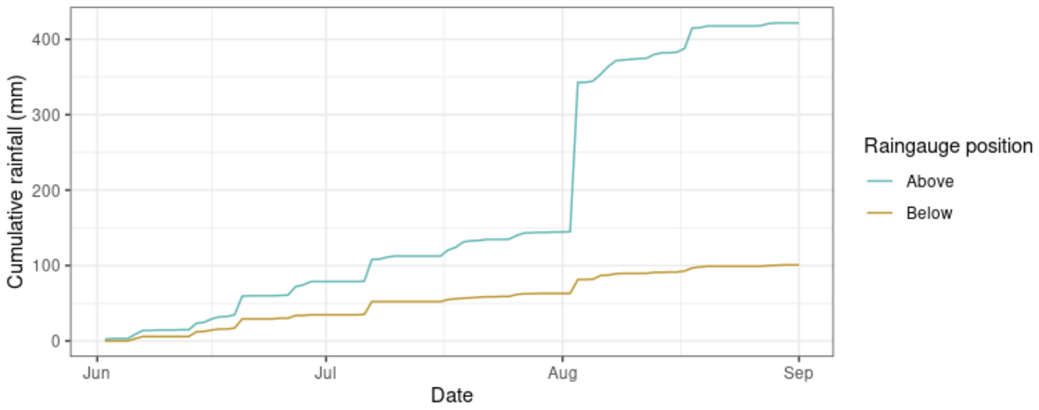

Figure 9: Cumulative rainfall recorded with the automated rain gauges placed above and below maanuka canopy in 2021.

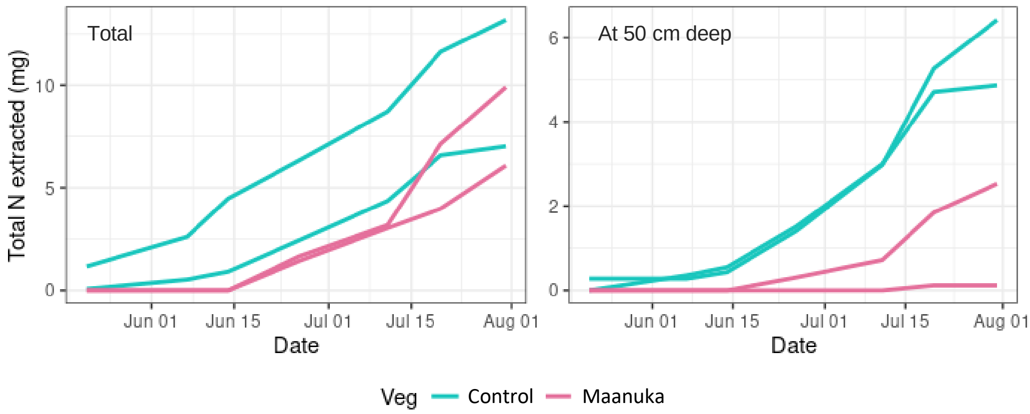

Figure 10: Total cumulative nitrogen extracted from each of the plots along the monitoring months. A) in the monitored soil profile (10 cm, 30 cm and 50 cm), B) only at 50 cm at all monitored distances (1 m, 4 m and 7m).

The three-month (Jul - Sep 2021) cumulative rainfall measured by rain gauges above and below the maanuka canopy showed that maanuka delivered only ~ 25% of the total rainfall (Figure 9). This explains, in general terms, the lower water content of the topsoil in the maanuka plots compared with the control plots (as measured by the soil moisture sensors). A lag of one month in the delivery of soil pore water to suction cups installed under maanuka compared with the control also highlighted that the soil was drier under maanuka.

Suction cups showed that the potential for NO_3^- loss under maanuka is significantly lower than under unplanted riparian buffer, due to both lower water exports as well as lower nitrate concentrations. Although the soil pore water data is insufficient to quantify the real leaching of NO_3^-, it can indicate the relative mobility of N under each of the plots. When the pore water volume is multiplied by the concentration of TN in the leachate in each plot, we obtained a mass of N "total N extracted" (Figure 10). When all depths were combined, 21 % more N was extracted from the control plots than the maanuka plots. The difference between the control and maanuka plots was most pronounced at 50 cm depth, where the extracted N was approximately six times higher in the control than the maanuka plots (Figure 10). Higher rooting depth of maanuka compared with pasture could be a reason for the increased effect at deeper soil horizons.

