Productive riparian buffers

Literature review

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Executive summary

Over the last two decades riparian buffers have emerged as a primary tool for protecting and restoring aquatic ecosystems (streams, lakes and wetlands) in New Zealand's intensively farmed catchments. They contribute to reducing the main agricultural contaminants (nutrients, sediment and microbial pathogens), stabilising stream banks against erosion, and restoring shade, organic matter input (leaves and wood), instream cover for fish and riparian habitat for adult aquatic insects. Riparian buffers generally become much more effective in performing these functions as their width increases. However, establishing extended buffers for environmental benefits often means the removal of valuable grazing land. In addition, riparian buffers are subject to several issues that develop over time, for example becoming reservoirs of weeds, becoming saturated in nutrients and fallen trees altering channel capacity. A possible solution for many of these problems is to plant and manage riparian buffers so that they become "productive", that is, they yield financial, social and/or cultural returns to the land owner.

A Productive Riparian Buffer (PRB) is a riparian buffer that is actively managed to provide a benefit to the farm, for example through products that can be used within the farming system or sold to external markets. This report is the first in a series of assessments that will be undertaken as part of SFF Project 405601 on Productive Riparian Buffers. It draws together available knowledge on productive riparian buffers (PRBs) for New Zealand's intensive farming catchments. In this review we consider the environmental, social, cultural and some financial benefits provided by a range of native and non-native species and explore various existing and novel options for using the plant products. We also discuss some of the practical growing, harvesting and management options for plant material grown on PRBs and their compatibility with existing farming operations on a variety of landforms. This literature review does not seek to quantify economic or other benefits, as these will be assessed in future components of the project.

This report does not seek to find one plant species or utilisation pathway. Rather, it is assumed that the success of PRBs will depend on land owners using the advantages and special features of various plant species (outlined in this report) in smart combinations, appropriate to their local context.

Through this review, we have identified a number of important factors to consider which may influence the success of PRBs:

- Time to maturity of the product. Some products (such as herbaceous feed, tree fodder, timber for fence posts and poplar poles, wood chip, flax for fibre, manuka for essential oil, some fruits, nuts and medicines) require a relatively short time until harvest. Others, such as some timbers and wood extracts, require decades to mature. Time to maturity affects not only the financial discount value of a product but also its environmental performance (e.g., the time to achieve full stream shading).
- Ability to market the product (including transport). Products that can be used on-farm (for example herbaceous feed, tree fodder, timber for fence posts and poplar poles) are more certain to provide value, as they don't depend on external markets. Selling a product off-farm helps a farm to diversify its business. However, for many PRB products, markets may take time to develop and will be subject to a range of uncertainties.

- Availability of mechanical harvesting methods. Mechanical harvesting will be needed for many PRB products. Some may be able to use existing harvesting technologies, but in other cases, mechanical harvesting will require either adaptation of existing technologies or development of new technologies. In some cases, the main issue is choosing which technology to invest in. In addition, mechanical harvesting potentially harms biodiversity and reduces the environmental performance of a buffer. Different crops vary widely in this regard.
- Their long, narrow shape and position in the landscape. Riparian buffers provide some unique advantages and disadvantages over more square-shaped forest blocks or paddocks. Riparian buffers are more susceptible to invasion by weeds and pests, and harder to isolate from surrounding vegetation (an issue for i.e., manuka honey production). Trees grow with a forest edge growth form (an issue for timber production), and mechanical harvest may be less efficient than in a paddock, particularly if they are in steep gullies. However, for some products riparian buffers are more accessible to mechanical harvest than contiguous blocks, and they may provide an environment with higher light and nutrients for rapid growth.
- Ability to balance environmental gains with environmental risks. Products harvested in large volumes, such as herbaceous feed, tree fodder and wood chips, are able to remove nutrients via plant uptake – a major benefit where soil nutrient saturation is an issue. However, for some of these products harvest often involves disturbance to soils, vegetation, resident fauna and/or important ecological processes. Achieving nutrient removal while minimising disturbance is a key element in a successful PRB.
- Multiple uses. The most promising species/cultivars for PRBs provide multiple possible products or uses. For example, poplars can be harvested for fodder and timber, totara can provide timber and essential oil, walnut trees can provide timber, leaves as fodder, walnuts for food, and prunings for growing shiitake mushrooms. Multiple uses not only provide multiple income or resource streams, but also help to mitigate risks. If one use proves not to be economic (e.g., due to market dynamics or time to maturity), then another use or product can provide a “fall back”.

1 Introduction

1.1 Riparian buffers: benefits and issues

Over the last two decades riparian buffers have emerged as a primary tool for protecting and restoring aquatic ecosystems (streams, lakes and wetlands) in New Zealand's intensively farmed catchments (McKergow et al. 2016). The basic concept of establishing a set-back and separation zone as a physical barrier between intensively grazed agricultural land and the waterways flowing through it has gained broad support among the farming industry, regulators and the public. Managing riparian areas is a key focal area of the Sustainable Dairying Water Accord, which expects all dairy farms to have excluded stock from Accord waterways, and to have a riparian management plan by 31 May 2020 (SDWA 2013).

Riparian buffers protect and enhance aquatic ecosystems in several ways. Fencing stock out of waterways reduces damage to stream banks and eliminates direct inputs of nutrients and faecal pathogens to water. Vegetated stream margins filter out (and/or take up) nutrient, sediment and bacterial runoff from land (Figure 1), moderate stream temperatures and reduce nuisance plant growth through shading and can increase aquatic and terrestrial biodiversity (Parkyn et al. 2004; McKergow et al. 2016). Each of these riparian buffer functions has differing requirements to create the "best practical" buffer at a location (Quinn et al. 2001).

Stock exclusion requirements have largely driven riparian management on intensive farms. Many riparian planting efforts and much of the advice provided to farmers is currently based on around a 3-5 m setback. Some environmental benefits have been shown to increase significantly if buffer width is extended to 10-15 m (see section 2.6.1). However, buffers of this width would represent a significant loss of grazing land. A 10 m buffer around all streams in a catchment would occupy between 2% and 7% of available land, depending on the density of the stream network. Assuming dairy farming occupies roughly 2 million hectares in New Zealand, this translates to 40,000 to 140,000 ha on dairy farms alone. Retiring so much land represents a significant loss in productivity.

In addition, planted riparian buffers are susceptible to several issues that can develop over time:

- Creating reservoirs of weeds and pests. Because weeds and pests (e.g., giant willow aphid) tend to thrive in edge habitats, riparian buffers usually require ongoing maintenance.
- Nutrient saturation. Riparian buffers used to intercept nutrients in overland and subsurface flow paths may reach their absorption capacity after some time. Plant nutrient uptake declines with plant age (see Dosskey et al. 2010) and riparian soils may become nutrient saturated when supply is greater than demand (Cooper et al. 1995).
- Over-mature trees. Certain common riparian tree species, e.g., poplars and willows, often fall into streams when they get old, creating safety and flooding issues.

A possible solution to many of these issues is to plant and manage riparian buffers so that they contribute a productive value to the farming system. Gaining financial, social and/or cultural returns from a buffer potentially may balance to some degree the loss of grazing land. Harvesting biomass from a riparian buffer removes nutrients and actively prevents saturation, while harvesting and actively managing the riparian area can minimise weed pressures. Furthermore, coppicing, pollarding or pruning trees for various products will prevent overgrowth, collapse and associated issues.

