NIWA
Taihoro Nukurangi

Productive Riparian Buffers Cost-Benefit Analysis

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Riparian buffers are strips of vegetation near a water course that are planted to help shade streams, protect the water course from the impact of nearby land use, and provide aesthetic and biodiversity benefits. They may also provide a direct economic benefit, should the vegetation have commercial or other financial value. Riparian buffers established to provide multiple benefits (including economic benefits) may be termed 'productive' riparian buffers.

The Sustainable Food and Fibre Productive Riparian Buffers (PRB) project aims to develop edge-of-field agricultural methods that improve water quality and ecological conditions, while also providing production benefits. To this end, the project is trialling a series of productive riparian buffers around pasture sites, as alternatives to pasture. This report documents an economic analysis of seven productive buffer options based on information provided by DairyNZ: Cut-and-carry pasture, tree fodder from short-rotation coppicing, tree fodder from pollarding, mānuka (oil), rewarewa (honey), tōtara (oil) and pine planting. The analysis took the form of a standard cost benefit analysis (CBA), with efforts made, where practical, to include both market values associated with productive riparian buffers as well as non-market values.

Data for the analysis was taken from consultations with DairyNZ and project farmers from the Waihou-Piako (Waikato) and Waitangi (Northland) catchment groups, published documentation and market (commercial) sources, as applied to three demonstration sites. Table i summarises the monetary costs and benefits estimated, with moderate assumptions for growth, harvest productivity, and market prices.

Table i: Comparison of option features per hectare.

Productive buffer option	Establishment cost	Average annual maintenance costs, years 1-10	Harvest frequency	Harvest benefit	Harvest cost	End-of-life value
Cut-and-carry pasture	$0	$120	Quarterly	$500	$430	$0
Tree fodder from short-rotation coppicing	$24,700	$0	Annual	$3,445	$1,800	$0
Tree fodder from pollarding	$2,110	$90	2-yearly from year 4	$2,200	$300	$0
Mānuka (oil)	$6,300	$190	2-yearly from year 5	$3,000	$2,100	$0
Rewarewa (honey)	$3,223	$143	Annual from year 8	$618	0	$32,200
Tōtara (oil)	$14,750	$2,025	Years 8, 15 and 35	$10-$16k	$1.5-9.5k	$110,000
Pine	$1,250	$181	N/A	$0	$0	$33,700

Results

Market benefits and costs were estimated. In addition, non-market values were estimated for nutrient absorption and carbon sequestration benefits arising from the PRB options. Other potential non-market values associated with the PRB options – such as cultural values, aesthetics, shade, habitat, firewood and biodiversity – were not estimated. Water quality benefits arising from sediment and nutrient interception were estimated in a separate analysis for the demonstration sites.

Table ii shows that feedstock options (cut-and-carry pasture, tree fodder from short rotation coppicing and tree fodder from pollarding) generally require little maintenance but have moderate to high labour requirements to harvest, process and transport fodder around the farm. Variations between the feedstock options arise for a variety of reasons, including differences in the means of harvest or plant density. For example, tree fodder pollarding has a higher labour cost than short rotation coppicing due to non-motorised harvesting and removes less nitrogen from the soil each year because of lower planting density. Timber species require labour for pruning, thinning and releasing. The labour intensity required to harvest foliage for oil ranges from relatively moderate to high. Final timber harvesting uses a lot of labour – in this case contractors, rather than on-farm labour.

Table ii: Comparison of option non-monetary features.

Productive buffer option	Maintenance labour	Harvest labour	Nitrogen removal (kg/ha/year)	Phosphorus removal (kg/ha/year)
Cut-and-carry pasture	Low	Medium	300	44
Tree fodder from short-rotation coppicing	Low	Medium	100	9.8
Tree fodder from pollarding	Low	High	20	2
Mānuka (oil)	Medium	Medium	56	5.7
Rewarewa (honey)	Medium	None	30	7
Tōtara (oil)	Medium	High	83	9.5
Pine	Medium	High (contractor)	87	3

Table iii shows indicative net present values for each production option over 60 years, with and without the non-market value of nutrient removal and carbon sequestration. Without consideration of non-market values, none of the productive riparian buffer options appear as profitable as direct grazing. Nevertheless, while all options would require at least a 3 m wide buffer that excludes stock from the area, all options generate benefits that offset the cost of stock exclusion. The NPV for short rotation coppicing is positive but only just, due to high establishment costs. If farmers are willing to await benefits for 60 years, native timber plantations will be expected to generate a positive NPV, especially where non-market benefits are considered or required by policy. The mānuka option has a negative NPV due to high foliage harvesting costs and low timber value. However, mānuka offers substantial non-market benefits for water quality and is low maintenance.

The cut-and-carry pasture option has a high non-market value due to the ability to remove large quantities of nutrients. However, non-pasture species also provide additional biodiversity, aesthetic and habitat benefits which have not been quantified. The cut-and-carry and short rotation coppicing options both require a site flat enough for mechanical harvesting.

Table iii: Comparison of 60-year net present value (NPV).

Productive buffer option	NPV 60 years @4% discount rate	NPV incl. non-market values
Grazing (8 t DM/ha)	$39,800	$39,800
Cut-and-carry pasture (8 t DM/ha)	$4,500	$142,000
Tree fodder from short-rotation coppicing*	$7,800	$15,600
Tree fodder from pollarding*	$300	$21,600
Mānuka planting	-$6,100	$24,300
Pine planting*	$7,600	$44,500
Rewarewa planting	$8,800	$21,500
Tōtara planting	$11,100	$56,700

*Replaced at 30 years

Where possible, non-market benefits were quantified and included in NPV calculations. Table iv indicates which parameters were quantified and which were not. When non-market values were included in calculations, the NPVs for PRB options increased considerably and cut and carry pasture offered the highest return on investment, even higher than returns from grazing. In practice, not all non-market benefits could be quantified in the analysis (Table iv). For instance, sediment interception (e.g., from the cut-and-carry option) has not been quantified. As a result, the net benefits for some options are underestimated.

Most benefits generated from PRBs are expected to accrue to the farmers who implement them. However, some non-market benefits – such as carbon sequestration on narrow riparian buffers[1] or improved downstream water quality – accrue to society generally. Widespread uptake of PRBs generating societal benefits will increase the importance and positive impacts of these options.

The PRB options vary in terms of their suitability for wider application (scalability). Timber production benefits significantly from economies of scale, while the scalability of foliage harvesting for essential oils may be limited by the small size of the market for these products. The PRB options also vary in terms of factors that influence the likelihood of adoption by farmers (Keuhne, Llewellyn & Pannell, 2017). Production options involving trees have longer time lags, are less reversible, and are less

[1] Participation in the carbon market is not possible for narrow sites.

convenient than pasture to maintain so they may be less likely to be generally adopted. On the other hand, the non-pasture production options can reduce business risk through diversification and provide a wider range of environmental benefits.

Table iv: Parameters quantified and comments

Parameter	Quantified?	Comment
Fodder benefits	Yes	
Fodder production costs	Yes	
Nutrient uptake benefits	Yes	Benefits to wider public
CO_2 sequestration benefits	Yes	Benefits to wider public
Honey benefits	Yes	Excluding pollination benefits
Foliage for oil	Yes	
Timber	Yes	
Harm to drainage from trees	No	Likely to be low if positioned appropriately
Sediment trapping	Yes	Only for demonstration sites, as highly site-specific
Cultural values	No	
Aesthetics	No	
Shade	No	
Habitat and biodiversity	No	

1 Introduction

Riparian buffers are strips of vegetation near a water course that are planted to help shade and protect the water course from the impact of agricultural contaminants derived from nearby land use. In New Zealand, riparian buffers have been identified as tools with the potential to protect water courses from inputs of sediment, nutrients (nitrogen and phosphorus) and microbial contaminants. They may also be economically beneficial in their own right, where the vegetation has commercial or other values – in these circumstances, vegetation planted along water courses have the potential to form 'productive' riparian buffers.

The Sustainable Food and Fibre Productive Riparian Buffers (PRB) project is funded by the Ministry of Primary Industries (MPI) through the Sustainable Farming Fund (SFF). The project was co-developed by NIWA and DairyNZ. The project aims to develop edge-of-field agricultural methods that improve water quality and ecological conditions, while also providing a productive benefit. To this end, the project is evaluating a series of alternative productive riparian buffers around pasture sites:

- cut-and-carry pasture
- tree fodder from short-rotation coppicing
- tree fodder from pollarding
- mānuka (oil) planting
- rewarewa (honey) planting
- tōtara (oil) planting
- pine planting.

The seven options are presently being evaluated and, in some cases, trialled at three pilot sites in New Zealand: two farms in the Waikato and one in Northland. Assessment of the economic value and water quality benefits of these candidate buffers was based on information derived from these sites.

NIWA was engaged by DairyNZ to develop a methodology to perform a cost benefit analysis (CBA) of at least five agreed species/solutions. It was agreed that this work would be undertaken with support from DairyNZ subject experts in a collaborative manner, consistent with other workstreams arising from the SFF PRB project. The CBA methodology would address the following requirements specifically:

1. Undertake analyses to determine the nutritional and financial value of productive buffers relative to current pasture crops for the locations where the project is trialled, based on information provided by DairyNZ.
2. Undertake modelling to determine the likely extent of contaminant uptake across a range of buffer widths and planting densities for the most appropriate species.
3. Estimate empirical relationships between planting density and age, and potential catchment scale nutrient uptake for the regions studied.

4. Evaluate (as far as possible) the potential for buffers to be used in other regions of New Zealand using the literature and data compiled in this study.

5. Estimate sediment and nutrient-related water quality benefits for 3-4 demonstration sites using readily available data and information sources.

The outcomes of these analyses are summarised in this report, where the nutritional and economic value and likely catchment scale uptake of nutrients at different planting densities across a range of plant species were used to provide a cost benefit analysis.

2 Method

Cost-benefit analysis is a systematic approach to estimate the strengths and weaknesses of alternative investment options. The key element is inclusion of all relevant present and future costs and benefits and discounting them to a present value. The total of the benefits and costs in present value terms is known as Net Present Value (NPV). When these costs and benefits are well documented, it provides a reliable assessment tool embedded in economic welfare theory. An alternative method is cost effectiveness analysis (CEA), which is commonly applied when comparing options with a similar benefit. If comparing PRB options on a single objective, such as nutrient removal, CEA would be an appropriate method. However, where PRB options potentially generate multiple benefits – as are expected in this project – CBA is more appropriate.

The main advantage of CBA is that it lends impartiality and objectivity to decision-making. A limitation is that it is only well-suited to costs and benefits that can be easily monetised. CBA can be extended by including non-monetary items (Brouwer and van Ek, 2004), but valuation can be challenging.

This analysis of productive riparian buffers compares the economic value of investing in different productive buffers. It includes estimates of selected non-monetary values, where data are available.

2.1 Production options evaluated

The PRB options in this CBA were drawn from a literature review by Heubeck et al. (2019). Two of these options (chainsaw-harvested tree fodder and tōtara oil) were the subject of field trials in the wider PRB project (Heubeck, 2020). The other options were assessed using published information. Some options from the literature review were not included due to lack of cost and benefit data. The following seven PRB options were assessed.

2.1.1 Cut-and-carry pasture

The cut-and-carry option involves the establishment of an ungrazed pasture strip alongside rivers that removes nutrients, sediment and pathogens. The strip is easy to harvest mechanically if fencing is flexible enough to allow mower access. All common pasture grass species (i.e., rye grass, timothy grass, fescue, cocksfoot, etc.,) as well as non-legume broad leaf pasture species, may be suitable for riparian buffers (Heubeck et al. 2019, p.19).

2.1.2 Tree fodder from short rotation coppicing

A recent review by Heubeck et al. (2019) identified the production of tree fodder as one of the most viable pathways for the large-scale adoption of productive use of riparian areas. This is due to the relatively large body of knowledge that exists regarding use of poplar and willow tree for fodder, the swiftness with which environmental benefits are likely to be realized, and the ability to use tree fodder within the existing farming operation.

In this option, poplar or willow trees are planted along riparian borders to protect the water course and, ultimately, may be regularly (e.g., annually) harvested for use as fodder for cattle. The short rotation coppicing (SRC) option uses poplar (*Poplar deltoides x P. nigra)* or willow (*Salix matsudana* x *alba*). Expected yields from poplar or willow are very similar, so these have been combined into a single option. The most suitable species or clone for a specific riparian site will depend on climate, soil moisture (for example, willow will perform better in wet sites), and risk of willow aphids. The New Zealand Poplar and Willow Research Trust (https://www.poplarandwillow.org.nz/) have amassed a substantial poplar and willow site-species/clone matching, willow growth, yield, cost and benefit, silviculture database which can be used to help select the most appropriate clone.

Annual coppice harvest is done close to the ground (20-30 cm above ground), from where regrowth will occur. This growth habit lends itself well to mechanical harvesting with an adapted maize harvester, so this option is best suited to a relatively flat and accessible site. The frequent and intensive harvest regime means that the trees should not grow large enough to fall and block drains.

2.1.3 Tree fodder from pollarding

In this option, poplar or willow trees are planted along the water course and growth above a certain tree height is removed. In order to create a robust trunk, the tree is allowed to grow for a few years before the first pollard. All above-ground biomass apart from the trunk is removed using a chainsaw or specialised mechanical pruner. This is then repeated 2 or 3-yearly. Wide spacing allows access for chainsaw harvest, longer rotations and increased flexibility as to time of harvest. This option was assessed using data from poplar (*P. deltoides x P. nigra*) – results using data for willow would be very similar. Maximising the net benefit of this option requires selecting the best clone for local conditions.