Highly variable soil chemical quality (Figure 11) masks statistically significant differences between the different sub-plots. Despite that, differences between the soil under maanuka and control plots were more pronounced in Dec 2020 than in Dec 2018, mostly due to the age and canopy cover of the maanuka 3.5 years after planting. At this time, the higher C:N ratio under maanuka compared with control could be explained by the incipient accumulation of maanuka litter in the soil following canopy closure and suppression of some exotic grasses. The higher Olsen P under maanuka compared to control plots could be explained by a higher plant uptake by herbaceous species. The higher Na and other cations were likely a result of less water flux under this species (as explained in previous section 3.2), and accumulation in the soil consequently. Higher concentration of NH_4^+ in control plots compared with maanuka is consistent with the wetter conditions in these plots and as a consequence, lower redox potential. However, the multiple transformations that N undergoes in soils (Cameron et al., 2013) make it complicated to attribute this as a single reason. A slower mineralization of organic N under maanuka compared with control, which could be related with the higher C:N ratio (lower N availability), could be another explanation for this difference. Similarly, potential interaction with microbial populations involved in this process, such as Biological Nitrification Inhibition, was also suggested by Esperschuetz et al. (2017a) and Halford et al. (2021).

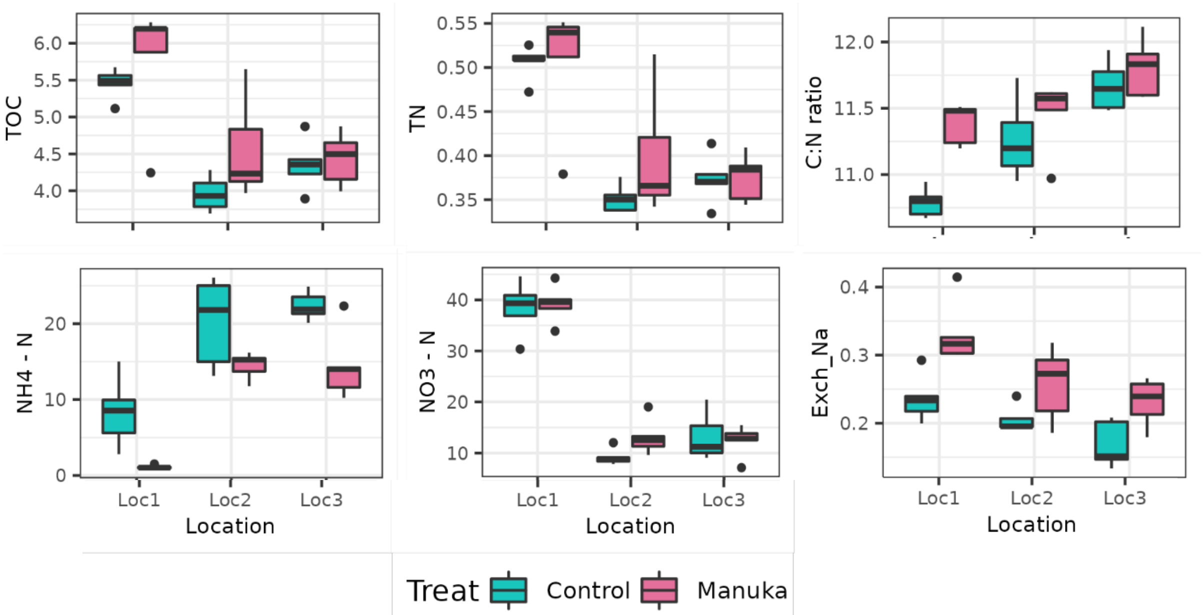

Figure 11: Soil chemical properties in different Locations and vegetation types in December 2020. Loc1 represent the two plots closer to the gate (Plots 2 and 3), Loc 2 are results from Plots 5 and 6, Loc3 represents the plots furthest from the gate (Plots 8 and 9). Units: TOC and TN (%), NO_3^- -N, NH_4^+ -N, (mg/kg), Exch_Na (cmol(+)/kg), Treat – Treatment.