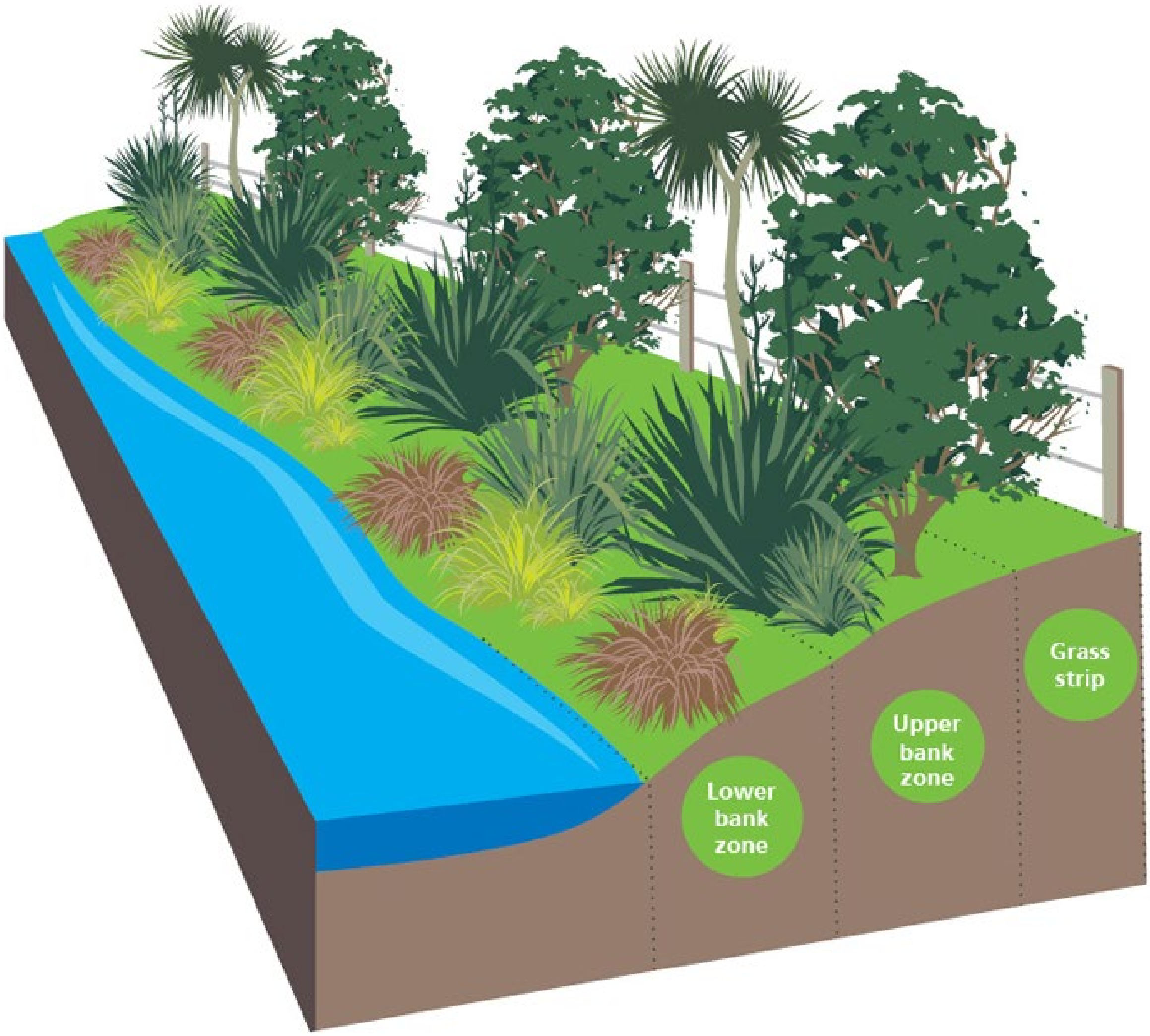

Figure 1: Schematic of a riparian buffer showing 3 distinct zones. Zone 1: the lower bank or near water zone, Zone 2: the upper bank zone, Zone 3: Grass filter strip or paddock boundary zone. (Source DairyNZ 40-062).

1.2 Productive riparian buffers

This review addresses the concept of a "productive riparian buffer" (PRB). A PRB is an area on a stream, river, lake or wetland margin, wider than most current buffers, where a combination of native and exotic herbaceous plants, shrubs and trees is actively managed to provide a productive return to the farming system through products that can be recycled on farm or exported. Through this active management, PRBs address some of the shortcomings of traditional riparian buffers described above.

The aim of this report is to summarise current understanding for the SFF Project 405601 on productive riparian buffers for New Zealand's intensive farming catchments. The project seeks to identify suitable combinations of native and non-native species that can be planted on riparian buffers in New Zealand's intensive farming catchments to improve water quality and ecological condition while at the same time yielding financial, social and cultural benefits.

For this purpose we consider in this review the environmental, social, cultural and financial benefits provided by a range of native and non-native species and explore various existing and novel options for using the plant products. As the project progresses, we will evaluate practical growing, harvesting and management options for plant material grown on productive riparian buffers and their compatibility with existing farming operations over a wide variety of landforms.

Complex problems, like improving fresh water quality in New Zealand's agricultural catchments, demand multifaceted and flexible responses. Therefore, we do not seek to find one plant species or utilisation pathway that will turn PRBs into an economic reality throughout the country. We assume that PRB design must be flexible so that PRBs are applicable over a wide range of climate and soil conditions, farm types, scales, environmental issues and productive values. Success for the PRB concept will depend on land owners using the advantages and special features of different productive species in smart combinations, appropriate for a given location.

The two initial sections of the report outline the environmental benefits provided by riparian buffers. We describe the pathways by which these benefits accrue, species that are most effective in providing those benefits, the dimensions of buffers required to achieve them, and factors that may reduce performance. In the following section we outline social and cultural values of planted riparian buffers that are often overlooked when weighing the costs and benefits of buffers. In the final section we discuss possible productive uses of buffers, considering one use or product at a time. In each section, the plant species with high potential for these benefits are described, as well as any issues related to growing, managing or harvesting these species. Results are summarised by plant type in Appendix A.

2 Environmental benefits & risks

2.1 Contaminant mitigation

Riparian buffers can be traps and transformers of waterborne contaminants moving from land to waterbodies.

2.1.1 Sediment, particulate P and faecal microbes

Riparian buffers may reduce inputs of fine sediment (and associated faecal microbes and phosphorus) to streams in several important ways. First, sediment from hillslope erosion, carried to streams in overland runoff, can be trapped in riparian vegetation. This filtering is most effective where the buffer is comprised of vegetation with a high stem density. Grasses, especially when growing as a tall, dense and uniform sward on a gradual slope, are the most effective (Smith 1989, Collins et al. 2004). Second, riparian buffers may trap sediment and sediment-bound phosphorus via soil infiltration. Soils in riparian buffers tend to be less compacted than those where stock have access, which improves infiltration of overland runoff into the soil (Cooper et al. 1995). The effectiveness of riparian buffers in performing these functions depends on factors such as slope and channelization of runoff (Quinn 2009).

Furthermore, riparian buffers may reduce soil erosion by intercepting rainfall, protecting bare soil against rain splash. For this reason, canopy closure and leaf density are important for reducing soil erosion in riparian areas (Marden et al. 2005; Phillips 2005). Evergreen species will provide soil cover and interception year-round, while deciduous trees provide them only until leaf fall.

2.1.2 Stream bank erosion

Stream bank stabilisation is another important function of riparian vegetation (Florsheim et al. 2008). Bank erosion is a natural process, but banks with trees are stronger and less prone to erosion during floods than those without trees (Abernethy and Rutherfurd 2000; Simon and Collison 2002). However, small stream channels beneath a closed tree canopy tend to be wider than those in open pasture (Davies-Colley 1997), which suggests that headwater channels may gradually widen following riparian planting, once the tree cover replaces groundcover grasses (Parkyn et al. 2005).

Native trees, planted at high density, can usually stabilise banks less than 2 m high, except where bank angles are very steep (Marden et al. 2005). However, root systems of native trees are typically relatively shallow (rarely >2 m deep at maturity) and slow-growing (e.g., average of 0.3 m after 5 years; Marden et al. 2005) compared with willows and poplars (typically 0.5-1 m deep after one year; Phillips et al. 2014). Willows typically outperform poplars for total root length (Phillips et al. 2014), although on hill slopes and non-uniform soils, poplars may perform better than willows as their thicker roots can penetrate better into compact soils (Phillips et al. 2014). Phillips et al. (2015) also recommend alder (*Alnus rubra*), cherry (*Prunus serrulatus*) and cypress (*Cupressus lusitanica*) for controlling soil erosion due to their root spread and depth. Among 12 native species in one trial (Marden et al. 2005), those with deepest roots after five years were cabbage tree (*Cordyline australis*), ribbonwood (*Plagianthus regius*), tutu (*Coriaria arborea*), karamu (*Coprosma robusta*) and lacebark (*Hoheria populnea*). Soil erosion includes shallow as well as deep forms of slope failure, and to stabilise banks against both forms, Marden et al. (2018) recommend planting species with high root spread, e.g., puriri (*Vitex lucens*) and titoki (*Alectryon excelsus*), as well as those with deep roots such as native conifers. They also recommend planting densely to increase “soil occupancy” of roots. Where rapid bank stabilisation is required, fast-growing poplars and/or willows may be more appropriate, but in general, a mix of native species should effectively stabilise banks (Marden et al. 2005) and have the additional benefits of evergreen foliage and indigenous biodiversity value. In some instances mechanical bank re-battering (reducing bank slope) may be required prior to riparian buffer planting to enable plant roots to effectively reinforce and protect streambanks.