It is also possible to use slower growing native shrubs – mahoe (*Melicytis ramiflorus*) or kohūhū (*Pittosporum tenuifolium*) – as fodder. The disadvantage of using native shrubs in pollarding for fodder is that they produce only 25-40% of the biomass of poplar and willow over 5 years. On the other hand, being slower growing, they are less likely to cause problems in drains, and can be planted closer to a waterway.

This option requires careful site selection and management to ensure tree roots do not block drains and branches do not fall into a stream. No cost estimate was included for drain blockage because this was assumed to be avoidable.

2.1.4 Tōtara oil and timber

Tōtara (*Podocarpus totara*) is a versatile productive species that can provide foliage for essential oils, poles for fences, and eventually, high value timber. In this option tōtara are planted alongside watercourses and the process of pruning and thinning the tōtara for timber provides intermediate commercial by-products: foliage and poles. Using the poles on-farm avoids the need for transport, or the requirement to find a market for this product.

2.1.5 Rewarewa honey and timber

Rewarewa (*Knightia excelsa*) is a native plant that can be used to produce high value timber as well as mono-floral honey. Rewarewa honey has established product lines and is increasingly being marketed overseas (Heubeck et al. 2019). As a secondary pioneer species, which quickly colonises gaps in established vegetation, rewarewa should be well suited for incorporation to a PRB. It can cope with full sunlight, most soil types and climates typically found in the North Island. Its tall, slender form and moderate growth could contribute to stream shading relatively soon after buffer establishment.

2.1.6 Pine for timber

Pinus radiata is a productive buffer option that provides flexibility and backup cashflow to a farming system. There is a wealth of information available about pine management and harvesting regimes in New Zealand. However, pine is not well suited for permanently wet soil conditions.

2.1.7 Mānuka for oil and water quality

Mānuka (*Leptospermum scoparium*) is a production option that involves harvesting foliage for the production of essential oils. Mānuka has growth and antimicrobial features that make it an attractive species for removing nutrients and reducing *E. coli* contamination of waterways (Prosser et al. 2016). Mānuka can fix upwards of 170 tonnes of CO_2 per hectare by year 30 (Gines et al. 2017). It grows well in permanently wet soils, peat, and other highly organic swamp soils (Sanders, 2017). While riparian margins are not large enough for mono-floral mānuka production, the foliage can be harvested for essential oils.

3 Data and calculations

3.1 Biomass estimation

Estimation of production and other benefits over time required allometric models of biomass accumulation[2]. However, few species-specific allometric models are available, and even fewer for specific harvesting regimes. Some studies model biomass accumulation per hectare which is less useful when the effect of different spacings needs to be estimated. Best data are available for *Pinus radiata*, followed by poplar and willow.

For each species, it was possible to find at least 3 data points from a nursery website (www.southernwoods.co.nz) for age or height (seedling, 5 years, and maturity). Additional age-height data points were located for tōtara and pittosporum (kohūhū) (Kimberley et al. 2014), mānuka and kānuka (Sanders, 2017), radiata pine (Scion, 2020), poplar and willow (Ge et al. 2015; Phillips et al. 2014). A 5-parameter Richards curve[3] was then fitted to each species to create smooth parametric curves (Figure 3-1) to describe potential biomass resulting from the PRB options. It is important to note that these curves assume adequate growing conditions over time. In addition, the slow growth rate of native trees means they reach maturity decades after pine, poplar and willow.

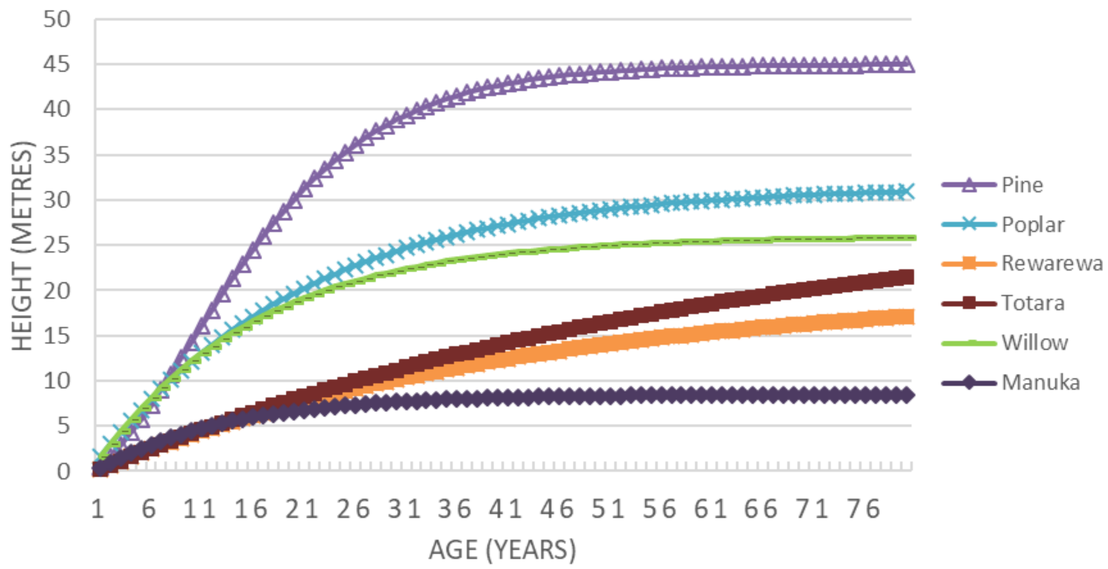

Figure 3-1: Height-age Richards curves for tree species.

Next, continuous curves for trunk diameter at breast height (DBH) were fitted for the trees, and root-collar diameter (RCD) were fitted for pittosporum and mahoe. Although Marden et al. (2018) used linear functions for height and diameter, these only work for juveniles or over short timeframes. Based on available survey data for various species, a power function better fits data acquired over the sapling to maturity phases (Bergin and Kimberley, 2011).

Finally, curves for net (after litterfall) above-ground biomass (AGB) were fitted. Sources of AGB data included studies of juvenile natives (Marden et al. 2018a; Marden et al. 2018b), and published estimates of carbon sequestration (carbon is assumed to be 50% of biomass) in mature trees

[2] Models based on the scaling relationship between the size of an organism part and the size of the organism as a whole, as both grow during development

[3] http://www.pisces-conservation.com/growthhelp/index.html?richards_curve.htm

(Kimberley et al. 2014). Aside from radiata pine, little information appears to be available regarding biomass in trees aged 5-40 years. AGB was therefore estimated by fitting the allometric equation:

$$AGB = a(D^2H)^b$$

where D is diameter in centimetres and H is height in m. Below-ground biomass (BGB) was estimated using the ratios published by Marden et al. (2018b). It was necessary to estimate AGB and BGB separately because fodder harvesting removes much of the above-ground biomass but root biomass remains. Figure 3-2 shows that poplar and willow have an early advantage in terms of net biomass accumulation but are exceeded by radiata pine around year 12.

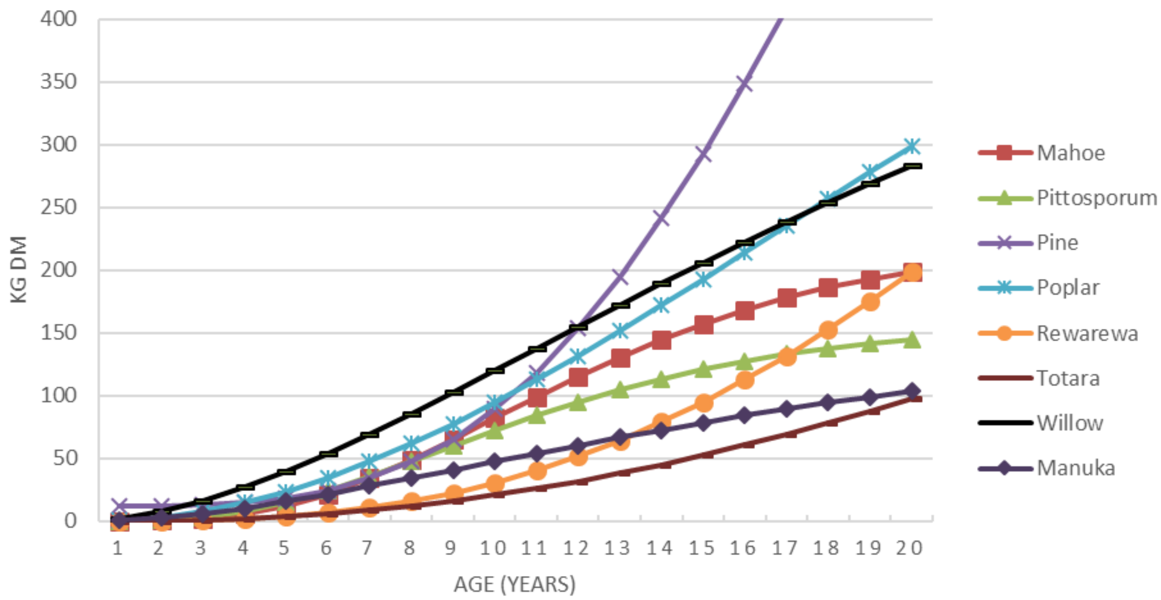

Figure 3-2: Estimated net above ground biomass for select species at end of year 1 through 20.

3.2 Calculation of costs

Data on the establishment and maintenance cost of alternative PRB options were sourced from DairyNZ, published documentation and commercial web sites. Detailed cost sources are noted in Table 3-1.

Table 3-1: Summary of sources of cost data.

Parameter	Method
Establishment	Seedling costs sourced from Scion (2020), Southernwoods.co.nz, and Richmond Downs farm trial Labour cost from Muller (2019), Scion (2020), and Tatuanui farm trial Herbicide cost from Bergin & Silvester (2012) Fencing costs from Muller (2019)
Maintenance	Weed control regimes from Hock et al. (2014) and Rainbow and Brown (2020) Tree pruning regimes from Scion (2020) and Bergin (2003)

3.2.1 Planting

Plant costs were estimated using data from a nursery website[4] which have prices for a wide range of trees in various quantities and grades. The total number of plants required is based on the required spacing between plants and total area of the riparian buffer. Labour cost per plant is assumed to be $2 (Muller, 2019). There is also a pre-plant herbicide application cost of $350 per hectare (Bergin and Silvester, 2012).

3.2.2 Weed control

The need for weed control depends on the species, harvesting regime and density of planting. Coppiced and pollarded trees require an application of weed spray after every harvest to ensure that weeds do not out-compete the regrowth from the stumps. Other options require weed control with targeted spraying or manual releasing (removing or destroying weeds growing around the collar) at least until canopy closure occurs.

Manually releasing plants involves a base labour cost of 3.5 hours per hectare at a density of 850 stems per hectare (Hock et al. 2014). This is equivalent to 15 seconds per stem.

The cost of herbicide is around $103 per hectare (Rainbow and Brown, 2020). Assuming a slow walking pace of 5 kilometres/hour, spraying a 2 kilometre strip would take around 0.4 hours plus travel time to the site. The total cost of knapsack spray weed control is therefore assumed to be around $120 per hectare.

3.2.3 Fencing

Riparian buffers require stock exclusion for the protection of the plants and water quality. If the area is not already fenced, this needs to be included as an upfront cost. Three-wire electric fencing on rolling land is assumed to cost $5.50 per metre including labour (DairyNZ, 2021). Materials comprise about half the cost so, if an existing electric fence can be moved to provide stock exclusion, this is a cheaper option.

In some areas it is desirable to maintain access for drain cleaning in which case options include the establishment of removable wooden rails, an electric fence that can be removed or dropped, or strategically placed gateways. It is assumed that, where relevant, fence posts are spaced at 10 metre intervals for electric fences (Muller, 2019). Fence costs for flat to rolling contour assume a post driver can be used. Fencing costs are based on reasonable ground conditions – establishment on rocky, swampy or extremely heavy clay soils may increase costs.

3.2.4 Opportunity cost of not grazing

It is likely that land retired to improve existing wetland areas has a lower productive potential than the average paddock on the farm due to wet soil conditions or slope. Based on conversations with the farmers involved in these case studies, it is assumed that pasture production from retired areas is 8 t DM/ha/year. The average pasture growth is 15 t DM/ha/year for a dairy farm in the Waikato region and 13.6 t DM/ha/year for a dairy farm in the Northland region (DairyNZ, 2020a).

The new stock exclusion regulations that came into force on 3 September 2020 (Ministry for the Environment, 2020) require a 3 metre exclusion, so this land will be lost to grazing whether or not

[4] www.southernwoods.co.nz

productive buffer options are used. Therefore, the cost of lost grazing is not included in the NPV totals.

3.3 Calculation of benefits

3.3.1 Fodder value and metabolizable energy

Fodder value is assumed to vary according to metabolizable energy (ME). ME is measured in megajoules per kilogram of dry matter (DM). Estimates of metabolisable energy for several crop species are summarised in Table 3-2. A fodder value is assumed to be worth 2 cents per unit of Metabolisable Energy. This is based on a value of $220 per tonne (delivered) for the commonly used feed palm kernel and implies that poplar fodder would be worth $190 per tonne.