Physical properties of the soil in the fenced-off area(Experimental Plot) improved compared with the adjacent paddock (Figure 12). The average bulk density in the

Experimental Plot (control and maanuka combined) was 1.08 t/m^3, significantly lower than in the nearby paddock (1.30 t/m^3). Consistently, the average microporosity of the Experimental Plot (11.6 %) was 38 % higher than in the paddock (4.4%). The effect of plant roots, macroinvertebrates, earthworm activity and lack of compaction by machinery, livestock or disturbance from cultivation are likely causes for the improvement of soil physical quality in the Experimental Plot, compared with the adjacent paddock (McLaren and Cameron, 1996).

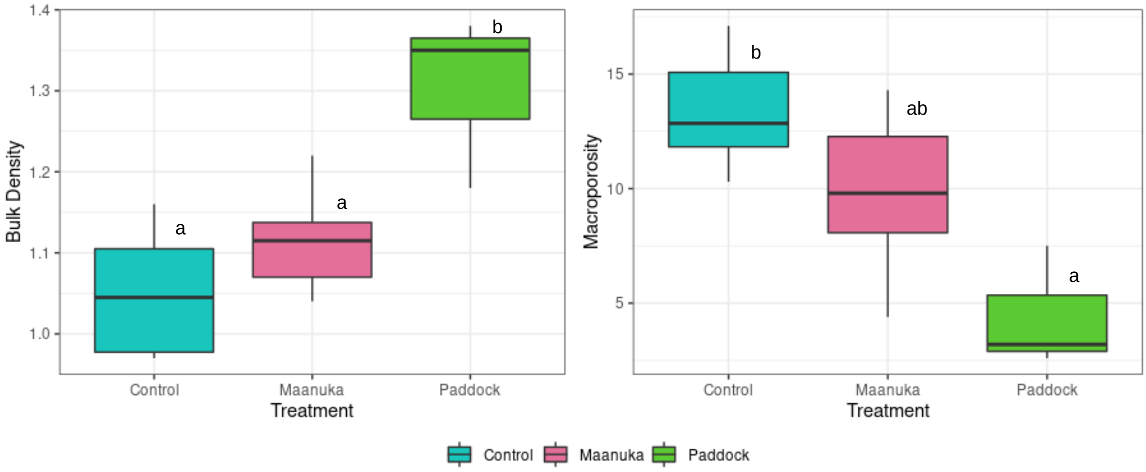

Figure 12: Bulk density (t/m^3) and macroporosity (v/v%, @-10 kPa) results for six different soil cores in the maanuka and control plots, and three in the adjacent paddock in July 2021. Different letters indicate significant differences between treatments (Tukey's HSD test, $p < 0.05$).

The relative abundance of each indicator invertebrate group was similar in the the survey before the planting (2017) and six months after planting (2018). However, significantly higher numbers were collected 1.5 years after planting (2019). This could be from the removal of agricultural influences such as cultivation (which creates disturbance, bare ground, and little shelter) and pesticide use, all of which can negatively impact soil invertebrate communities (Carlesso et al., 2019, Kremer, 2018). Although there was a significant increase in biodiversity in the native plant plots in 2019 compared with pre-planting, the distribution of species in their trophic levels did not show a pyramidal trophic structure expected in natural ecosystems, and which was evident in a remnant of kahikatea forest sampled in the north side of the Lake (Figure 13), probably in part reflecting the absence of coarse wood and leaf litter layers in the planted plots.