2.1.3 Nutrients

Riparian plants can significantly intercept and reduce the transport of soluble nutrients (mainly nitrate and phosphate) entering streams via shallow groundwater and overland flows (Mayer et al. 2007; Zhang et al. 2010). The first way they do this is via uptake of nutrients into plant tissues. In general, plant species with deep and extensive root systems, high biomass, high tissue nutrient content, deciduous species and those that are fast-growing are likely to be particularly effective at nutrient uptake (Franklin et al. 2015a). In general, plant species that produce a lot of biomass and/or have high evapo-transpiration rates are considered most likely to remove high levels of nitrogen from soils and groundwater (Kennen and Kirkwood 2015).

Exotic tree species with high nutrient uptake potential include:

- Willow species (*Salix spp.*)
- Poplar species *(Populus spp.*)
- White Mulberry (*Morus alba*)

Compared to exotics, New Zealand native species typically have relatively low nutrient uptake rates. They are adapted to low nutrient soils, and most species do not increase their growth rates when additional nutrients are available (Franklin et al. 2015a). However, among 11 species of native riparian plant seedlings tested by Franklin et al. (2015a), monocots (e.g., cabbage tree (*Cordyline australis*)), flax (*Phormium tenax*) and sedges (e.g., *Carex virgata*) were found to have the highest nitrogen uptake rates. Other native species that may be effective in nutrient uptake due to their relatively fast growth rates include:

- wineberry (*Aristotelia serrata)*
- karamu *(Coprosma lucida, C. robusta)*
- kawakawa (*Piper excelsum)*
- cabbage tree (*Cordyline australis*)
- lacebark (*Hoheria spp.*)
- koromiko (*Veronica stricta*)
- mapou (*Myrsine australis*)
- manuka (*Leptospermum scoparium*)
- five-finger (*Pseudopanax arboreus*)
- karaka (*Corynocarpus laevigatus)*

Plant species that are slower-growing or with less extensive root systems also take up nutrients, though probably less effectively. Furthermore, it needs to be kept in mind that plant nutrient removal from sub-surface flows will depend on the individual rooting depth of plants. In this regard re-battering stream banks may help plants with shallower root systems to better intercept shallow groundwater flows.

Nitrogen can also be removed in riparian buffers by the process of denitrification where soil bacteria convert nitrate to nitrogen gases (Cooper 1990). Rates of denitrification are usually highest in organic-rich and anoxic (wet) soils so are likely to be highest in the dampest areas of the riparian buffer. Certain species of riparian or wetland plants may have root microbial communities that support higher rates of denitrification (e.g., the swamp hibiscus (*Hibiscus moscheutus),* Morgan et al. 2008). Other plant species may enhance soil denitrification by altering water infiltration rates or leaching organic carbon through their roots (Hobbie 1992). Because nitrogen arrives in several forms and more than one transformation is required to remove it, a mixture of plant species, including both herbaceous and woody, may be most effective at enhancing nitrogen removal (Morgan et al. 2008, Kennen and Kirkwood 2015).

Plants that are able to fix nitrogen (i.e., produce soluble nitrogen forms out of atmospheric nitrogen gas) should not be planted in riparian zones where nitrogen contamination of adjacent waterways is of concern. The nitrogen production rates of the following species can be in the order of 30-50 kg N ha^{-1} yr^{-1}. Nitrogen-fixing plant species include (Thomas and Spurway 2001):

- kakabeak (*Clianthus* spp.)
- native broom (*Carmichaelia* spp.)
- matagouri (*Discaria toumatou*)
- dogwood (*Pomaderris apetala and P. hamiltonii*)
- tree lucerne (*Chamaecytisus proliferus*)
- kowhai (*Sophora* spp.)
- tutu (*Coraria* spp.)
- scotch broom (*Cytisus scoparius*)
- lupins (*Lupinus* spp.)
- all forage legumes (e.g., white clover (*Trifolium repens*)

2.1.4 Greenhouse gases

As plants grow they sequester carbon (Burrows et al. 2018), removing carbon dioxide from the atmosphere for photosynthesis. The accumulation of plant litter in riparian buffers creates organic-rich soils, which also contributes to carbon sequestration (Rheinhardt et al. 2012). BERG (2019) suggested that of existing on-farm vegetation types considered in their review riparian strips offered the highest sequestration rates after woodlots and shelter belts, potentially sequestering between 0 and 5.28 $t{\cdot}CO_2e{\cdot}ha^{-1}{\cdot}yr^{-1}$. However, there is still little clarity on the potential for additional revenue or liability for landowners if the scope of carbon accounting or offsetting schemes were to be expanded (BERG 2019).

However, riparian buffers are also potentially a source of greenhouse gases, particularly nitrous oxide (N_2O) and also methane (CH_4). Nitrous oxide can be released by denitrification and methane by methanogenesis (both bacterial processes that occur without oxygen). Soils with higher amounts of organic matter, water saturation and “reducing” (i.e., low-oxygen) conditions, which are often features of riparian buffers, are considered likely to be hotspots for nitrous oxide and methane emissions (Vidon and Serchan 2016). Some studies suggest that riparian buffers, especially those that receive and process high loadings of nitrogen, may be significant sources of N_2O (Hefting et al. 2003), although other studies suggest that adjacent agricultural land have higher greenhouse gas (GHG) emission rates (Fisher et al. 2014). Ultimately the net GHG balance of a riparian buffer will depend on the ratio of N_2O released from denitrification and CH_4 from anaerobic processes to the amount of

CO_2 fixed via plant growth. Riparian buffers with vigorous plant growth that remove the majority of nitrogen via plant assimilation rather than denitrification will likely produce less net GHG emissions.

2.2 Shade

Shading by riparian vegetation, especially tall plants with dense canopies, provides two key benefits:

1. Peak water temperatures are reduced, which benefits aquatic insects and fish (Quinn and Hickey 1990, Quinn et al. 2004).
2. Shading >65-70% also reduces the growth of nuisance aquatic plants (Matheson et al. 2017).

However, shading may also affect other functions of the riparian buffer. Interception of overland runoff may be reduced when shade from tall species reduces the growth of understory and ground cover plants (like grasses) within the buffer. Shading may also alter the timing of nutrient transport to downstream waters. Aquatic plants growing in the stream take up nutrients from the water during the growing season, but this uptake will be less effective where shading reduces their growth. However, where large numbers of aquatic plants are present, nutrients taken up into aquatic plant biomass get re-released into the stream during autumn and winter when plants die back and their biomass is gradually decomposed. Therefore, the annual net nutrient load to receiving waters such as lakes and estuaries may not be greatly altered if aquatic plants are reduced by shading.

2.3 Habitat enhancement

Riparian buffers contribute to enhancement of stream habitat and biodiversity in agricultural landscapes (Sabo et al. 2005). Instream wood and leaf litter from riparian vegetation provides habitat diversity, cover for aquatic insects, crustacea and fish, and an important carbon source for stream food webs (e.g., Duehr et al. 2006, Parkyn et al. 2009). Overhanging bank vegetation creates further instream cover for fish. In the riparian zone itself, streambank grasses, sedges and leaf litter can be used by native galaxiid fishes, such as kokopu and inanga, to lay their eggs during bankfull flood events (Hickford and Schiel 2011, Franklin et al. 2015b). And fish such as eels feed in riparian zones during floods (Collier et al. 1995). Aquatic insects, in their winged adult stage, benefit from the food, refuge and mild microclimate provided by riparian vegetation (Collier et al. 1995). Extensive buffer networks provide wildlife habitat and corridors for movement and migration of aquatic, semi-aquatic and riparian terrestrial species (McGruddy 2006).

However, riparian buffers can also provide a refuge for weed and pest species if not actively managed, particularly during their establishment phase. Narrow buffers (<5 m wide) are more likely to have ongoing issues with weed incursion and growth. Consequently, wider buffers (e.g., >10 m) are usually recommended as they create a more self-sustaining vegetation, minimize weed maintenance and provide greater habitat diversity (Parkyn 2004, Reeves et al. 2006).

2.4 Flood protection

Riparian buffers may contribute to flood protection, though with some possible negative effects that must be managed. Dense grass buffers can potentially reduce peak flood flows by intercepting overland flow and increasing the time that rainfall takes to reach a stream (Karssies and Prosser 1999). Vegetation growing on banks can slow the flow rate slightly by increasing hydraulic drag. This reduces flood peaks downstream by delaying transport of flood waters, but it can increase flood levels locally. Some riparian tree species such as willows, if they grow into the stream channel or fall into it, may increase local flooding by reducing the channel capacity (Dadson et al. 2017).