However, the cost of palm kernel can be 50-100% higher during a dry, late summer period (DairyNZ, 2020b), so the pollard option assumes fodder is harvested and used when the price of feed is highest.

Feed value of native trees and shrubs is relatively low, due to generally lower concentrations of nutrients and slower growth rates (Heubeck et al. 2019). Kohūhū (*Pittosporum tenuifolium*) and mahoe (*Melicytus ramiflorus*) have relatively high palatability (for native shrubs), but they are still much slower growing than exotic poplar and willow.

Table 3-2: Average estimated metabolisable energy per kilogram of dry matter.

Crop/Species	Metabolisable energy (MJ/kg DM)	Source
Sedge (*Carex secta*)	7.50	DairyNZ and NIWA, 2020
Poplar (*Populus deltoides x nigra*)	9.53	McWilliam et al. 2005
Willow (*Salix matsudana x alba*)	8.57	Heubeck 2020
Silage	10.00	DairyNZ
Mahoe (*Melicytus ramiflorus*)	10.00	DairyNZ and NIWA, 2020
Pasture	11.00	DairyNZ
Palm kernel	11.00	DairyNZ
Kohūhū (*Pittosporum tenuifolium*)	12.00	DairyNZ and NIWA, 2020

3.3.2 Fodder harvest yield and cost

Two alternative harvest strategies are coppicing and pollarding. Coppicing involves cutting the stem close to the ground during harvest, which generally occurs every 1 to 4 years. This enables the highest biomass yield, which can be 3.9 kg DM per stem per year with wide spacing (400/ha) and good loamy soils (Phillips et al. 2014). Biomass per hectare depends on planting density, although biomass per stem is lower at high densities.

A 2-year-old whole tree poplar coppice is comprised of 37% leaf, 9% bark, 12% branch, and 42% wood chip (Dou et al. 2017). Studies of poplar short-rotation coppicing report biomass yields of 14-25 t DM/ ha/year (Debell, 1996; Dou et al. 2017; Strong and Hansen, 1993), with little difference between 0.5 m spacing (20,000 stems/ha) and 1 m spacing (10,000 stems/ha). The first rotation has a lower yield due to immature root systems, and is around 75% of subsequent rotations (Hauk et al. 2014).

Coppicing is most efficient if stock graze the crop directly, but grazing is not appropriate for riparian buffers. Mechanised harvest is the next most efficient method (Douglas and McIvor, 2010). Single-pass cut-and-chip harvesters are commonly used. Harvesting costs in Europe average €18 per tonne fresh matter with a standard deviation of €13 (Vanbeveren et al. 2017). Freshly harvested shoots are 56% moisture, so the equivalent cost in NZD is \$68 ± \$50 /t DM. Consultation with the Tatuanui farmer – who is planning to use a maize harvester – suggests that this cost range is reasonable in New Zealand.

Pollarding involves removing all growth above a certain height (e.g., 1.4 m) using a chainsaw or a mechanical pruner if the terrain is flat with easy access. The tree is allowed to grow for a few years before the first pollard, which is then repeated 2 or 3-yearly. Annual harvest may be possible in highly fertile sites but delaying a year allows the trees to replenish root starch reserves and increase biomass yield (Garcia, 2016). The other advantage of a longer interval is that it allows greater flexibility to harvest when supplementary feed prices are high.

Pollarding may begin after 2-7 years, and all biomass above 1.4 m is removed. There is more woody branch biomass than with short rotation coppicing. The proportion of leaves in a 6-year-old poplar is 38% (Fortier et al. 2015). For willows, about 30% is edible foliage (Douglas and McIvor, 2010). However, with fine chipping and ensiling, branches and stems can also be edible (Heubeck et al. 2019). It is assumed that the edible portion will be leaf biomass plus an equal amount of branch and stem biomass. For longer rotations, manual harvesting is more economic than motorised, with costs in the order of \$100/t DM (Hauk et al. 2014).

3.3.3 Nutrient uptake

The removal of nutrients via uptake into biomass is modelled by assuming nitrogen and phosphorus comprise a fixed proportion of the modelled biomass. In reality, nutrient content depends on growing conditions and nutrient availability, so this approach generates indicative estimates of uptake. It is assumed that the main stem of trees and shrubs contain 3.38 kg nitrogen per tonne of dry matter, and 0.4 kg phosphorus (Fortier et al. 2015).

Branches and leaves have higher nutrient contents. Willow biomass is assumed to contain 2% nitrogen and 0.2% phosphorus (Heubeck, 2020), while poplar biomass has 1.9% nitrogen and 0.18% phosphorus (Ge et al. 2015). In preliminary testing for this project, slightly higher nutrient contents were found for 9-month old coppiced willow biomass (Tangoio cultivar): 2.4-2.6% nitrogen and 0.20-0.23% phosphorus for foliage, and 0.4% nitrogen and 0.07% phosphorus in woody stems (Heubeck 2020).

A recent study has shown that mānuka and kānuka are able to assimilate large amounts of nutrients and allocate up to 100 kg nitrogen per hectare to stems and leaves (Esperschuetz et al. 2017). In a high nitrogen environment, leaching under mānuka and kānuka was just a third of that leached under pasture (Gines et al. 2017).

Daigneault et al. (2017) suggest that the public value of nutrients removed from streams is \$10-\$40 per kilogram of nitrogen and \$50-\$200 per kilogram of phosphorus. This analysis reports nutrient quantity and approximate non-market value using middle-of-the-range values for nitrogen and phosphorus.

3.3.4 Carbon sequestration

It is assumed that carbon comprises 50% of total modelled biomass. This is multiplied by 1.65 (Marden et al. 2018b) to convert to tonnes of carbon dioxide sequestered. The potential commercial value to farmers of carbon sequestration from PRB tree planting is then estimated by multiplying the volume of carbon sequestered by the price available under the New Zealand Emissions Trading Scheme.

In practice, to earn carbon credits in the New Zealand Emissions Trading Scheme, a forest must have an average width of 30 m, be at least 1 hectare in area, and have at least 30% of the area in forest species that can reach at least 5 m height (Te Uru Rākau, 2020a). These restrictions exclude a typical narrow riparian buffer. Nevertheless, the sequestration represents real benefits to broader society. Adopting the New Zealand Emissions Trading Scheme price of carbon as a proxy for the potential social value of trees suggests that a higher per hectare social value can be achieved by retaining PRB trees along borders than felling them for commercial income.

3.3.5 Honey

As indicated in Section 2.1.4, rewarewa honey is a mono-floral honey from a New Zealand native plant which already has established product lines. While rewarewa honey is reported to have anti-microbial and anti-inflammatory properties and may be expected to command a premium price (Wilkinson and Cavanagh 2005, Leong et al. 2011), most rewarewa honey is marketed for culinary use at prices of NZ$8 - 15/kg.

Mono-floral mānuka honey requires a plantation of at least 40 ha with no alternative pollen or nectar sources to dilute the mānuka-derived honey (Sanders, 2017). This makes riparian buffers unsuitable for the production of Unique Mānuka Factor (UMF) honey. The alternative is to plant species that bees prefer, such as rewarewa (*Knightia excelsa*). Planting a mix of other native species (or ensuring that clover is available) can ensure alternative food sources are available to bees when rewarewa is not flowering.

A honey bee hive is capable of producing 25 to 35 kg mono-floral honey per season, with yields being at the high end in the Waikato region (Sanders, 2017). Each hive requires five rewarewa trees at least seven years old, with other species used as alternative nectar sources when rewarewa are not in flower. The land owner does not need to own or manage beehives. Rather, a hive owner pays royalties for the use of the land and nectar sources. These royalties range from 10-30% of honey wholesale value (Sanders, 2017, p. 25). The costs of the hive and honey harvest are paid by the hive owner so are not included in this analysis.

Bees may also pollinate pasture and other plants and trees in the area. However, the benefit of pollination is not quantified in this analysis.

3.3.6 Oils

Estimation of the value of tōtara foliage for oil production uses the harvesting regime described in Heubeck (2020). The first harvest of foliage occurs around 8 years (sapling stage), producing 20 tonnes fresh matter/ha on a density of 2,300/ha. The second harvest occurs in year 15 (22 t/ha) when the trees are thinned to 1200/ha. There is a third harvest from the crown of the mature tree around year 35 (150 t/ha).

Harvesting costs assume an hourly labour cost of $25 and 19 hours per tonne for saplings and 26 hours per tonne for poles and mature trees. It is assumed that the harvest can be sold to distillers for

$500 per tonne (Sanders, 2017). However, the total size of the market for foliage for essential oil is likely to be small so scalability is not assured.

Mānuka also has a high essential oil content and high concentrations of fragrant and bio-active components (Essien et al. 2019). The mānuka harvesting regime needs to be regular (annual or two yearly) to retain a good ratio of foliage to branch matter, and to keep plants at a convenient height (~3 m). Unlike valuable timber species such as tōtara, there is little economic value in letting mānuka reach its maximum height. Harvesting is assumed to be done with a mechanical hedge cutter, which incurs a $150 start fee plus $130 per hour including operator [5.] No references for harvest productivity could be found. However, if it is assumed that the cutter moves at a slow walking pace, it could trim a 2 kilometre by 5 metre strip (1 ha) in an hour. The time is doubled to allow for collection of the fresh matter.

3.3.7 Timber

When managed adjacent to a farming operation, sustainable forest management requires relatively small capital investment and low management costs.

Exotic species (e.g., *Radiata pine* and Douglas fir) may not be well suited for PRBs because the wet conditions often found along stream margins are not ideal for these species (Heubeck, 2020), restricting rooting depth and making them prone to toppling during storms. Nevertheless, one of this project's Northland farmers has successfully grown and harvested a riparian pine woodlot, netting (after harvest costs only) approximately $30,000/ha. If a suitable site is available, the economic value can be estimated using the Forecaster Calculator, a forest simulation tool for radiata pine and Douglas-fir in New Zealand (Scion, 2020). The Forecaster Calculator predicts tree growth and yield of log products derived from a single clear fell age on a per hectare basis. Its target audience is primarily the small woodlot owner wishing to calculate a rough estimate of the volume and log product mix on a particular site at a particular age.

To harvest and mill indigenous timber requires a sustainable forest management (SFM) permit. The harvest must be 10% of the standing volume by species, unless it comes from a recognised source such as windfall trees or trees planted specifically for timber (Te Uru Rākau, 2020b). In the latter case, a planted indigenous forest certificate should be obtained as part of the planting process. This requires evidence, such as photos and receipts, to show the trees were planted for the purpose of timber harvesting. The permit required to harvest native timber may cost around $100 per hectare (Griffiths, 2002, p. 10).

Rewarewa is known for its symmetrical conical shape, which is a desirable feature for timber. A tree could be harvested when it reaches a trunk diameter of 30 cm, although it would be worth more (due to larger volume and width) at 40 cm (Griffiths, 2002). This implies harvesting after 50-80 years. The mill-door sale price depends on local supply and demand, but it is safe to assume that the price per cubic metre would be at least as high as macrocarpa ($375) and probably similar to rimu ($500) (Griffiths, 2002). The clear fell logging cost is reported to be around $90/m^3 for native hardwoods (Griffiths, 2002). This is higher than the $35/m^3 logging cost used in the radiata forestry calculator (Scion, 2020), perhaps due to a lack of economies of scale.

Tōtara is a long-rotation timber crop with a similar value to rewarewa. Tōtara may be thinned to produce fence posts in stages after 15 to 25 years, yielding posts of different sizes over time. Being a

[5] https://farmbackup.co.nz/categories/hedge%20cutter%2Fmulcher

naturally durable hardwood, these would not require chemical treatment like pine does. Assuming a production equivalent to 1,500/ha durable No.1 round fence posts (115-140 millimetres diameter and 2.4 m length) over 25 years (Bergin 2003), gross earnings may be around $22,500 over 25 years ($15 per pole).

Timber species are generally planted at a higher density than is ultimately harvested, to encourage good vertical form and suppress weeds (Bergin and Silvester, 2012). The cost of thinning radiata is specified in the Forecaster Calculator and is based on 1 minute per tree. In the tōtara harvest trial it took 6 minutes per tree (Heubeck, 2020). This suggests significant cost savings are likely from use of experienced labour and economies of scale. Form pruning is another maintenance cost. Pine is pruned in years 5-8 to 6 m which takes 2-3 minutes per tree (Scion, 2020). Annual form pruning for indigenous trees is recommended to 3 m (NZFFA, 2005). Pruning to 3 m is easier than 6 m and this probably makes up for lower economies of scale, so pruning is assumed to take 3 minutes per tree, similar to pine.

Poplar and willow can also provide useful timber, if form-pruned rather than harvested for fodder[6]. However, the feasibility of this option relies on sufficient demand for the timber from accessible sawmills. In practice, there may not be sufficient market support for this. Landowners who are able to mill logs on-farm and use or sell timber themselves may derive an economic benefit, but poplar and willow for timber is not a PRB option analysed in this report.

The methods used to value PRB benefits are summarised in Table 3-3. These benefits are added for each year, for each production option to which they apply.

Table 3-3: Summary of benefit estimation methods.