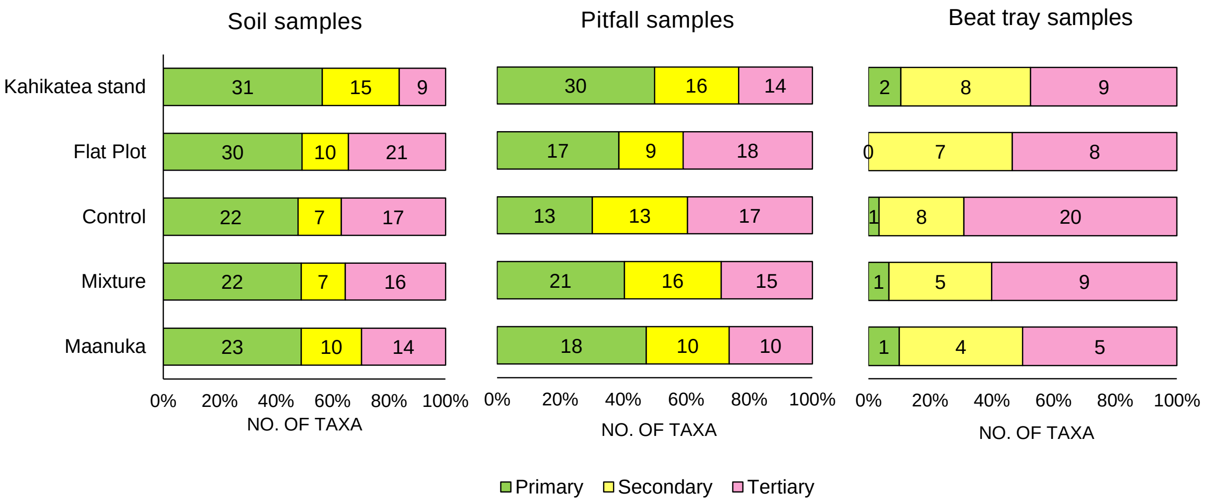

Figure 13: Number of taxa at each site within each of the three trophic levels. Primary = saprophagous feeders. Secondary = plant, sap, seeds, and fungi feeders. Tertiary = parasites and predators. Data displayed is from soil samples, pitfall trap samples, and beating tray samples.

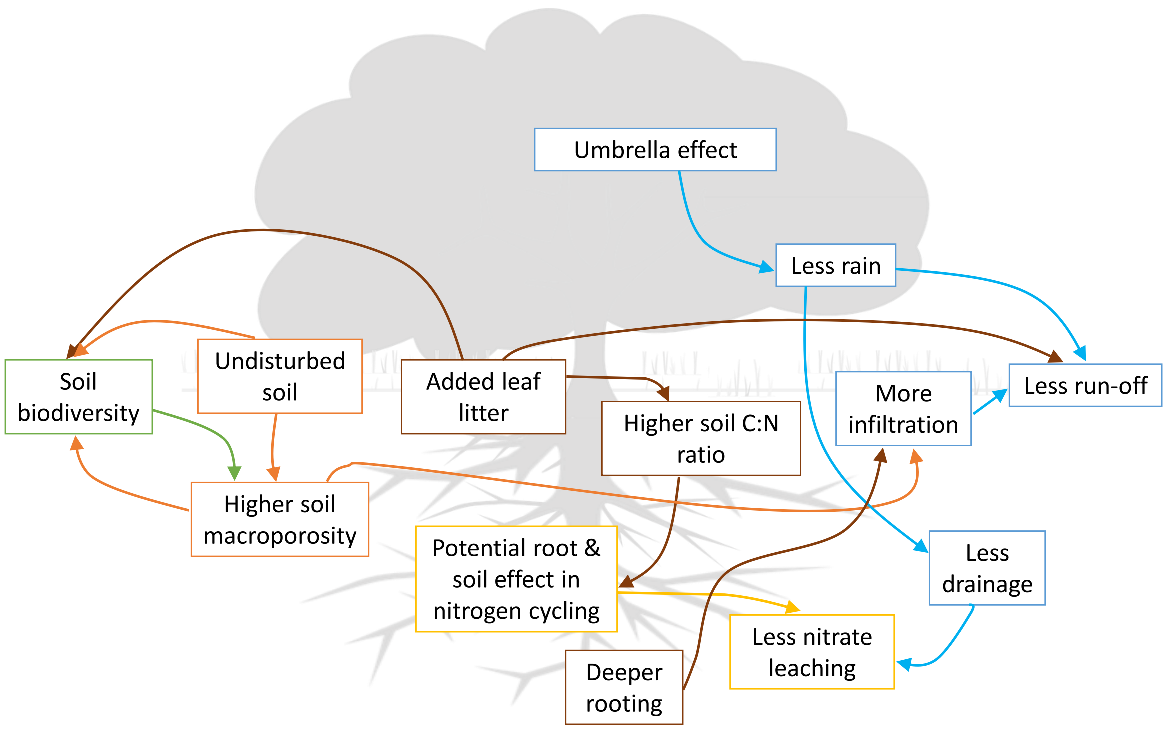

Figure 14: General representation of the factors explaining the demonstrated and potential benefits of planting riparian bands compared with unplanted fenced-off areas.