Riparian buffers can potentially reduce the impacts of flooding by creating a set-back area that separates infrastructure and livestock from the main flood zone. However, the buffer itself is an infrastructure investment that can be severely damaged by flooding (Karssies and Prosser 1999). An evaluation of bank stability (see Quinn 2009) and careful selection of appropriate species in lower and upper bank sections of a riparian buffer can reduce the likelihood of plantings being swept away during flood events.

2.5 Terrestrial biodiversity

Riparian buffers can contribute to the biological diversity of a region because of the unique habitat they provide. Riparian habitats are "ecotones" (transitional zones between terrestrial and aquatic systems) and have high edge to area ratio. Because of these features and because they are often disturbed (Naiman et al. 1993), species able to cope with disturbance will thrive. Riparian buffers increase regional biodiversity, not necessarily because they contain high diversity themselves but because they add different species to the regional species assemblage (Sabo et al. 2005).

In New Zealand, native terrestrial animals well adapted to riparian zones include bats, frogs, geckos and skinks (Collier et al. 1995). The rare Hochstetter's frog is closely associated with riparian zones, as it is found in moist conditions where it feeds on insects (Collier et al. 1995). Generalist birds such as fantails, tūī, kererū and swallows thrive in riparian habitats due to the abundance of flowers, berries, aquatic and adult aquatic insects (Collier and Smith 1995, Krejcek 2009). Fish-eating birds such as kingfishers and shags are strongly associated with riparian zones and make use of trees for nesting and perching (Collier et al. 1995). A few bird species such as whio (blue duck), dotterels and wrybills are river specialists and use riparian zones for nesting (Collier et al. 1995). Extensive buffer networks also provide corridors for movement and migration of species. It seems reasonable to assume (though specific studies are lacking) that native species of plants are more likely to provide appropriate conditions for native animals than introduced species (Collier et al. 1995).

There is some risk that using riparian zones to harvest plant products could reduce their biodiversity value. This will depend on the species present in the riparian buffer, the products harvested, the intensity of productive use and harvesting methods.

2.6 Buffer dimensions

2.6.1 Buffer width

The optimal width of a riparian buffer width will vary according to the functions desired from the buffer, and from one site to another (Quinn et al. 2001). It will depend on the key target contaminants, land contour, catchment layout, runoff flowpaths, local soil and climate, flood size and frequency and many factors besides.

As overland runoff enters a buffer with dense groundcover, water flow velocity is reduced, allowing sediment to be deposited at the buffer edge and within the buffer vegetation (Karssies and Prosser 1999). Buffer width is one of many factors that influences sediment removal; others include contributing area, land use, soil type, vegetation type and density, slope, sediment load, rainfall intensity, topography, artificial drainage, soil moisture conditions (see reviews by Dosskey 2001, Parkyn 2004, Sweeney and Newbold 2014). Much of the research comparing buffer widths is conducted under optimal experimental conditions and is not directly transferable to long-term performance of buffers in paddocks (Sweeney and Newbold 2014). New Zealand research using this natural experimental approach is limited to two retired grass buffer studies. Retired grass strips 10-

13 m wide on a Waikato drystock farm reduced flow-weighted mean suspended sediment concentrations in surface runoff by 87% over 2 years (Smith 1989). Narrow dense grass buffers can successfully trap suspended sediment; a 3 m wide in-paddock buffer on a dairy farm near Rotorua reduced suspended sediment loads by 50% to 70%, but variability in removal was large over the 15 month monitoring period (McKergow et al. 2008). Analysis of numerous international “natural experiments” predicts about 65% removal for a 10 m buffer, although variability is large, and beyond 15 m gains in removal per metre of additional width become smaller (e.g., about 85% removal for a 30 m wide buffer) (Sweeney and Newbold 2014).

Specifying a buffer width for a certain percent removal of nitrogen or phosphorus is complicated as multiple removal processes may operate in a riparian buffer. Processes removing nutrients from overland flow include particulate nutrient deposition and infiltration of dissolved nutrients. Particulate nutrient removal from overland flow is similar to sediment removal. For most slopes with a slope of <10 %, a buffer of 8-15 m is sufficient to give total P retention of ~60% (Dorioz et al. 2006). However, phosphorus may be attached to the finer particles which take longer to settle and therefore may require a wider buffer (Dorioz et al. 2006).

Processes removing nutrients beneath the soil surface include plant uptake and denitrification. Plant uptake requires plant roots to intercept nutrient flows, and denitrification is promoted when nitrate passes through saturated, organic rich soils. Combining the results of many buffer studies, Mayer et al. (2007) found a weak relationship between nitrogen removal and buffer width (and also flow path and vegetation type). They suggest that other factors - soil type, soil hydrology and saturation, and organic carbon supply - govern nitrogen removal (Mayer et al. 2007). This is consistent with findings from a drystock farm in the Waikato, where the majority of nitrate loss (56-100%) occurred in riparian organic soils, with hotspots of denitrification activity near upslope edge of organic soils (Cooper 1990).

2.6.2 Practical considerations

Practical considerations in a New Zealand farming context may also influence the effective PRB width. Mechanical harvesting and processing of the biomass grown on the buffer is a pre-requisite for large scale uptake of the concept. Typical farm tractors of the 100 HP class have a turning radius of about 5 m (turning circle of 10 m) which means that for some productive uses of PRBs (i.e., cut and carry pasture grass), a width >10 m may be required for easy mechanisation.

2.6.3 Buffer height

Taller trees tend to have greater biomass, wider and deeper root networks and a wider crown, all of which confer various benefits. However, the main benefit of buffer height itself is shading of wide streams. The ability of riparian vegetation to shade the channel decreases with stream width and increases with the height of the vegetation (Davies-Colley and Quinn 1998). In small streams <3.5 m wide, mature undisturbed native podocarp/broadleaf forest provides high levels of shade (median shading 99%; Davies-Colley and Quinn 1998). As channel width increases above 6 m, some partial gaps in the canopy occur, and thereafter shading decreases rapidly with stream width (Davies-Colley and Quinn 1998). As a general rule shading greater than 70% is normally enough to eliminate nuisance macrophyte and periphyton growths (Collier et al. 1995, Matheson et al. 2017).

3 Buffer design: management zones

Standard advice for riparian buffers (e.g., DairyNZ 40-062) describes three zones (Figure 1) for planting:

- Zone 1: Lower bank or near water zone. The lower bank zone is flooded several times per year. Plants in this zone need to be tolerant of waterlogging for many days at a time. They also need to be strongly-rooted and have very flexible stems so they can lie flat and not get ripped out when fast-moving flood waters overtop them. Sedges and rushes are commonly used here.
- Zone 2: Upper bank zone. The upper bank zone is on higher ground but may still be partially flooded every 1-2 years. Trees, shrubs and flaxes are planted here.
- Zone 3: Paddock boundary zone. With traditional riparian buffers a grass strip at least one metre wide is usually recommended between stock exclusion fence and permanent plantings (trees/shrubs/natives) to help filter sediment, phosphorus and faecal bacteria from runoff before it reaches the water. The grass strip also prevents plants from tripping electric wires or being grazed if the lower banks are planted.

This basic design is maintained in productive riparian buffers. However, the width of each zone might vary for practical reasons such as machine harvesting.

4 Social and cultural values of riparian buffers

Riparian buffers add value to farming systems in ways that extend well beyond their direct environmental benefits. The indirect values of healthy riparian ecosystems, particularly with indigenous vegetation, include aesthetic, amenity, recreational, cultural and heritage values (Maseyk et al. 2018, Environment Waikato 2002). However, the value of these benefits relative to the cost of creating and maintaining the riparian buffer varies greatly among different environments and is difficult to quantify (Environment Waikato 2002).

Healthy natural environments on farms can provide opportunities for recreation and tourism such as swimming, game habitat, farm stays or potentially walking or cycling areas. The value of a freshwater body for contact recreation (swimming) depends strongly on the risk of illness from pathogens (disease-causing microbes). Riparian buffers, by excluding livestock, can be effective at reducing concentrations of pathogens in streams; some case studies show reductions of 60-90% in the faecal indicator bacteria *E. coli* compared with un-buffered streams (Quinn et al. 2009).

Aesthetic values can be very important to land owners. In a workshop on riparian margins for dairy farmers, the majority of participants referred to riparian-margin plantings as visually appealing features that improved the appearance of the farm and wider landscape (Figure 2) (Maseyk et al. 2017a cited in Maseyk et al. 2018). And in a survey of over 600 farmers, “increasing the attractiveness of the waterway bank” was one of the strongest motivators for farmers intending to fence or plant riparian zones (Parminter, 2008).