Productive buffer option	Method
Fodder	Estimation of biomass produced per ha using allometric model derived from published values Conversion of biomass per ha to fodder energy and commercial values Estimation of costs from harvest trial and published values
Nutrient uptake	Estimation of uptake using published values Conversion of uptake levels to dollar values using Daigneault et al. (2017)
CO_2 sequestration	Estimation of CO_2 uptake based on biomass accumulation Conversion of carbon uptake values to dollar values using Daigneault et al. (2017)
Honey	Conversion of tree density to honey production from published values
Foliage for oil	Estimation of yield from harvest trial Estimation of cost from published values
Timber	Estimation of volume from allometric models and Radiata Forecaster (Scion, 2020) Conversion of volume to net stumpage from published values

[6] https://www.poplarandwillow.org.nz/farmer-guides/timber-uses-and-farm-milling

3.4 Water quality benefits

Potential water quality benefits of the demonstration site PRBs were assessed for each single specific planting option. In the case of the two Waikato farms, the planting option was that being trialled at the site. Benefits were estimated by comparing plant uptake of dissolved nutrients to nutrient export for the adjacent NZ river segment. Sediment and particulate nutrient attenuation relative to sediment export was also assessed. All of the demonstration site PRBs are located in first-order headwater river segments (there is no river segment upstream). For the purpose of this analysis, it was assumed that the PRB was implemented across the entire river segment.

Using NZ River Maps (https://shiny.niwa.co.nz/nzrivermaps/), data on long-term average annual sediment export was acquired (source: Hicks et al. 2011). From these the concentrations of median suspended sediment (SS), total nitrogen (TN) and total phosphorus (TP) concentrations were used (source: Whitehead, 2019) to calculate annual TN and TP export in tonnes per year (t/year) for each of the PRB headwater river segments. Annual TN and TP export was further divided into particulate and dissolved fractions. The sum of median nitrate and ammonium concentrations represented dissolved nitrogen. Water phosphorus content was represented by the median dissolved reactive phosphorus concentration.

Estimates of dissolved nitrogen and phosphorus uptake from shallow groundwater for the PRB at each site (t/year) were calculated from annual uptake rates (kg/ha/year, converted to t/ha/year) multiplied by buffer area (ha). The proportion (percentage) of stream nutrient export subject to uptake by the PRB as dissolved nutrient (P_{UN}, per cent) was calculated as follows:

$$P_{UN} = ((U_{NB} x A_B)/E_N)x100$$

Where: E_N = Dissolved nutrient export from the river segment (t/year)

U_{NB} = Dissolved nutrient uptake by the PRB vegetation (t/ha/year)

A_B = PRB area available in the river segment at designated width (ha)

To estimate sediment and particulate nutrient attenuation, the guideline curves in McKergow et al. (2020) were used (Figure 3-3). The curves present sediment removal (per cent) from surface runoff as a function of the ratio of buffer width (m) to contributing hillslope length (m). For each demonstration site, the hillslope length draining to the buffer was estimated using measurement tools in ArcGIS to derive the slope length to buffer width ratio. The appropriate guideline curve (corresponding to low, average or high performance) was selected according to the adjustment factors provided by McKergow et al. (2020). All sites had soils with less than 28.5% clay content. The corresponding sediment removal (per cent) from surface runoff was identified and then conversion factors from McKergow et al. (2020) were used to derive the corresponding particulate TN and TP removal (per cent) (Table 3-4).

No estimates of stream bank erosion contribution to sediment export from the river segment were available, so it was assumed that all sediment exported was derived from land runoff. Bank erosion may have zero net contribution to sediment exports in streams where sediment eroded from banks is balanced by deposition on point-bars and floodplains. Bank erosion is mostly likely to contribute to sediment export in situations where the channel is enlarging in response to a change in hydrological regime (Davies-Colley et al. 2015).

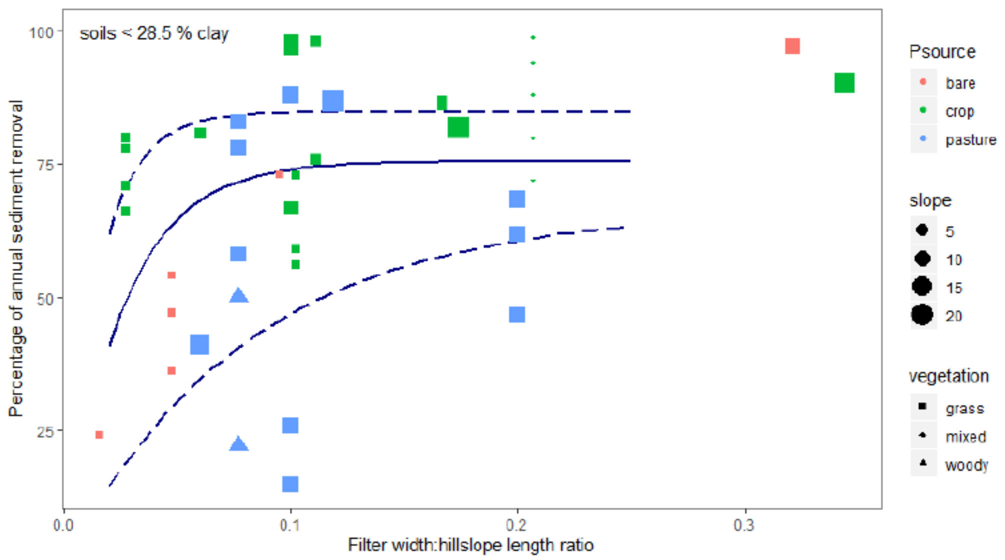

Figure 3-3: Relationship between sediment removal and filter width: hillslope length ratio for riparian buffers. From McKergow et al. 2020.

Table 3-4: Conversion factors for estimating total nitrogen and total phosphorus removal from annual sediment removal for riparian buffers. From McKergow et al. 2020.

	Measured (SS) and predicted (TP, TN) contaminant attenuation		
	SS (%)	TP (%)	TN (%)
Equation		TP = 5.49 + (0.724 × SS)	TN = 3.08 + (0.86 × SS)
		$r^2 = 0.66$	$r^2 = 0.81$
Values	30	27	29
	40	34	37
	50	42	46
	60	49	55
	70	56	63
	80	63	72
	90	71	80

3.5 Discount rate

A CBA uses discounting to render costs and benefits to a common temporal setting. A discount rate is used to convert future costs and benefits to present day values, indicating the rate at which the entity making the investment is willing to trade off future benefits. There are two alternative views about what is an appropriate discount rate for a CBA. These approaches are the Social Rate of Time Preference (SRTP) and the Social Opportunity Cost of capital (SOC) (Creedy and Passi, 2017). The opportunity cost of capital for a dairy farm is mortgage interest rates. Dairy farm mortgage rates are currently 4.1%, and are expected to decrease further (Research First, 2020), so 4% was selected as the discount rate for the case studies in this report.

A smaller discount rate makes current and future values more equal, meaning that investments that take longer to generate benefits retain some attractiveness compared to ones with faster payoff. Conversely, high discount rates render projects with long-term benefits (e.g., timber production) less attractive, and favour those that create short-term benefits (e.g., fodder production). Therefore, if landowners have a lower/higher cost of capital or rate of time preference, this may affect the relative attractiveness of different options for them.

The New Zealand Treasury[7] currently recommends 5% for general projects, which, if used instead of 4%, would slightly reduce the NPV of every option except cut-and-carry pasture and short rotation coppicing.

3.6 Timeframes

The production options in this report have different rotation periods. Tree fodder crops such as poplar and willow have a maximum lifetime of 20-30 years (Dimitriou and Rutz, 2015), whereas timber options may take 60-80 years to provide an economic yield. To accommodate the time differences involved for the different PRB options, the NPV is calculated using a timeframe of 60 years and includes two rotations for tree fodder and radiata pine.

[7] https://www.treasury.govt.nz/information-and-services/state-sector-leadership/guidance/financial-reporting-policies-and-guidance/discount-rates

4 Case study 1 – Tatuanui dairy farm

4.1 Description of riparian area

The riparian area under consideration for retirement as a PRB in this option comprises a strip of pasture adjacent to a drain, approximately 6 m wide and 80 m long (0.05 ha). The area is relatively flat and often boggy. All costs and benefits are estimated on a per-hectare basis for easier comparison with other sites.

4.2 Costs and benefits common to each production option

The landowner fenced the site using electric reels and standards, which can be moved to allow harvester access. The cost of this fencing was $482 per hectare.

Fencing a previously unfenced drain would be expected to avert 2 cow injuries or deaths per year, based on discussion with the landowner. This is worth $3,200 per year.

The productivity of the pasture is assumed to be 8 t DM per hectare per year. With an average ME of 11 MJ/kg DM, this is worth $1,760 per year. The NPV is **$39,800** for 60 years.

4.3 Cut-and-carry pasture

Regularly harvested grass is the most effective type of riparian vegetation for removing sediment, microbial pathogens and phosphorus in overland runoff. Dense and uniform grass covers effectively intercept overland flows and improve infiltration (Cooper et al. 1995), attenuating sediment and microbial contaminants (Smith 1989, Collins et al. 2004, McKergow et al. 2020). They also effectively reduce erosion associated with preferential flow paths that often occur on sloping riparian areas stocked with larger, woody plants.

It is assumed that the area to be excluded is already in pasture and would not need sowing. Occasional spot weed control may be needed, at a cost of $120 per hectare per year.

The cost to harvest, transport and ensile (preserve as silage) is assumed to cost 16 cents per kg, similar to the cost to grow and ensile maize (10.3-24.1c /kg DM[8]). The value of the silage with an ME of 10 MJ/kg DM is assumed to be $200 per tonne DM. The net benefit depends on the steady-state fertility (the level at which removed nutrients are replenished with run-off from adjacent grazing) of the soil. At 8 tonnes DM generated per year the net benefit would be $200 per year (Table 4-1). At 12 tonnes DM generated per year, the net benefit is estimated to rise to $360 per year. The NPV over 60 years is estimated to be between $4,470-$8,040.

Pasture biomass contains a high proportion of nutrients, around 2.25% nitrogen and 0.3% phosphorus (Kirchgessner, 1997). Cut-and-carry pasture therefore may remove 200-300 kg nitrogen and 24-44 kg phosphorus that enters the riparian buffer, with an annual non-market benefit of $6,000 to $11,000.

[8] https://www.pioneer.co.nz/maize-silage/tools/growing-and-harvesting-costs-calculator/

Table 4-1: Cut-and-carry pasture fodder benefit and cost, per hectare per year.

Value	Low fertility (8 t DM/ha/year)	Medium fertility (12 t DM/ha/year)
Harvest benefit	$1,600	$2,400
Harvest cost	-$1,280	-$1,920
Weed control	-$120	-$120
Nett benefit	$200	$360

4.4 Tree fodder short-rotation coppicing (poplar)

The area has just been planted with poplar wands at a very dense rate with 0.5 m and 0.75 m spacing between plants (approximately 18,000 per hectare) (Figure 4-1). The landowner used free wand cuttings so the establishment cost primarily consisted of labour. Planting a poplar wand is significantly quicker than planting a bagged or potted tree, which requires digging a hole. Planting required 272 hours /ha at $50 per hour ($13,600). Pre-planting herbicide cost $91 /ha and post-planting weed releasing took 222 hours /ha ($11,100). The total establishment cost (excluding fencing) was therefore $24,700.

Figure 4-1: Photo of planted poplar wands on 29/09/20.

One further application of knapsack weed control may be required ($120/ha) in year 2, after which the trees should outperform any weeds (Dimitriou and Rutz, 2015). The failure rate is expected to be around 5%, but these may be "gapped up" with cuttings from the first harvest. Fertilization is not recommended in early rotations unless the site is nutrient poor (Dimitriou and Rutz, 2015), which is unlikely to be the case at the edge of dairy pasture. After 20-30 years the cultivation may need to be replaced if age-related declining yields and disease susceptibility become apparent.

In this analysis, it is assumed that harvest yield will be within the range of values reported in the literature (14 t/ha to 25 t/ha), with the first harvest in year 1 being only 75% that of subsequent annual harvests. The resulting feed values range from **$2,953 to $3,937** /ha/year. The low estimate for harvest cost is $18.42/t DM and the high estimate is $118/t DM.

Table 4-1 summarises the NPV over 20 years with high and low estimates for both yield and harvest costs. Establishment cost (capex) is not varied because it is based on actual costs reported by the landowner. The NPV is positive except for a low yield and high harvest cost situation.

Table 4-2: Short-rotation coppicing 20-year NPV per hectare.

Value	Low yield, high cost	Low yield, low cost	High yield, high cost	High yield, low cost
Fodder benefit	$34,198	$34,198	$61,068	$61,068
Capex	$25,182	$25,182	$25,182	$25,182
Opex	$30,307	$2,007	$30,307	$3,417
Net benefit	-$21,291	$7,009	$5,579	$32,469

Assuming high yields, poplar growth removes 127 kg nitrogen /ha/year per year and 12.7 kg phosphorus /ha/year. If nutrient removal capacity exceeds the level of nutrients available, then yields may reduce over time. Using values from Daigneault et al. (2017), the non-market value of these nutrients was estimated at around $3,818 per year. Under the low yield scenario, a total of 71 kg of nitrogen and 7 kg of phosphorus are removed per year. This annual non-market benefit is presented along with farm system costs and benefits in Figure 4-2. If nutrient removal is an important consideration, this performance should make short rotation coppicing an attractive option.

Figure 4-2 illustrates that harvest costs and benefits are expected to be fairly constant over the lifetime of the poplar, assuming climate, nutrient availability and other stressors are also constant.