4. HOW TO DO TRANSDISCIPLINARY RESEARCH WITH MANA WHENUA

Currently there are many documents available to understand how science partnerships with mana whenua could be developed and nurtured. We recommend Potter and Rauika Māngai (2022), Kukutai et al. (2021), and Rauika Māngai (2020). However, when our project started in 2016, the extent of guidance was limited. The learnings and experience from previous research by the Centre for Integrated Biowaste Research in collaboration with mana whenua (Goven et al., 2015) were the best guidance to create a transdisciplinary project responsive to Te Tiriti o Waitangi. Although there is not a formal definition of transdisciplinary, Goven et al. (2015) described elements that are expected to be found in so-called transdisciplinary research, such as a) addressing complex problems, b) involve the collaboration between different disciplines, and c) include collaborators from non-academic backgrounds but with an interest in the problem, and finally d) entail mutual learning which includes different forms of knowledge. The authors also highlighted challenges inherent to this way of research, and which are expected in a transdisciplinary project: project ownership, participation, integration, and reflexibility. Many of these elements fit and respond to aspirations of Aotearoa to move to a science system more responsive to Te Tiriti obligations (MBIE, 2022). A formal reflection on transdisciplinarity (Goven et al., 2015) within our project only happened during the hui marking the end of the project. Far from developing a formal assessment of the project, we highlight here some elements that the authors considered that were important for the success of this collaboration, as well as some challenges that we faced.

Understanding that building a relationship is a long process that cannot be done with just one or two hui was a key challenge. About three to four in person hui per year occurred for the duration of the project. These were held in Matahuru Marae, making sure that appropriate (tika) protocols were followed on each occasion. It was fundamental for our maaori partners/team to be patient and keen to teach the protocols, and for the scientist team to commit to engage and respect them. In this aspect, Covid-19 and the inability to hold kanohi ki te kanohi (face to face) hui posed a big challenge to the usual and best way to communicate, which was in person. Another challenge was the amount of resources needed to engage meaningfully, in terms of people’s time, and funds for travel and support of these activities.

It was very important that this project fit within the restoration programmes taking place around Lake Waikare, and in the Nikau Farm in particular. Scientists tried to respect this from the beginning as the project needed to respond to the aspiration of the maaori community for their rohe. In this regard, familiarizing with the general aspirations and goals of the iwi was important, and the Waikato Tainui Environmental Plan (Waikato-Tainui, 2013) was (and still is) a mandatory to read document. It was very valuable that all the participants in this project shared a common long-term goal of improving the environment in Lake Waikare and as an expansion Aotearoa.

However, this long-term goal needs to also achieve smaller short-term research projects that reflect the interests and expertise of each collaborator (and funding time frames): we created a Research Community or Community of Knowledge or Learning Community. In such community, we all experienced enthusiasm and courage to explore complex questions related with the functioning of nature (in small scale in our Experimental Plot), and to understand the cause and the ways to solve the degradation and pollution of the environment. For addressing (although not sure if achieving) these questions, the amalgamation of different disciplines and bodies of knowledge were necessary, useful and respected. In this sense, it is important to mention respect of the rich environment we were working in, not only from different disciplines, but also from different cultures, with representation from eight nationalities.

Finally, this partnership has demonstrated to be valuable and respected by all participants in this project. The scientists had a space to conduct research, share ideas and knowledge, and communicate their findings to make sure they are useful for the communities and the local authorities. Mana whenua expanded their knowledge on the value of science and found support and capability to be used in other environmental challenges that were important for them, even if not necessarily related with the work carried out in the Experimental Plots.

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