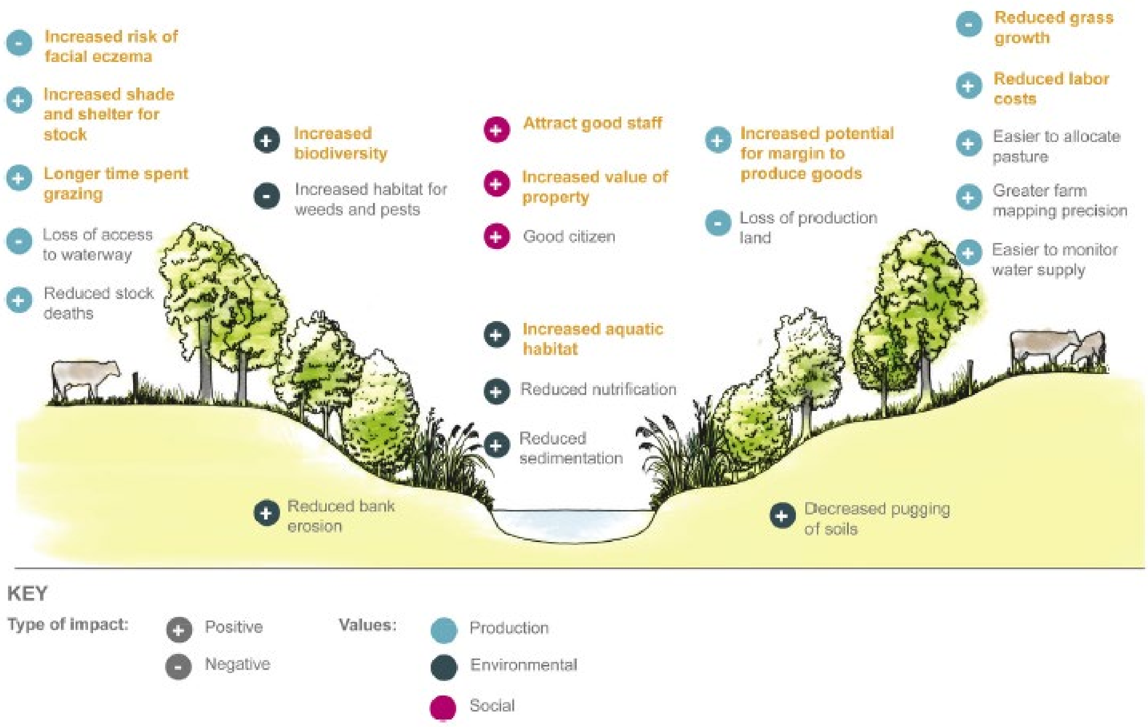

Figure 2: Pros and cons of retired multi-tier riparian margins as identified by Taranaki dairy farmers. (Maseyk et al. 2017).

However, aesthetic value should be considered beyond simply appreciation. The important links between human wellbeing and a healthy natural environment have been highlighted by several authors (e.g., Keniger et al. 2013; Speldewinde et al. 2009; Albrecht et al. 2007). While indirect effects of healthy riparian buffers on human health and well-being are difficult to measure and causal links difficult to establish, it has been observed that they can contribute to factors such as staff retention on farms (Maseyk et al. 2017, see Figure 2).

Healthy riparian buffers provide a strong visual indication of the environmental stewardship ethic of the farmer, which has become increasingly important in recent years. Relationships between farmers and local iwi/hapu, schools, businesses and community groups can benefit from enhanced riparian areas, particularly when riparian planting is the focus of communal activities, for example through programmes like Trees for Survival, Million Metres Streams and some Enviroschools programmes.

For Māori, interconnectedness with the environment is particularly strong and multifaceted. For example, in the National Policy Statement for Freshwater Management (NPS-FM 2017), “te Mana o te Wai” recognises the connection between Te Hauora o te Taiao (the health of the environment), Te Hauora o te Wai (the health of the waterbody) and Te Hauora o te Tangata (the health of the people) (Ministry for the Environment 2017).

Concepts such as (but not limited to) Ki Uta Ki Tai and Ma Uta Ki Tai (e.g., Te Rūnanga o Ngāi Tahu. 2003, Henwood and Henwood 2011) are used by Māori to describe their holistic understanding of aquatic ecosystems and how the health and wellbeing of the people is intrinsically linked to that of the natural environment. Ki Uta Ki Tai recognises the movement of water through the landscape and the numerous interactions it may have on its journey and acknowledges the connections between the atmosphere, surface water, groundwater, land use, water quality, water quantity, and the coast. It also acknowledges the connections between people and communities, people and the land, and people and water (NZ Govt 2017). This Māori resource management framework reflects that resources are connected, from the mountains to the sea, and must be managed as such (Ngāi Tahu ki Murihiku 2008).

Interactions between human wellbeing and ecosystem health are also reflected in cultural assessment frameworks such as the Cultural Health Index (Tipa and Teirney 2006), which assesses the health and wellbeing of sites based on their significance for traditional use and mahinga kai species as well as stream health (which includes water quality, water clarity, flow and habitat variety, catchment land use, riparian vegetation, riverbed condition/sediment, use of riparian margin, channel modification).

Many cultural values can be supported by PRBs. Some of the species significant to Māori are in the riparian zone itself, for example plants used for raranga (weaving), rongoā (medicine) and food. Other species are found in the stream but depend on riparian zones to provide suitable aquatic habitat and food. These include fish (e.g., tuna (eels) and whitebait), kōura (crayfish) and kākahi (mussels) used for food. Some of these species, such as longfin eels (tuna) are considered cultural keystone species (Noble et al. 2016) or “taonga” species with particular cultural importance (Harmsworth et al. 2011).

5 Productive uses of riparian buffers

5.1 Herbaceous feed and silage crops

Advantages:

- Easy to integrate with existing farm operations.
- Mechanical harvesting methods are known. Equipment may already be available. Very easy if using temporary fences.
- Mechanical harvesting may provide better weed control than grazing.
- Grass is the most effective type of riparian vegetation for removing sediment, microbial pathogens and phosphorus in overland runoff.

Limitations:

- If not harvested at the right time, feed quality reduces as grass gets older.
- Grass strips have low biodiversity value.
- Risk of legumes (e.g., red clover) invading. Might require spraying.
- Don't provide shade/habitat for native terrestrial species.

Conclusions: A grass buffer strip is a simple and potentially profitable option. It is already recommended in Zone 3 (pasture-side zone) of a riparian buffer. Since it provides only a few environmental benefits, it should be used in combination with trees and shrubs in Zones 1 and 2.

Preferred species: A diverse mix of non-leguminous pasture grasses and herbs.

Pasture grasses and other herbaceous species can be valuable on an ungrazed, or seasonally grazed extended riparian buffer, providing a harvestable product as well as environmental services. Dense and uniform pasture covers effectively intercept overland flows and improve infiltration (Cooper et al. 1995), attenuating sediment and microbial contaminants (Smith 1989, Collins et al. 2004). They also effectively prevent erosion of preferential flow paths that often occurs on sloping riparian areas stocked with larger, woody plants.

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 potentially suitable for riparian buffers. Using a mix of different (non-legume) species may be advantageous in terms of coping with the variable moisture and shade conditions, which will change over time as the buffer vegetation matures and taller tree species are harvested. Pasture grasses have a broad range of dry matter nitrogen and phosphorus concentrations, from 1.5 – 3.0%N and 0.2 – 0.4%P, respectively (Kirchgessner 1997), with nutrient concentration declining as pasture grasses mature. These nutrient concentrations are much higher than for the biomass of tree species like hybrid aspen (Tullus et al. 2010) or radiata pine (Beets and Pollock 1987). Pasture grass species may therefore be very well suited for removing large amounts of nitrogen and phosphorus from the riparian buffer zone through regular harvesting, effectively preventing a gradual build up and eventual re-release of nutrients.

Pasture grasses can be easily recycled and incorporated into conventional dairy or dry-stock farming operations. Regular mowing and harvesting of grass biomass on a productive riparian buffer behind a stock-proof fence can potentially be carried out with a hydraulic arm mower (Figure 3). The recovered biomass can be either directly fed to stock in an adjacent paddock like topped pasture (DairyNZ 2018) or preserved as hay or silage when productive riparian buffer harvest is co-ordinated with pasture harvest in adjacent paddocks.

Figure 3: Example of a hydraulic arm mower with suction biomass recovery. (Source: www.herder.nl).