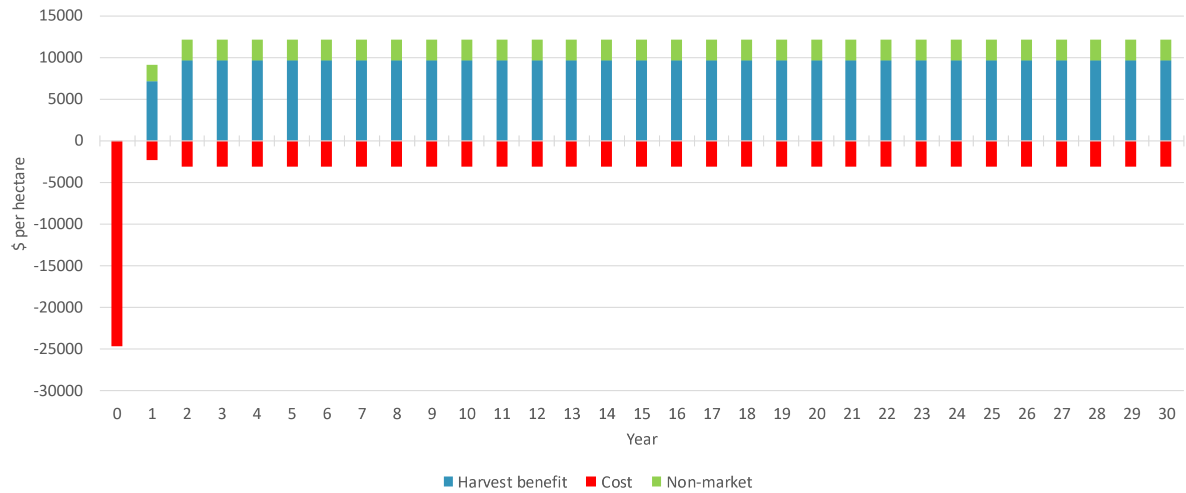

Figure 4-2: Timing of short rotation fodder benefits, costs and non-market values.

4.4.1 Water quality benefits

Water quality benefits were estimated for the poplar PRB using the methodology outlined in Section 3.4. The methodology used the river segment attributes outlined in Table 4-3 and the productive buffer attributes described in Table 4-4.

The results show that the PRB might be expected to provide low to moderate water quality benefits (Table 4-5). Specifically, if it is assumed that a 6 m-wide strip of poplar PRB were planted along the margins of the entire headwater tributary at this farm, it could trap between 9 and 16% of dissolved nitrogen export, between 36 and 65% of dissolved phosphorus export and between 34 and 40% of annual sediment and particulate nutrient export.

Table 4-3: Tatuanui Dairy Farm headwater river segment attributes.

River segment attribute	Units	Value
Stream order		1
NZ reach		3056785
Total riverbank length[a]	m	3740
Average hillslope length	m	308
Average slope angle	degrees	2.95
Catchment area	hectares	82
Annual sediment export[b]	t/ year	7.5
Annual particulate nitrogen export[b]	t/ year	0.62
Annual dissolved nitrogen export[b]	t/ year	1.75
Annual particulate phosphorus export[b]	t/ year	0.03
Annual dissolved phosphorus export[a]	T/ year	0.04

[a] Twice the stream length

[b] From the headwater river segment/first order catchment

Table 4-4: Tatuanui Dairy Farm productive river buffer attributes.

Buffer attributes	Units	Value
Existing PRB length	m	80
Existing PRB width	m	6
Existing PRB area	ha	0.048
Max. PRB area possible at designated width	ha	2.24
Plant species		short rotation poplar coppice (with dense rank grass)
Planting density	stems/hectare	18,000

Table 4-5: Tatuanui Dairy Farm estimated water quality benefits.

Water quality benefits[a]	Units	Value
Dissolved nitrogen uptake	% of segment export	9-16
Dissolved phosphorus uptake	% of segment export	36-65
Sediment attenuation	% of segment export	40
Particulate nitrogen attenuation	% of segment export	37
Particulate phosphorus attenuation	% of segment export	34

[a] If PRB occupies the banks of the entire river segment.

4.5 Mānuka (oil) planting

Mānuka can be established at relatively low cost using seed-bearing slash (laying a mulch of seed-bearing branches) if a local source of seed-bearing material exists (Sanders, 2017). Otherwise, plants can be sourced from nurseries at a bulk price of $3.15 per seedling. Planting at a high density (greater than 2500 stems/ ha) helps ensure rapid canopy closure and reduces the need to weed. A lower density of 1100 stems/ ha requires twice-yearly releasing for at least 5 years but is the cheaper option if paying for seedlings (Sanders, 2017). The cost to plant 1100 stems/ ha (replanting 5% failures) is $6,300. Weed control involves twice-yearly releasing ($230 per year) until year 5 (total cost $2,300).

Harvesting of foliage for oil begins after 5 years, with 6 tonnes of fresh matter harvested every two years. The foliage is worth $3,000, with harvesting costs of $2,100 every two years. The NPV for 60 years is negative $6,115 due to establishment costs and the delay before harvest can start. However, using seed-bearing slash rather than seedlings would render it cost neutral.

There may also be small on-farm benefits from using mānuka as firewood or woodchip calf bedding. Assuming a calf requires 2 m^2 of bedding 0.1 m deep, and there are 75 calves from a herd of 300, this implies 15 m^3 of woodchip bedding could be used per year (personal communication with an ex-dairy farmer, January 2021). The cost to buy 15 m^3 of woodchip is around $600[9] delivered.

The amount of nutrients removed by mānuka increases over time, as the root biomass increases. Averaged over 30 years, nutrient removal would be 56 kg nitrogen and 5.7 kg of phosphorus (worth $1,690) per year. By year 30, it could fix (in the non-harvested biomass) upwards of 170 tonnes of CO_2 per hectare more than pasture. Mānuka may also reduce *E. coli* levels in waterways but there is insufficient information to monetize this benefit.

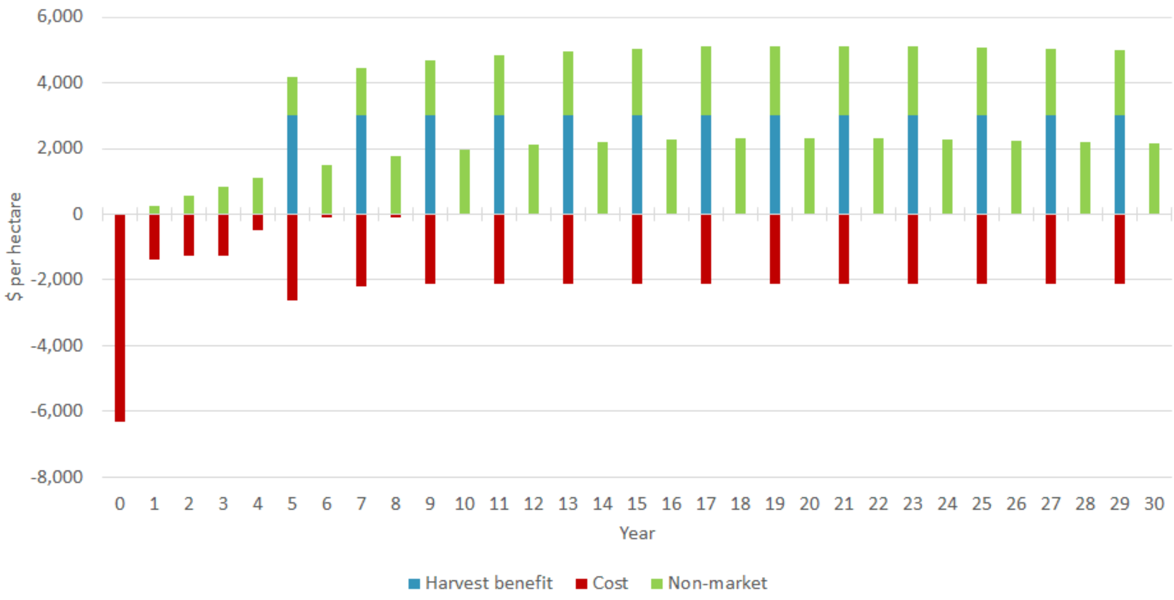

Figure 4-3: Timing of mānuka benefits, costs and non-market values.

[9] https://www.captaincompost.co.nz/shop/Example+Category+2/Wood+Chip+%28Tree+Mulch%29.html

5 Case study 2 – Richmond Downs dairy farm

5.1 Description of riparian area

The PRB demonstration site is an area close to the house. For the project the fence lines have been moved to take in a larger area. The demonstration area is too steep for mechanical harvesting, so production options need to be passive or include manual harvesting. Costs and benefits are on a per-hectare basis, assuming a riparian area 2000 m long and 5 m wide.

5.2 Costs and benefits common to each production option

The cost of a new two-wire fence 2000 m long is around $10,800. Excluding stock from the sloped area may avert 2 cow injury or deaths per year, worth $3,200 (using estimates provided in previous case study).

The annual productivity of the pasture is assumed to be 8 t DM /ha. With an average ME of 11 MJ/kg DM, this is worth $1,760 per year.

5.3 Rewarewa (honey) planting

5.3.1 Honey

Rewarewa has been planted for future honey production. This option requires little maintenance in the short term, supports native biodiversity and pollination and provides the potential for timber production. In order to maintain bee populations and support biodiversity, other bee-friendly species were planted together with the rewarewa trees.

The planting rate is approximately 1 rewarewa to 3 other trees, mostly mānuka and kanuka, for an overall density of 430 stems per hectare. Assuming a cost for $8 per rewarewa tree, $3.15 for other plants, and $2 per plant labour cost, the total planting cost for the PRB is around $1,234. Assuming a 5% failure rate in the first 5 years and replanting of failures, the planting cost is estimated at $3,223. If releasing four times per year for five years, there is an NPV of **$798**.

Honey production is expected to be 538 kg per hectare per year from year 8. A low estimate of honey revenue ($8/kg x 10%) for the area is $430. A high estimate ($15/kg x 30%) would be $2,419 per year.

Nutrient incorporation into biomass is relatively low in the early years but increases as the native trees mature. Over 30 years the NPV of the non-market value of this nutrient removal is estimated to be in the order of $14,279.

Carbon dioxide is also sequestered by the rewarewa trees and other plants in the bee-friendly mix at an increasing rate over time. At a value of $40 per tonne of carbon absorbed, this sequestration has an average non-market value of $543 per year. In practice, the riparian area is too small for the farmer to be eligible for carbon credits under the existing emissions trading scheme. Nevertheless, this carbon absorption provides a global benefit.

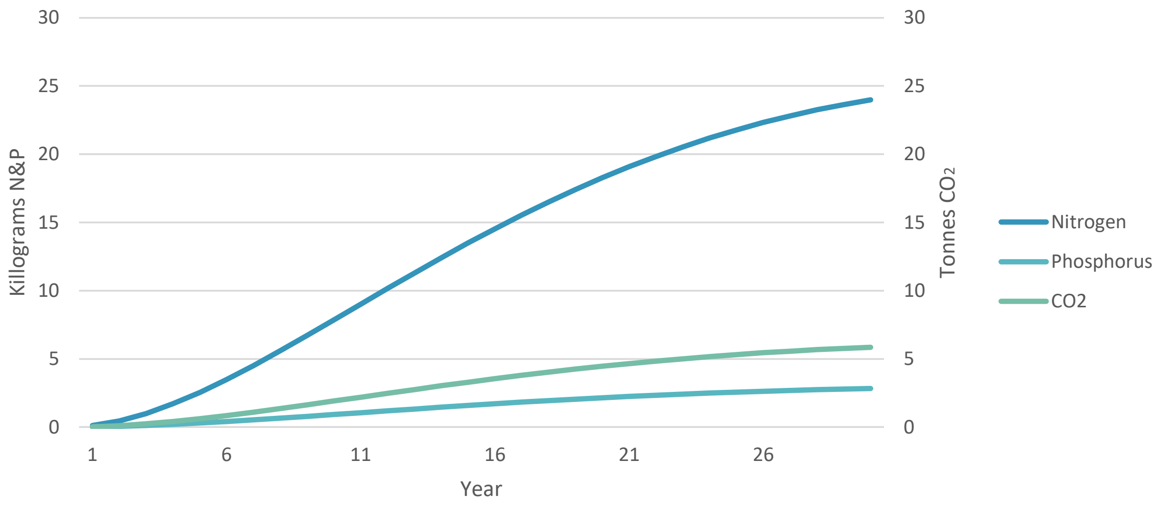

Figure 5-1: Mass of nutrients and carbon dioxide fixed into total biomass.

5.3.2 Sustainable harvest of timber

Assuming harvest costs of $90 per cubic metre and mill-door value of $500/m^3, rewarewa stumpage is estimated to be worth around $31,545 per hectare (current prices) in year 60. Form pruning is assumed from years 3 to 7. The NPV of timber harvest would therefore be around $2,565 over 60 years. However, prices are variable and there is flexibility to wait for favourable timber market conditions.

The mānuka and kānuka planted as part of the bee-friendly mix have a lifespan of around 40 years and could be harvested for firewood or specialist wood turning. It is unlikely the value would significantly exceed the felling cost, but this makes the removal of old trees an economic benefit rather than a maintenance expense. Mānuka is a premium firewood and retails for several hundred dollars per metre^3 when dry[10]. The costs to cut, split, store, and transport firewood may vary widely between farms, however, so the net benefit of firewood has not been included in the NPV.

The rewarewa production option is characterised by small benefits from honey and low maintenance for most of the rotation (Figure 5-2). Timber harvest provides a large final benefit but reverses most of the carbon sequestration benefits so has a large non-market cost. It is important to note that the assumption of harvesting all trees in year 60 is only to allow comparison of NPV with other options. A more sustainable and flexible option would be to fell and replant a few trees every year from year 60 onwards.

[10] https://ignitionfirewood.co.nz/product/tea-tree-manuka-kanuka/

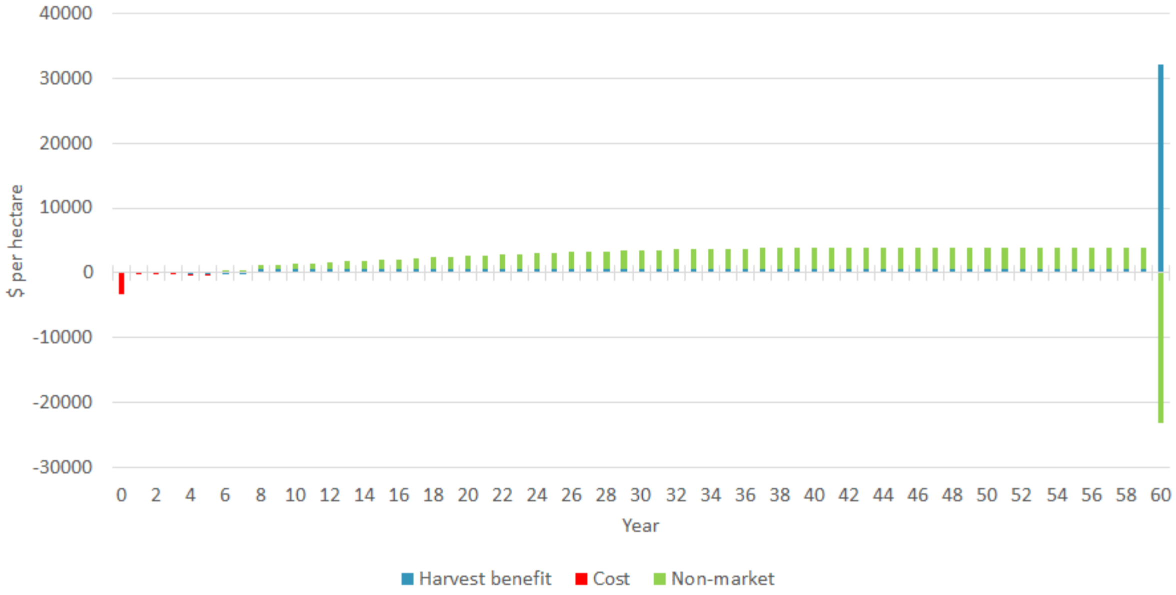

Figure 5-2: Timing of rewarewa benefits, costs and non-market values.

5.3.3 Water quality benefits

Water quality benefits were estimated for the honey PRB using the methodology outlined in Section 3.4. The methodology used the river segment attributes outlined in Table 5-1 and the productive buffer attributes described in Table 5-2.

The results of this analysis show that the honey mix PRB might be expected to provide low to moderate water quality benefits (Table 5-3). Specifically, assuming a honey mix PRB of 30 m width is planted along the margins of the entire headwater tributary at the Richmond Downs farm this is estimated to assimilate a very modest proportion of the dissolved nutrient export (2-3%), but is likely to trap a considerable fraction of the sediment and particulate nutrient export (49-60%). The small percentages for dissolved nutrients reflect the relatively low (and slow) nutrient uptake rates for the native tree species.

Table 5-1: Richmond Downs dairy farm river segment attributes.

River segment attribute	Units	Value
Stream order		1
NZ reach		3062107
Total riverbank length[a]	m	1200
Average hillslope length	m	172
Average slope angle	degrees	10.6
Catchment area	hectares	35.5
Annual sediment export[b]	t/ year	3.5
Annual particulate nitrogen export[b]	t/ year	0.62
Annual dissolved nitrogen export[b]	t/ year	0.45
Annual particulate phosphorus export[b]	t/ year	0.02
Annual dissolved phosphorus export[b]	t/ year	0.03

[a] Twice the stream length

[b] From the headwater river segment/first order catchment

Table 5-2: Richmond Downs dairy farm productive buffer attributes.

Buffer attributes	Units	Value
Existing PRB length	m	100
Existing PRB width	m	30
Existing PRB area	ha	0.3
Max. PRB area possible at designated width	ha	3.60
Plant species		rewarewa, mānuka, kānuka honey mix (with dense rank grass)
Planting density	stems/hectare	430

Table 5-3: Richmond Downs dairy farm estimated water quality benefits.

Water quality benefits[a]	Units	Value
Dissolved nitrogen uptake	% of segment export	2
Dissolved phosphorus uptake	% of segment export	3
Sediment attenuation	% of segment export	60
Particulate nitrogen attenuation	% of segment export	55
Particulate phosphorus attenuation	% of segment export	49

[a]If PRB occupies the banks of the entire river segment.

6 Case study 3 – Northland dairy farm

6.1 Description of riparian area

This Northland farm features multiple gullies and riparian areas. For ease of comparison, all production options will assume an area 2000 m long and 5 m wide (1 hectare).

6.2 Costs and benefits common to each option

A two-wire electric fence for a 2000 m buffer would cost $10,800.

6.3 Tree fodder from pollarding

Pollarding is a longer-rotation option than coppicing. This option would suit a riparian area that is not flat enough for mechanical harvesting, but not too steep that trees could be undercut and fall into a waterway. For this option the poplar are planted at a lower density (430 stems/ha) so that canopy closure is achieved not long before the first harvest. At $2 per stem with a 5% failure rate, the total planting cost is $2,117. Weed control involves twice-annual releasing ($90 per year) around the stems of trees until first harvest, and once after every harvest.

The long growing season in Northland means that forest biomass tends to accumulate faster than in the lower North Island, or South Island (Scion, 2020). Therefore, the first harvest is assumed to occur after 3 years and be repeated 2-yearly. Figure 6-1 shows the expected trends in forage yield and biomass over time. The above-ground biomass is partially removed at each harvest, but trunk and root biomass accumulates and helps fuel regrowth.

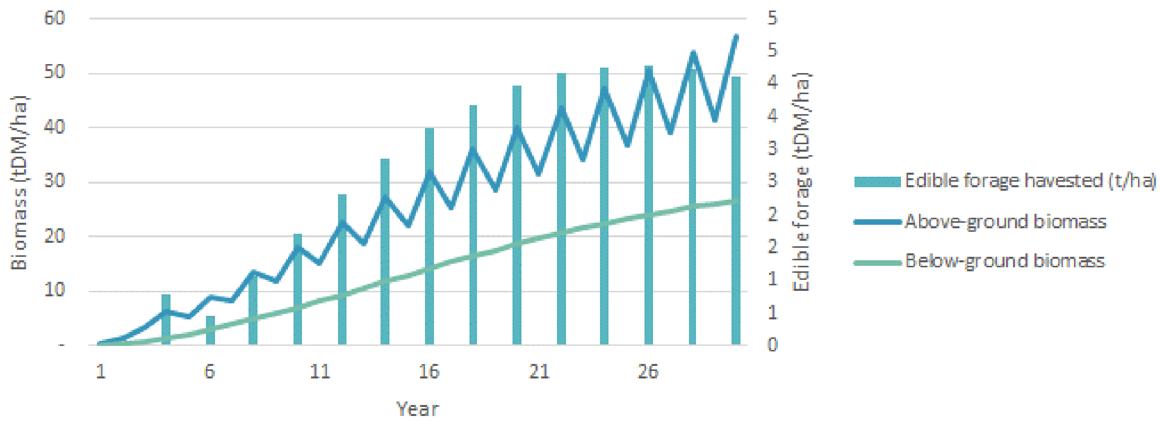

Figure 6-1: Poplar biomass and edible fodder yield per hectare.

It is assumed that this fodder will be harvested and used during a drought, when the price of feed is double the usual cost. During drought conditions the fodder value is assumed to be $381 per tonne. The cost to pollard and chip is $100 per tonne. The net fodder benefit ranges from $300-$2800 per harvest.

An average of 18 kg of nitrogen and 1.7 kg of phosphorus per hectare per year are incorporated into biomass, with a non-market value of $530 per year. The following figure shows that harvests increase over time as root biomass increases to support foliage regrowth.

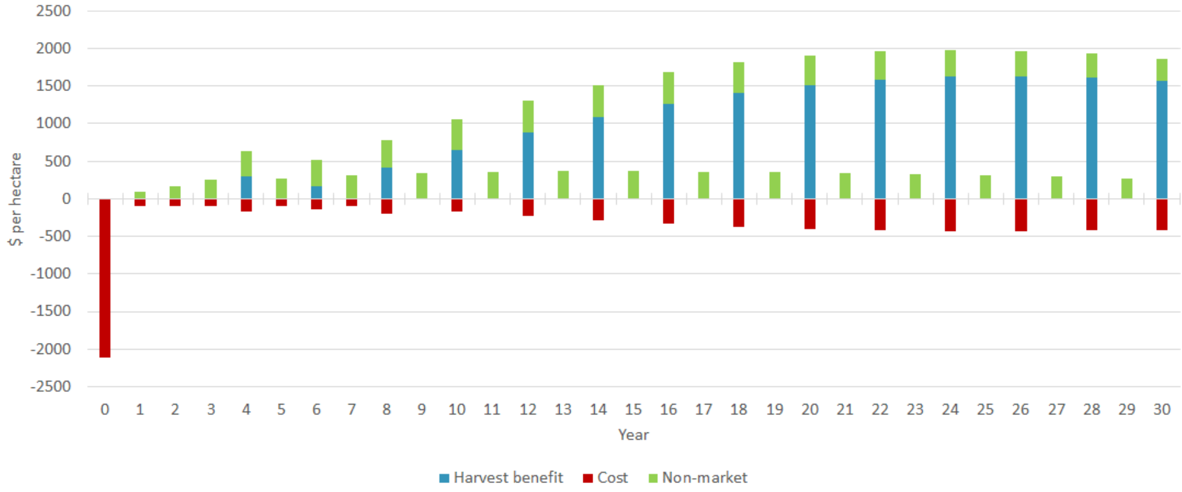

Figure 6-2: Timing of pollard tree fodder benefits, costs and non-market values.

6.4 Pine planting

6.4.1 Establishment costs, harvest benefit, nutrient uptake and carbon sequestration

The Forecaster Calculator was used to estimate the economic results with Northland-specific site parameters (Scion, 2020). The 300 index (an indicator of relative growth rate) was 25.64 for the location of the Northland farm. Default values were used with an initial density of 850 trees per hectare, a 3-prune 2-trim regime, and a final density of 320.

The Forecaster Calculator has a default establishment cost of 50 cents per tree. However, riparian planting costs may be higher due to reduced economies of scale. A cost of $3 per stem was used instead ($1 for the seedling and $2 labour). Stumpage after harvesting cost is $33,700 per hectare ($105 per tree). The NPV for 80 years (2 rotations) is **$7,554**/ha.

The pruning's and thinned trees can be used for firewood (retails for $110-$165 /m^3) or chipped for calf bedding (worth $40 /m^3).

A 30-year-old pine plantation can contain 2,200-3000 kg of nitrogen and 70-100 kg of phosphorus per hectare (Turner and Lambert, 1986). However, there is some evidence that microorganisms associated with pine tree roots can fix 50 kg/ha/year atmospheric nitrogen (Moyes et al. 2016) so this is expected to reduce the amount of nitrogen that the trees acquire from soil and groundwater by an equivalent amount. Net nitrogen uptake from soil and groundwater by pine trees is therefore expected to be only 690-1500 kg/ha over 30 years.

Pine also sequesters 886 tonnes/ha of carbon dioxide after 30 years, with a NPV of $17,800 per 30 year rotation at $40 per tonne. Continued carbon sequestration would be a more valuable option than harvesting, if the site met the requirements to receive carbon credits. Figure 6-3 shows the thinning at year 10 and reversal of non-market carbon sequestration benefits from felling in year 30.

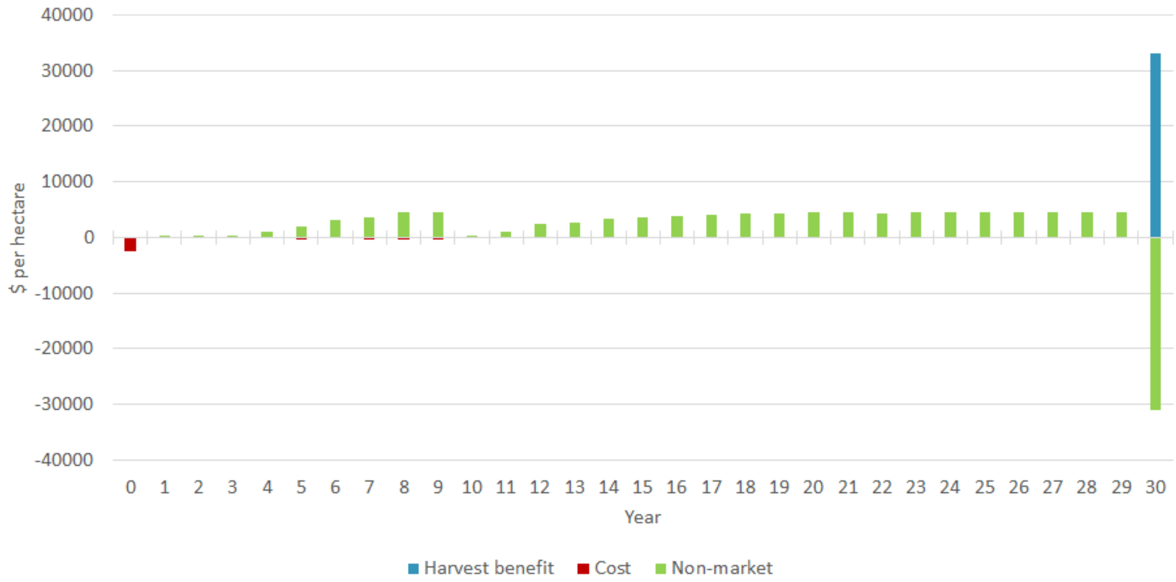

Figure 6-3: Timing of pine benefits, costs and non-market values.