In simple terms, pasture grass grown on a productive riparian buffer, may be considered as a partial, permanent or semi-permanent silage paddock, which remains integrated with the conventional farming operation. Harvesting grass could potentially be more complicated and costly in PRBs than in open paddocks. Pasture productivity may be lower on PRBs than in open paddocks due to lack of legumes or additional fertilisation, although their position in the landscape may mean they intercept additional nutrients. Shading may also influence pasture growth depending on the time of day or year, and should be considered in the selection of trees and shrubs for adjacent areas of the PRB. Despite these effects, pasture grasses offer a direct and relatively simple pathway for the productive use of riparian areas that is fully compatible with existing farming techniques and processes.

5.2 Fuel and bioenergy

Advantages:

- Many species are suitable, and can be used together.
- Many options for mechanical harvest.
- High volume biomass removal means high nutrient removal from buffer zone.
- Suitable as a fall-back if other intended uses fail.
- More bio-energy options in the future.

Limitations:

- No one mechanical harvest method will suit all farm situations.
- Harvesting could harm riparian fauna, especially in spring (breeding/nesting).
- Harvest reduces stream shading (impact greatest if harvesting in spring).
- Need a local buyer, as transport costs are high relative to value of product.

Conclusions: A good option, as harvesting and selling the product is simple and works with many different species, but not a highly profitable option.

Preferred species: poplar (fast-growing), willow. Native shrubs also suitable.

The primary focus for bio-energy production on productive riparian buffers is expected to be wood chip material, or chip material from alternative energy crops, for larger scale boiler applications. Traditional firewood harvesting can be facilitated on an opportunistic basis, and bio-energy crops for anaerobic digestion are an option for the future.

New markets for wood chips as industrial boiler fuel are developing. A strong driver for increasing the use of renewable fuels in New Zealand industry is New Zealand's commitments to the 2016 UNFCCC "Paris Agreement". While it is anticipated that the bulk of wood fuel for industrial use will be provided by the New Zealand forestry industry, there are regions where forestry-sourced wood fuel will be in short supply and relatively expensive due to long (>200 km) transport distances, particularly in Canterbury and North Waikato (Hall and Gifford 2008). In these areas, farm sourced wood chips from PRBs could become an important and valued supplementary industrial biofuel.

The key advantage of wood chips and energy wood from PRBs is the flexibility of this option. Essentially all native and non-native woody plants (trees and shrubs) can be used for wood chip, and the timing of harvest is **flexible**. Harvesting wood chips removes large amounts of biomass from the PRB, and therefore nutrients, particularly if leaf material is removed with the wood. For deciduous species the nutrient removal can be increased by harvesting wood chips with green leaves. Coppiced poplars and willows can produce 10 – 20 t dry matter wood chip per ha/y and remove up to 120 kg N and 15 kg P /ha/y (Schweier and Becker 2012, Fortier et al. 2015). Little information is available for fast growing native species like mahoe or *Coprosma* spp. but observations of mean light-saturated radial growth rates (Bee et al. 2007) suggest New Zealand native saplings are likely to grow at less than half to less than a quarter of the rate of exotic species. Selection of harvest technology would be determined by the location of the wood resource on the PRB and the distinction between trees and shrubs. Trees are likely to be harvested with conventional forestry equipment (chain saws, winches, tractors, etc.,) and chipped on-site. Shrubs, coppice trees and pollard trees would be harvested with more specialised equipment such as boom mowers with pneumatic biomass recovery, hydraulic pruning scissors (Figure 4) and other equipment (Spinelli et al. 2011; Schweier and Becker 2012; Hauck et al. 2014).

Figure 4: Proven wood harvesting technology: Hydraulic pruning scissors with long reach. (Source: Energreen Italy).

A non-woody alternative for boiler fuel could be miscanthus, a highly productive, rhizomatous C4 perennial grass that grows to over 4 m tall. *Miscanthus x giganteus* is a sterile hybrid introduced to New Zealand in 2007 both as a bio-energy crop and for the provision of fibre (bedding material) and landscape benefits (flexible shelterbelts). Dry matter yields in New Zealand may be as high as 20-30 t DM/ha/y and the plant benefits from good water supply (Merfield 2015). Harvested in its dormant state (winter), the senesced stalks contain only 0.2% nitrogen, while green miscanthus biomass can contain up to 2.5% nitrogen (Merfield 2015). Miscanthus could therefore be a flexible tool for nitrogen (and other nutrient) removal from PRBs, depending on the timing of harvest. Existing forage harvesting technology can be used for the harvest of miscanthus from PRBs, however this restricts the planting to Zone 3 of the PRB.

Traditional firewood can be recovered from a PRB. However, it is unlikely that targeted cultivation of firewood trees on productive riparian buffers will become a primary use, particularly since many productive options (tree fodder, general purpose and speciality timber production, speciality honey production) offer ample scope for the opportunistic harvest of firewood in the context of tree maintenance and pollarding, as well as end of productive life use.

There may also be potential for future cultivation of biogas energy crops, particularly on zone 3 of the buffer. The target species would be all perennials that are also used for animal feed, in particular cut and carry pasture (see section 5.1). Conceptually, green-cut miscanthus, or other perennials like jerusalem artichoke (*Helianthus tuberosus*) (Kerckhoffs et al. 2014), could also be considered. However, while energy crop digestion for biogas is a mature industry overseas, no rural biogas plants with the capacity to utilise energy crops are currently operating in New Zealand.

5.3 Tree fodder

Advantages:

- Fully internal to the farm system. No external marketing required.
- Feed quantity (yield per tree) and quality are known.
- High volume biomass removal means high nutrient removal from buffer zone.
- Suitable species are fast-growing. Rapidly provide stream shading and streambank stabilisation.

Limitations:

- No one mechanisation option will suit all farming situations.
- Left-over branches must be removed or processed.
- Harvest is difficult in very narrow steep-sided gullies.
- Native species are not suitable, so potentially lower biodiversity value.

Conclusions: One of the best PRB options for on-farm use. No further research required, but does require some fine-tuning to integrate with current farming systems.

Preferred species: Poplar (well-managed). Willow and mulberry also suitable.

5.3.1 Common issues

Using tree foliage as fodder for ruminants would be a simple way of achieving an economic return from a productive riparian buffer, while providing stream shading and nutrient removal. They can also provide resilience to the farming system through an additional fodder source in times of drought. Tree fodder crops are diverse, and several promising species are described in detail below.

The vast majority of research papers, textbooks and practical experience reports about tree fodder crops in New Zealand and internationally relate to less intensive farming practices, particularly deer, sheep, goat and extensive dry-stock farming. Findings from these studies may not always be transferable to more intensive farming practices like dairy farming. This “low intensity character” of tree fodder crops is also reflected in the relative lack of mechanisation and automation of tree fodder harvest and management.

One fundamentally important principle of tree fodder crops on a PRB is that trees with nitrogen fixing potential (leguminous trees) should be avoided as this can minimise or even negate the nitrogen removal benefit of riparian buffers. This immediately excludes a large number of tree fodder crops used internationally, and the associated knowledge of managing them, from any further consideration for PRBs. These nitrogen-fixing crops include:

- *Alnus spp.* (including black alder, *Alnus glutinosa*)
- honey locust (*Gleditsia triacanthos*)
- kowhai (*Sophora microphylla*)
- algarobas (*Prosopis spp*.)
- *Robinia spp.* (including black locust, *Robinia pseudoacacia*)
- *Acacia spp*. (including *A. longifolia* and *A. decurrens* - golden and black wattle)
- she-oaks (*Casuarina spp.*)
- wild tamarind (*Leucaena leucocephala*)
- carob (*Ceratonia siliqua*)
- tagasaste (tree Lucerne, *Cytisus proliferus*)
- tree medick (*Medicago arborea*)
- siberian pea-tree (*Caragana arborescens*)
- *Ceanothus spp*.

A knowledge gap (and possibly a technology gap) identified in this literature review are practical, mechanized or automated harvesting techniques for tree fodder grown on productive riparian buffers. New Zealand literature on tree forage (Halliwell, 1979, Hawke's Bay Regional Council 1996, Charlton et al. 2003) focuses exclusively on 3 mainly manual utilisation pathways for drystock farming: passive leaf fall from in-paddock trees (including drought induced leaf fall from willows and poplars), break grazing of coppice blocks (with and without prior or post cutting of branches on-site) and manual pollarding of in-paddock trees using chain saws and ladders or pruning saws. None of these methods are directly applicable to productive riparian buffers, where stock exclusion needs to be maintained. Furthermore, the leftover branch wood accumulating in the paddock as a consequence of these operations is seen as a safety and/or environmental concern (blocking drains and streams; Hawke's Bay Regional Council 1996, Charlton et al. 2003) and often requires more manual labour to be rectified (Figure 5). Most overseas literature reviewed (Papanastasis et al. 1995, Temel and Pehluvan2015, Novak et al. 2016, Luske et al. 2017) also relies on passive leaf fall or break grazing of coppice blocks.