6.4.2 Water quality benefits

Water quality benefits were estimated for a pine PRB at this farm using the methodology outlined in section 3.4. The methodology used the river segment attributes outlined in Table 6-1 and the productive buffer attributes described in Table 6-2.

The results of this analysis show that the pine PRB might be expected to provide low to moderate water quality benefits (Table 6-3). Specifically, assuming a 10 m wide buffer of pine trees with interspersed dense rank grass is estimated to trap between 27 and 30% of sediment and particulate nutrient export and up to 8% and 34% of dissolved nitrogen and phosphorus export, respectively (Table 6-1). The nutrient results reflect the relatively low phosphorus uptake rates of pine trees (2.3-3.3 kg/ ha/ year), and the effect of atmospheric nitrogen fixation on lowering rates of pine nitrogen removal from soil and groundwater sources.

Table 6-1: Northland dairy farm river segment attributes.

River segment attribute	Units	Value
Stream order		1
NZ reach		1010956
Total riverbank length[a]	m	3086
Average hillslope length	m	440
Average slope angle	degrees	5.4
Catchment area	hectares	61.4
Annual sediment export [b]	t/ year	10.4
Annual particulate nitrogen export [b]	t/ year	1.61
Annual dissolved nitrogen export [b]	t/ year	1.93
Annual particulate phosphorus export [b]	t/ year	0.06
Annual dissolved phosphorus export [b]	t/ year	0.03

[a]Twice the stream length

[b] From the headwater river segment/first order catchment

Table 6-2: Northland dairy farm productive riparian buffer attributes.

Buffer attributes	Units	Value
Existing PRB length	**m**	100
Existing PRB width	**m**	10
Existing PRB area	ha	0.1
Max. PRB area possible at designated width	ha	3.08
Plant species		pine for timber (with dense rank grass)
Planting density	stems/hectare	850 (initial) to 320 (final)

Table 6-3: Northland dairy farm estimated water quality benefits.

Water quality benefits[a]	Units	Value
Dissolved nitrogen uptake	% of segment export	4-8
Dissolved phosphorus uptake	% of segment export	23-34
Sediment attenuation	% of segment export	30
Particulate nitrogen attenuation	% of segment export	29
Particulate phosphorus attenuation	% of segment export	27

[a] If PRB occupies the banks of the entire river segment.

6.5 Tōtara (oil and timber) planting

Tōtara is planted at a density of 3600 per hectare to encourage good vertical form and suppress weed growth. Seedlings are assumed to cost $2 each, for a total planting cost of $14,750 per hectare. Failures are not usually replanted since the intention is to reduce the density over time.

Tōtara foliage is harvested during form pruning (year 8), thinning (year 15) and from a mature crown (year 35) (Heubeck, 2020). The foliage revenue is expected to be $10,000 in year 8 and $11,000 in year 15 (Figure 6-4). Foliage harvest costs are relatively high, however. The year 8 harvest would take 380 hours with a sapling harvest productivity 0.875 kg/minute and the year 15 harvest would take 728 hours using the pole stand productivity of 0.641 kg/minute (Heubeck, 2020, p. 16). This would make the second harvest uneconomic ($3,000 loss) at a standard contractor labour rate of $25. If lower-cost labour is available, the foliage harvest may become economic.

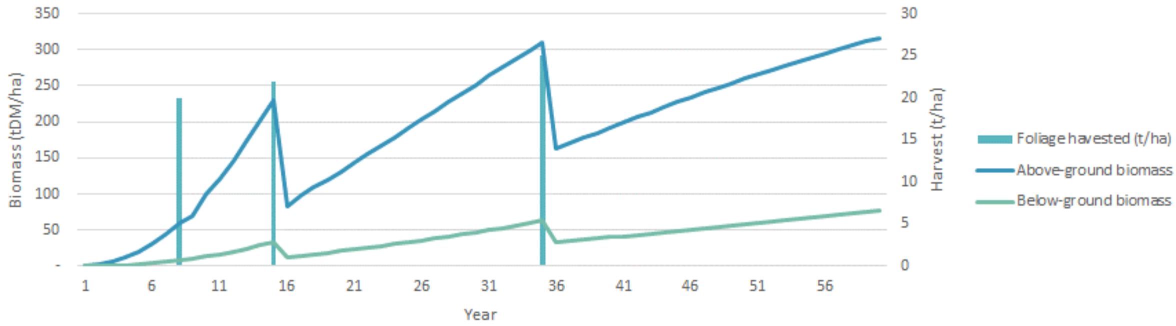

Figure 6-4: **Tōtara biomass (t DM) and foliage harvest.**

Thinning to 1200 stems/ha at year 15 can produce 2,400 saleable tōtara posts worth $36,000, which offsets the thinning cost of $6,250. There is a production thin to 600 stems in year 35 (Hock et al. 2014), with a harvest volume of 110 m^3. The value of this thinned timber is about 1/3 of a mature tree due to the narrow diameter (Griffiths, 2002), so the net stumpage is $16,480.

Final timber volume is expected to be 267 m^3 per hectare in year 60 based on modelled diameter and height, significantly lower than the harvest volume of pine (826 m^3 at year 30). Assuming $500 per m^3 for mill-door price and $90 per cubic metre for ground-based harvesting (Scion, 2020), net stumpage would be $109,700/ha (Figure 6-5).

The overall NPV of the 60-year rotation is $11,140, excluding uneconomic foliage harvests in years 15 and 35.

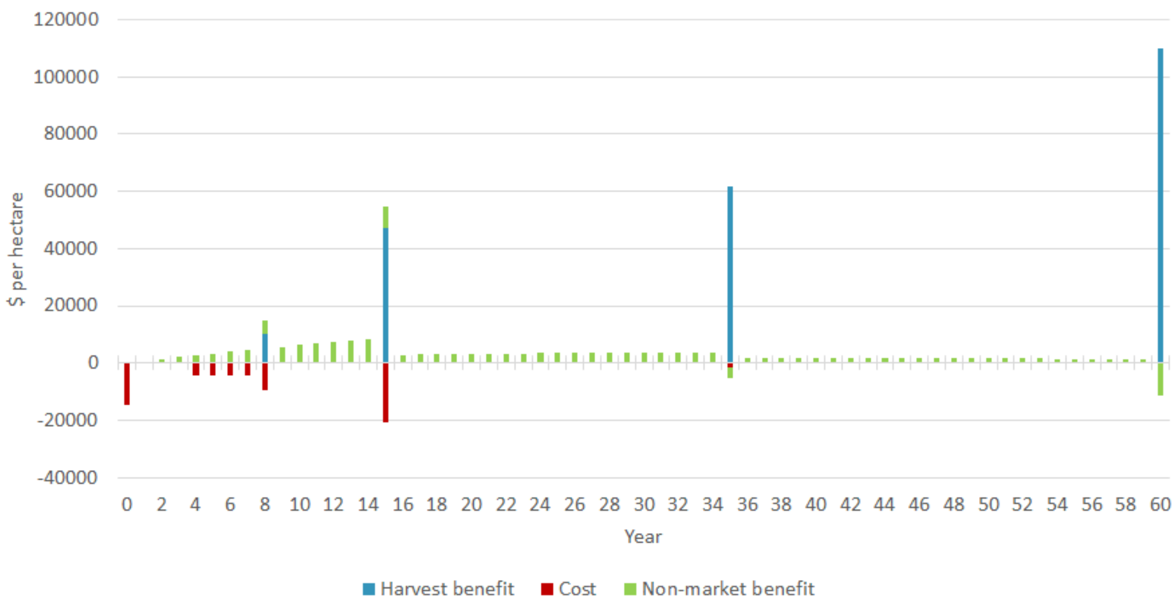

Figure 6-5: **Timing of tōtara benefits, costs and non-market values.**

7 Discussion

Each PRB option involves different harvest methods and time frames. Table 7-1 summarises the estimated establishment, maintenance and harvest costs, and benefits associated with each PRB option.

The option with the lowest establishment costs is cut-and-carry pasture as no planting is required. The most costly option to establish is tree fodder from short-rotation coppicing due to the need for dense planting of poplar. Maintenance costs also vary across options, being lowest for tree fodder from short-rotation coppicing, as a result of mechanical harvesting. By comparison, Tōtara planting incurs the highest maintenance costs due to having the highest number of stems for form pruning.

There is also a trade-off between harvest value, frequency and flexibility. As an example, cut-and-carry pasture requires the most frequent harvest. The harvest cannot be significantly delayed, but ensiling means it does not have to be used immediately. With pollarding, by contrast, the harvest can be delayed a year or more if fodder is cheap. The indigenous timber species can be left to grow for decades longer if market conditions are unfavourable.

Table 7-1: Comparison of option features per hectare.

Productive buffer option	Establishment cost	Avg annual maintenance costs in years 1-10	Harvest frequency	Harvest benefit	Harvest cost	End-of-life value
Cut-and-carry pasture (10t DM/ ha/ year)	$0	$120	Quarterly	$500	$430	$0
Tree fodder from short-rotation coppicing	$24,700	$0	Annual	$3,445	$1,800	$0
Tree fodder from pollarding	$2,110	$90	2-yearly from year 4	$2,200	$300	$0
Mānuka planting	$6,300	$190	2-yearly from year 5	$3,000	$2,100	$0
Rewarewa planting	$3,223	$143	Annual from year 8	$618	0	$32,200
Tōtara planting	$14,750	$2,025	Years 8, 15 and 35	$10-$16k	$1.5-9,5k	$110,000
Pine planting	$1,250	$181	No inter-mediate harvest	$0	$0	$33,700

Table 7-2 shows that feedstock options generally require little maintenance but have moderate to high labour requirements to harvest, process and transport fodder around the farm. Timber species require on-farm labour for pruning, thinning, and releasing. Felling is assumed to be done by experienced forestry contractors and this cost is subtracted from log income. The labour intensity of harvesting foliage for oil is relatively moderate to high.

Table 7-2: Comparison of option non-monetary features.

Productive buffer option	Maintenance labour	Harvest labour	Nitrogen uptake (kg/ha/year)	Phosphorus uptake (kg/ha/year)
Cut-and-carry pasture (8 t DM/ha)	Low	Medium	300	44
Tree fodder from short-rotation coppicing	Low	Medium	100	9.8
Tree fodder from pollarding	Low	High	20	2
Mānuka planting	Medium	Medium	56	5.7
Rewarewa planting	Medium	None	30	7
Tōtara planting	Medium	High	83	9.5
Pine planting	Medium	High (contractor)	87	3

Some PRB options generate non-monetary benefits. Nutrient removal and labour intensity have been identified as significant factors influencing attractiveness of proceeding with PRB options for farmers (Heubeck and Kalaugher, 2019). Although vegetation can provide a variety of non-market benefits such as aesthetics, shade, habitat, firewood, mahinga kai and biodiversity, the value of these is highly subjective and has not been quantified in this analysis.

Table 7-3 shows an indicative net present value of each production option over 60 years, with and without the non-market value of nutrient uptake and carbon sequestration. If non-market benefits are ignored, none of the production options appear as profitable as direct grazing along riparian borders. Nevertheless, the PRB options can reduce the cost of excluding stock from a riparian buffer. Short rotation coppicing may not be enough to cover the high establishment costs. If farmers are willing to wait 60 years for benefits, native timber plantations have a positive NPV. The mānuka option has a negative NPV due to high foliage harvesting costs and low timber value. However, mānuka offers substantial non-market benefits for water quality and is low maintenance.

If quantified non-market benefits are considered, cut-and-carry pasture, tree fodder short-rotation coppicing, tōtara planting and pine planting all offer higher net benefits from the use of riparian borders than grazing (Table 7-3). The cut-and-carry pasture option offers a significant non-market value due to the ability to uptake (and recycle on-farm) large quantities of nutrients. Moreover, native species have other biodiversity, aesthetic and habitat benefits which have not been included.

When considering the potential payoffs of the assessed PRB options, it is important to note that not all aspects of benefits and costs have been quantified. Table 6.4 summarises the parameters that have been quantified. Sediment attenuation (e.g., from the cut-and-carry option) has not been quantified so the net benefits of options providing sediment attenuation are underestimated.

Most benefits generated from PRB are expected to accrue to the farmers who execute them. However, some benefits – such as carbon sequestration on narrow riparian buffers[11] or improved downstream water quality – accrue to wider society. Where the uptake of options generating these benefits is anticipated to be high, these wider public benefits will be important.

[11] Participation in the carbon market is not currently possible for narrow riparian buffers.

Table 7-3: Comparison of 60-year net present value.

Productive buffer option	NPV 60 years @4%	NPV incl. non-market values
Grazing (8 t DM/ha)	$39,817.34	$39,817
Cut-and-carry pasture (8 t DM/ha)	$4,524.70	$141,999
Tree fodder from short-rotation coppicing*	$7,778.07	$15,607
Tree fodder from pollarding*	$330	$49,397
Mānuka planting	-$6,115.48	$24,293
Pine planting*	$7,553.54	$44,506
Rewarewa planting	$8,818.98	$21,516
Tōtara planting	$11,141.50	$56,676

*Replaced at 30 years

Table 7-4: Parameters quantified and comments.

Value	Quantified?	Comment
Fodder benefits	Yes	
Fodder production costs	Yes	
Nutrient uptake benefits	Yes	Benefits to wider public
CO_2 sequestration benefits	Yes	Benefits to wider public
Honey benefits	Yes	Excluding pollination benefits
Foliage for oil	Yes	
Timber	Yes	
Harm to drainage from trees	No	Likely to be low if positioned appropriately
Sediment trapping	Yes	Estimated for a single PRB option at each demonstration site. Low to moderate.
Cultural values	No	
Aesthetics	No	
Shade	No	
Habitat and biodiversity	No	

7.1 Applicability to other regions

Most of the productive buffer options analysed in this report can potentially be used in any region in New Zealand, with some caveats. Cut-and-carry pasture can be produced in any region, and production estimates can be adjusted depending on local soil fertility and climate conditions. However, the cut-and-carry and short rotation coppicing options both require a site flat enough for mechanical harvesting. Poplar and willow require moderate soil moisture (Dimitrou and Rutz, 2015) so should not be planted on exposed hillsides in summer-dry areas. There are a wide range of cultivars and clones however, and some are more drought resistant than others. Tōtara may be limited to areas below 600 m elevation in the North Island, and 500 m in the South Island (Bergin and Kimberley, 2011). Mānuka can be found from sea level to 1800 m and can tolerate wind, drought and frost (Sanders, 2017). However, mānuka foliage yields will be lower at more southern latitudes, due to the shorter growing season. Pine can be grown in any region, and the Forest Forecaster tool (Scion, 2020) provides an adjustment for different regional growth rates. Rewarewa is a frost-tender species so the rewarewa honey option is limited to the North Island and coastal Marlborough (Bergin and Kimberley, 2011).

7.2 Scalability

The cut-and-carry pasture option should be easily scalable from small to large areas. Assuming the farmer already owns a hay harvester, there are unlikely to be significant economy of scale benefits. Nor is scale likely to be limited by a lack of demand for hay or silage.

Tree fodder options, on the other hand, could offer economies of scale. Larger numbers of trees make it worthwhile to invest in specialised labour, harvesting and chipping machinery. However, these options are constrained to sites that are accessible with machinery.

The profitability of timber production benefits significantly from economies of scale (Bergaman and Bergaman, 2013). Log harvesting and transport is more efficient for higher volumes, which means log buyers will pay more to tree owners after subtracting their costs. Farmers with many trees may prefer to cut out log buyers and buy a portable sawmill for $8,000-$12,000 (https://woodlandmills.co.nz/portable-sawmills/) to mill and treat timber on the farm. Milled timber is a higher value product than logs and may be used for farm projects instead of purchased timber. Rough sawn 100x50 mm pine timber costs around $800 /m^3 while the mill-door price for log sales is less than $200 /m^3 (https://www.nzffa.org.nz/market-report/). For small or less accessible areas it is recommended to plant trees with higher value than pine, to make log removal worthwhile (Bergaman & Bergaman, 2013).

Scalability of the mānuka and tōtara foliage harvesting will probably be limited by the small, niche market for essential oils. Further research would be useful to determine the current and potential markets for foliage and niche tree products such as salicin from willows.

The market for honey is well established and the annual New Zealand production of 23,000 tonnes (https://apinz.org.nz/about/) would be equivalent to the harvest from 46,000 ha of the rewarewa plant mix described in this report. The honey market should therefore be able to absorb extra production from a few hundred hectares of riparian buffers without a large deleterious price impact.

7.3 Factors affecting adoption

The ADOPT framework (Keuhne, Llewellyn & Pannell, 2017) is a conceptual model of factors that affect the likelihood of adoption of new practices by farmers. These include learnability characteristics of the practice, and relative advantages of the practice. Learnability characteristics include trialling ease, observability and practice complexity Figure 7-1. All of the productive buffer options are relatively easy to trial on a small area of land. However, they differ widely on the length of time the trial would require in order evaluate the outcome. Cut-and-carry pasture requires only one growing season, while a rewarewa honey trial would take 8 years. Tōtara and mānuka foliage can be harvested within 5-10 years. Timber production requires decades, whereas a 5-year trial can establish the ease of pruning and weed control, or which species/hybrids are best suited to a particular site (Marden et al. 2018a). Harvest productivity and volume is relatively simple to evaluate, although verification of the nutritional quality of tree fodder is more complex (Heubeck, 2020). Observability of productive buffers is relatively high, since trees and beehives can be seen from a distance.

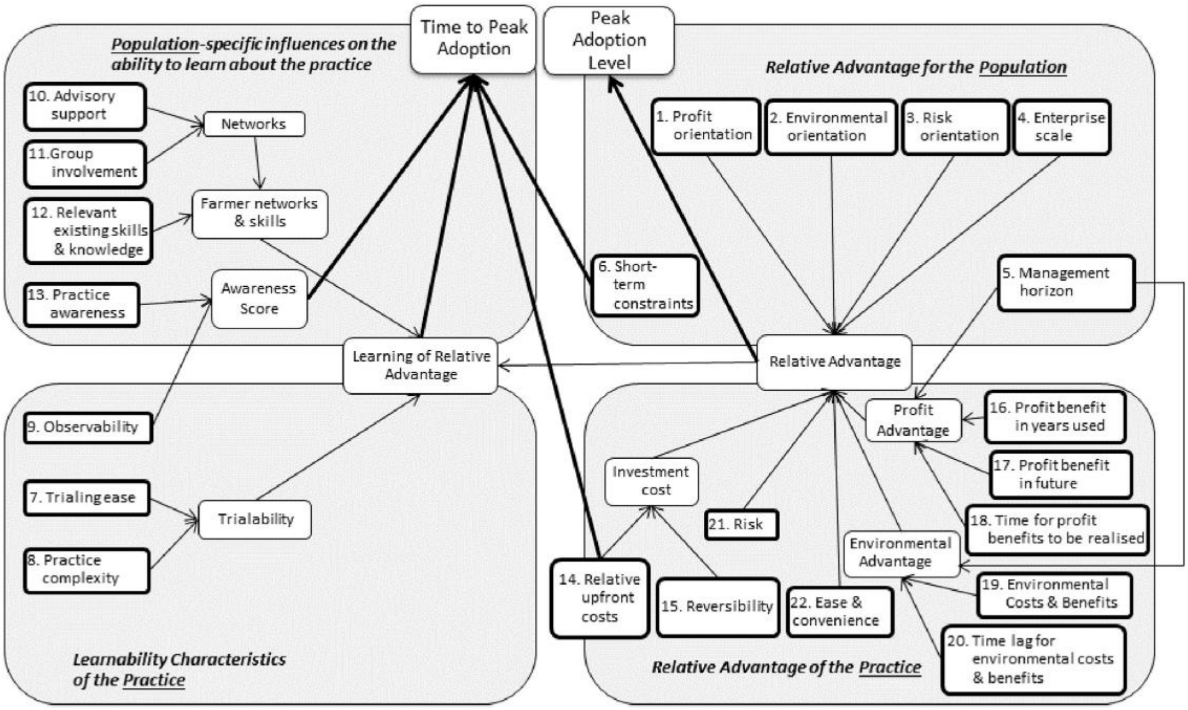

Figure 7-1: The ADOPT conceptual framework that describes the interplay of influences on adoption. Kuehne et al. 2017.

Table 7-5 provides an indicative assessment of the relative advantages of each production option in relation to the ADOPT framework. Practice reversibility is assumed to be highest for cut-and-carry pasture, while trees become increasingly difficult to remove as they grow. Profit benefit is equivalent to harvest net benefit and the feed production options score more highly on this. Profit benefit in the future refers to whether profit is expected to grow over time. In this case, timber production options score more highly. Time for benefit to be realised is rated based on the time-weighted average market benefit, which is longest for PRB options that involve timber harvest.

Environmental impact refers to diversity and the level of environmental benefits a PRB option is expected to generate. Cut-and-carry pasture and tree fodder short-rotation coppicing have high nutrient removal environmental benefits but offer little in the way of other environmental benefits. Pollard poplar is rated “low” for this parameter because it has a low impact on nutrient removal and does not sequester much carbon due to intensive harvesting. By comparison, mānuka, rewarewa and tōtara planting are rated "high" for this parameter because they provide habitat and biodiversity in addition to nutrient and carbon removal.

Pine and tōtara planting take the longest time to realize environmental benefits because they remove nutrients at a slower rate and because carbon sequestration takes time. Mānuka planting and the shrubs that form part of the rewarewa honey planting option would provide more biodiversity benefits in the early years.

All options except pasture are assumed to reduce farm business risk by adding diversity to production. However, while established trees and shrubs are more resilient to droughts and flooding than pasture, they may increase other risks such as fire or drain blockages.

Finally, PRB options that require higher investment of labour rate more poorly against the parameter for ease and convenience. The least convenient options are assumed to be those that require chainsaw harvesting of foliage (mānuka and tōtara planting). Rewarewa honey and pine planting rate highly for convenience because they can use external labour.

Table 7-5: Assessment of ADOPT relative advantages.

Relative Advantage	Cut-and-carry pasture	Poplar (replaced at 30 years)	Poplar SRC (replaced at 30 years)	Mānuka	Pine (replaced at 30 years)	Rewarewa	Tōtara
Relative upfront cost of the practice	Low	Medium	High	Medium	Medium	Medium	Medium
Reversibility of the practice	High	Medium	Medium	Medium	Medium	Medium	Medium
Profit benefit in years that it is used	Medium	Medium	Medium	Low	Low	Low	Medium
Profit benefit in future	Low	Medium	Low	Low	High	High	High
Time for profit benefit to be realized	Short	Medium	Short	Medium	Long	Long	Long
Environmental impact	Medium	Low	Medium	High	Medium	High	High
Time for environmental impacts to be realized	Short	Medium	Short	Medium	Long	Medium	Long
Risk	No change	Reduce	Reduce	Reduce	Reduce	Reduce	Reduce
Ease and convenience	High	Medium-low	Medium	Low	High	High	Low

7.4 Combining production options

The costs and benefits of each production option were calculated on a per-hectare basis – generally it is desirable to plant a mix of species in a riparian buffer (Bergin and Silvester, 2012). In the lower bank zone it is better to plant sedges and flax rather than trees, which could fall into the waterway. A variety of tree species on the upper bank provide better pest resistance, biodiversity and more reliable food for bees and birds than a single-species woodlot. The density of trees for timber could be reduced and under-planted with native shrubs to improve biodiversity and habitat values. The options that involve mechanical harvest can be combined with a strip of taller trees on one side, to provide other benefits without impeding harvester access.

8 Conclusion

Using the CBA methodology described in this report, the nutritional and financial value of seven productive buffer options, several of which are currently being trialled on three farms (requirement 1 from the introduction), have been analysed. The allometric model underlying this analysis uses empirical relationships between age and nutrient concentration to estimate the likely nutrient uptake over time, per hectare, for different species and densities (requirements 2 and 3). An indication has been provided of the wider applicability of these production options to other regions (requirement 4), and it has been noted that production of rewarewa honey is likely to be the most geographically limited option.

The impact of nutrient uptake on water quality has been estimated for the demonstration farm catchments (requirement 3). The water quality results show that PRB options could reduce a significant proportion of sediment and nutrients exported from these stream segments (requirement 5).

A limitation of this analysis is that several assumptions have not been extensively tested in field trials. It would be useful to collect more information about labour productivity (e.g., for weeding and pruning), harvest efficiency, yields, water quality impacts, and growth rates of PRB species in different areas. This would allow the estimation of confidence intervals for benefits and costs.

Further research is recommended to evaluate the non-market values for biodiversity, habitat, mahinga kai, or aesthetics that could not be quantified for this report. Another useful research direction would be to investigate potential pathways to markets for forestry products such as biofuels, wood pellets, and medicinal compounds.

9 Acknowledgements

We appreciate the review and constructive advice provided by Paula Holland and Lucy McKergow who reviewed the water quality benefits sections. We are also grateful for the contributions of Stephen Heubeck and farmers from the demonstration sites.

10 Glossary of abbreviations and terms

Allometric	The scaling relationship between the size of an organism part and the size of the organism as a whole, as both grow during development
DM	Dry matter. The weight of plant biomass excluding water
FM	Fresh matter
ha	Hectare. Equals 10,000 m^2.
ME	Metabolizable energy, megajoules per kilogram of dry matter (MJ/kg DM)
NPV	Net present value. Total benefit minus total cost, in current dollar terms.
ODT	Oven-dry tonnes of wood
PRB	Productive Riparian Buffer
SRC	Short-rotation coppicing
SS	Suspended sediment
Stumpage	The value of trees for timber after harvesting costs
TN	Total nitrogen
TP	Total phosphorus

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