A pathway to more practical mechanical management of forage tree biomass on riparian buffers may have been drafted by the practical experiments of Hawke's Bay farmer Tim Forde (Taylor 2016). Forde is using natural poplar leaf fall from in-paddock trees as part of his beef steer fattening regime. However, in autumn he supplements the steer diet with a mixture of concentrate (palm kernel) and chipped poplar (branch and stem wood) and reports high animal palatability as well as health benefits. The feed value of wood fibre for ruminants is generally considered minimal, however some overseas studies indicate that poplar species may be an exception. Robertson et al. (1971) conducted feeding experiments with poplar stem wood silage on Hereford yearling steers and observed dry matter digestibility from 73% to 58% for feed rations containing 20% to 60% poplar stem wood silage. Based on these results Robertson et al. (1971) calculated a poplar stem wood silage dry matter digestibility of 35%-40%, substantially higher than the 20% and 37% in-vitro digestibility of untreated poplar wood and bark, respectively (Robertson et al. 1971 and references therein). These numbers are broadly in line with in-vitro dry matter digestibility for crude aspen poplar wood of 23% reported by Mathews and Pepper (1978), which increased to 57% in-vitro digestibility with a 5-minute steam treatment of the poplar wood.

These practical New Zealand field observations and overseas laboratory studies regarding the digestibility and palatability of poplar stem and branch wood, provide a conceptually superior pathway for forage tree harvesting of poplar species from PRBs. With poplar wood providing a small, but at least not negative, feed value, it would be conceptually possible to harvest poplar leaves and branch wood simultaneously (38%-45% of total branch DM being wood, Kemp et al. 2001) through high pollarding. Subsequently the material could be chipped and ensiled, potentially together with other forage crops such as maize silage or grass silage. Combined ensiling of leaf and wood biomass from a PRB could utilize relatively mature technology currently used in Europe for harvesting energy wood from willow and poplar coppice plantations (Figure 4). Use of known technology also allows for the estimation of harvesting costs, which European publications put in the range of Euro 19 – 55/t (about NZ$32-92/tDM) dry matter harvesting and in-situ chipping for poplars, the costs of larger diameter, more mature trees being near the upper end of the range (Spinelli et al. 2011, Schweier and Becker 2012, Hauck et al. 2014).

5.3.2 Poplars

The various poplar species (aspen poplar, silver poplar, black poplar, hybrid poplar, lombardy poplar, 'Veronese' poplar, etc.,) are the non-legume tree fodder crop for which most information on palatability and nutritional value for ruminants is available from New Zealand and international literature.

Forage yields have been estimated in several New Zealand field trials (Table 1). Yields tend to increase as trees get older. However, after pollarding, subsequent re-growth might be initially subdued (Figure 5). Harris and Wills (2005), report a year 1 regrowth from 13-year-old poplars in Otago of only 0.9 kg DM leaf material with an unfavourable leaf to branch wood ratio of about 1:2. However by year 3, post-pollarding leaf yields had increased again to 7.8 kg DM leaf material and a leaf to branch wood ratio of about 1:1.

Yield estimates for poplar tree fodder crops available from the literature are difficult to apply to productive riparian buffers, since most New Zealand yield studies have either focused on solitary trees in hill country paddocks or on low density plantations, i.e., 20-50 trees/ha (Hawkes Bay Regional Council 1996, Charlton et al. 2003). We calculate poplar tree yields for PRBs by assuming a double row of poplars on zone 2 and zone 3 of the PRB, spaced 2.0 m apart with 7.5 m in-row spacing and 50% off-set. This planting regime would lead to full canopy closure at age 10 years with hybrid poplar (average canopy width 4.2 m) and equate to a planting density of 667 stems/ha (or 430 stems/ha including the row edge effect; Kemp et al. 2001), a common planting density for poplar pollarding blocks (Charlton et al. 2003). Stantiall (2008) quotes the establishment cost of a 400 stems/ha pollarding poplar block as NZ$1,680/ha excluding labour and NZ$3,140/ha including labour – figures which can also serve as a guideline for the establishment costs of pollarding poplars on PRBs.

Based on these hill country data, it may be reasonable to expect, after an initial establishment period and on a 3 year pollarding/harvesting regime, a poplar leaf yield of 3.5 t DM/ha from a PRB, which would be associated with an equal yield of branch wood. These figures are broadly in line with poplar leaf yields from northern India (Table 1; Newman 1997), as well as New Zealand short rotation poplar coppice trial yields in Canterbury (Table 1; Radcliffe 1983).

Table 1: Fodder yields from poplars at various ages from several field trials in New Zealand and India. Abbreviations: DM = dry matter; DBH = diameter at breast height

Species	Location	Tree component	Age in years (size DBH)	Yield per tree (kg DM)	Yield (t DM/ ha)	Reference
Hybrid poplars	Wairarapa	Leaves and twigs <5 mm diam.	10	18.0	7.74 (@ 430 stems/ha)	Kemp et al. (2003)
Average of 9 species	Wairarapa	Additional branch wood	10		5 (@ 430 stems/ha)	Kemp et al. (2001)
Poplars	Palmerston North	Leaves and stems	5	2-3		Jones and McIvor (2013)
Poplars	Palmerston North	Leaves and stems	10	18-22		Jones and McIvor (2013)
Poplars	Palmerston North	Leaves	Older (30 cm)	50		Jones and McIvor (2013
Poplars	India	Leaves	3		2.5 (@ 594 stems/ha)	Newman (1997)
Poplars	India	Leaves	11		9 (@400 stems/ha)	Newman (1997)
Short-rotations poplars	Diamond Harbour (Canterbury)	Leaves + stems			3.3 + 6.4	Radcliffe (1983)

There is broad agreement in the literature that poplar leaf forage is an excellent feed for ruminants, with high crude protein concentrations and good dry matter digestibility, equalling or exceeding the values for other supplements such as Lucerne hay or autumn pasture (Table 2). McWilliam et al. (2005) observed a steady, but comparatively small decline in feed quality with poplar forage for progressing harvesting dates from late January to end of April.

Table 2: Protein content, DM (dry matter) digestibility and ME (energy content) for poplars in several studies.

Species	Tree component	% Protein content	% DM digestibility	ME (MJ/kg)	Reference
Poplar (various cultivars)	Leaves + stems <5 mm diam	12.8-17.9	61-70	8.9-10.4	Kemp et al. (2001)
Poplar (various cultivars)	Bark (5-10 year old plants)	3.1-3.3	55.6-57.7	8.8-9.2	Kemp et al. (2001)
Poplar	Leaves + stems <8 mm diam	13-18.5	59.5-65.4	9.04-10.02	McWilliam et al. (2005)
Poplar	Mature leaves (90% yellow, 50% fallen)	6.6	63	10.3	Temel and Pehluvan (2015)
Poplar	Stem wood silage		35-40		Robertson et al. (1971)

Overseas, data from yellow and fallen leaves in Turkey (Temel and Pehluvan 2015; Table 2) indicate that poplar leaves maintaining their relatively high digestibility and ME content until very late in the farming season. Hejcmanová et al. (2014) analysed poplar leaves grown in the Czech Republic and determined nitrogen and phosphorus concentrations of 3.29% N and 0.25% P, respectively. Tullus et al. (2010) determined the nitrogen and phosphorus content of aspen poplar stem wood as 0.25% N and 0.043% P respectively.

Extrapolating from the above numbers and assuming a pollard poplar PRB with 430 stems/ha being harvested every 3 years yielding 3.5t DM/ha leaf material as well as an equal amount of branch wood, the total N and P removal of such a harvest can be projected as 85 kg N /ha and 10 kg P /ha (for 3 years). These numbers fall within the wide range of values (32-124 kg N /ha/y and 3.2-15.6 kg P /ha/y) which Frontier et al. (2015) recorded as the annual nutrient absorption rate of 4.5m wide riparian buffers planted in 9-year-old hybrid poplar (2,222 stems/ha) at 4 trial sites in agricultural catchments in southern Quebec, Canada.

Figure 5: First year re-growth of pollard poplars on a Hawke's Bay dry stock farm. Note the unmanaged branch wood from previous pollarding requiring further work. (Source: New Zealand Farm Forestry Association).

5.3.3 Willows

Similar to poplars, the generic term willows covers a wide range of willow species, cultivars and hybrids, some more suitable for farm plantings and tree fodder use than others. As far back as 1880 crack willow (*Salix fragilis*) was identified as problem species in New Zealand contributing to flooding issues in the Nelson region (VanKraayenoord et al. 1995). Halliwell (1979) warned that some willow species like pussy willow (*Salix caprea*) can become serious weeds in swamp lands and that bitter willow (*Salix purpurea*) is strongly avoided by stock. Careful selection of the right willow species is therefore very important.

Willows could be used as tall pollard trees, like poplars, on Zone 2 and 3 of a PRB, or as a short rotation coppice on Zone 3. Farmers and land managers in New Zealand often do not distinguish willows by their botanical classification, i.e., weeping willow (*Salix babylonica*), golden willow (*Salix alba*), matsudana (*Salix matsudana*), narrow-leaf willow (*Salix schwerinii*) etc., but more often use the name of specific hybrids, clones or cultivars, such as 'Tangoio', 'Hiwinui' and 'Moutere' (*Salix matsudana x alba*), 'Kinuyanag' (*Salix schwerinii*), bee willow / 'Semperflorens' (*Salix triandra*), 'Gigantea' (*Salix viminalis*) etc. As an example, in an information brochure of the New Zealand Poplar and Willow Research Trust (McIvor 2013), the usefulness of different willow hybrid clones for planting to prevent erosion on exposed hill sites, on stream banks, in tunnel gullies or as a shelter belt are discussed in detail. As tree fodder, the hybrid 'Tangoio' (*Salix matsudana x alba*) and the botanically different 'Kinuyanag' (*Salix schwerinii*) are considered equally useful and advantageous.

Tree fodder yield numbers for high pollarding willows are available from Kemp et al. (2001) for the hybrid 'Tangoio', grown as in-paddock trees on Wairarapa dry stock land (Table 3). These forage yields are about 20% higher than for hybrid poplar trees of the same age. Subsequent work by Kemp et al. (2003) confirmed these observations and the authors postulated that the forage dry matter yield of 'Tangoio' willow up to 30 cm diameter at breast height (DBH) can be projected from the DBH according to the formula: $y=0.0262x^{2.2581}$.

Table 3: Willow tree fodder yield as kg DM (dry matter) for different-aged trees before and after pollarding. DBH = diameter and breast height.

Species	Tree component	Age in years (diam DBH)	Yield per tree (kg DM)	Reference
Tangoio hybrid	Leaves + stems <5 mm diam	5 (9 cm)	3.0	Kemp et al. (2001)
Tangoio hybrid	Leaves + stems <5 mm diam	7 (14 cm)	9.5	Kemp et al. (2001)
Tangoio hybrid	Leaves + stems <5 mm diam	10 (20 cm)	22.4	Kemp et al. (2001)
Tangoio hybrid	Leaves + stems <5 mm diam	Unspecified (30 cm)	56.7	Kemp et al. (2001)
Unspec.	Unspecified (regrowth)	5 after pollarding	29.3	Douglas and McIvor (2010)
Unspec.	Leaves (regrowth)	Otago: 5 after pollarding Hawke's Bay: 3 after pollarding	60	Hawke's Bay Regional Council (1996)

There is general agreement in the literature that willow regrowth is slow in the initial period post pollarding (Charlton et al. 2003). However, a relatively wide range of total DM and forage DM regrowth after pollarding is reported in the New Zealand literature (Table 3), and the edible portion of regrowth may be as low as 30% (Douglas and McIvor 2010). Extrapolating from the observations of Kemp et al. (2001) that 'Tangoio' willow yields about 20% more forage than hybrid poplar, and assuming a double row (2m apart 7.5m in row spacing) of willows on zone 2 and 3 of the PRB a forage DM yield of 4.2t DM/ha every 3 years may be expected.

Willow yields also vary widely in New Zealand willow coppice and graze blocks. For drystock farms in New Zealand, including the Ballantrae Research station in Manawatu, Oppong et al. (2001) report annual forage DM yields of 1.19 t/ha and 3.20 t/ha for hybrid willow (*S. matsudana x alba*) as well as 1.84 t/ha and 2.40 t/ha for 'Kinuyanagi', respectively. The coppice block experiments also confirm the observation by Douglas and McIvor (2010) that regrowth on willow trees can produce 3x more woody biomass than leaf biomass.

Willow forage contains high levels of condensed tannins (CT), lignin, and other anti-nutritive compounds such as phenolic glycosides, relative to poplar forage and more traditional feeds such as pasture grasses (McCabe and Barry 1988, Kemp et al. 2001, McWilliam et al. 2005). Despite this, digestibility and nutritive value are generally higher for willow forage than poplar forage. For 'Tangoio', matsudana and 'Moutere' willow forage Kemp et al. (2001) report a protein content of 11.7% to 15.5%, dry matter digestibility of 57.9% to 69.9% and an energy content of 8.7 to 10.5 MJ(ME)/kg; values which are very much in line with poplar forage. For hybrid willow McCabe and Barry (1988) report 11.1% protein, 64.2% dry matter digestibility and an energy content of 10.0

MJ(ME)/kg. Oppong et. al. (2001) report similar protein concentrations and a dry mater digestibility of 64.8% to 69.1% for hybrid willow and 61.1%-61.5% for 'Kinuyanagi', despite the latter showing a 4-fold higher concentration in condensed tannins.

In summary, considering slightly higher willow forage yields, a slightly reduced protein concentration and a wider leaf to stem ratio, it can be assumed that pollard willows will remove a similar amount of N and P from a PRB to poplars. However, there may be high yield variability due to changing and uncertain total biomass yields.

5.3.4 Mulberry (*Morus* spp.)

Compared to poplars and willows little information is available in New Zealand and international literature on other exotic trees that may be suitable as a PRB crop for tree fodder. Halliwell (1979) speculates that mulberry species (*Morus spp*.) hold potential as a tree fodder crop. Like poplars and willows, mulberry trees can be propagated via cuttings/poles (as well as seeds) and grow vigorously. However, as shallow rooters (Halliwell 1979), they may not fulfil some key requirements of trees on PRBs, such as stream bank stabilization. *Morus alba* grows well in climates with 600 – 1,500 mm annual rain fall and are suited to growing on river margins as they can tolerate sporadic waterlogging of the soil.

Forage from pollarded *Morus alba* may have exceptional feed quality. Emile et al. (2016) reported 24% protein concentration and 89% in vitro dry matter digestibility, similar to concentrate feeds such as grain and pulses (Kirchgessner 1997) and better than nine other tree forages analysed in parallel. However, feed quality diminishes as the forage matures. Late in the season (at a stage when 90% of leaves had turned yellow and 50% of leaves had fallen), mulberry tree fodder leaves in Turkey had 9.2% crude protein, 64.7% dry matter digestibility and 10.5 MJ(ME)/kg (Temel and Pehluvan 2015). The exceptional feed quality of *Morus* spp. is confirmed by a FAO summary paper by Sanchez (2000), primarily focusing on mulberry forage in tropical countries. The information summarized by Sanchez (2000), indicates 70%-90% dry digestibility of mulberry forage, very high mineral concentrations, crude protein concentrations of 15-28% and an amino acid profile, that makes the material suitable for raising monogastric livestock such as pigs. Similar to poplar, mulberry shows a high digestibility not only for leaf biomass, but also for bark (60.3%) and stem (37-44%) resulting in whole plant digestibility of 58-79% (Sanchez 2000).

As a representative example of yield in temperate climates, Talamucci et al. (2000) report on a mulberry alley pasture system with 600 stems/ha *Morus alba*, with subterranean clover pasture in the understorey on fertile land in central Italy. Various cutting and grazing regimes yielded 7.5-10.5 t DM/ha/y mulberry forage, in addition to 4.5-8.5 t DM/ha clover pasture. Mulberry, especially in intensive coppice culture, requires substantial fertilisation (Sanchez 2000), hence it can be assumed that *Morus* spp. grown and harvested on PRBs will remove substantial amounts of nutrients. Sanchez (2000) quotes the leaf nitrogen content as 2.5-4.5% and the phosphorus content as 0.14-0.24%. Assuming only 50% of the DM yield reported by Talamucci et al. (2000) being leaf, this would indicate a N and P removal potential of 90 – 180 kg N/ha/y and 5-10 kg P/ha/y, respectively.

5.3.5 Other non-native tree fodder species

Emile et al. (2016) identified other tree fodder species potentially suitable for PRBs, based on crude protein content and digestibility (Table 4). Since Dutch elm disease (*Ophiostoma novo-ulmi*) has been detected in New Zealand, it would be unwise to plant elm trees that could potentially be completely destroyed over the next decades, however some Dutch elm disease resistant cultivars are available in

NZ (pers. com Trevor Jones 2019). Halliwell (1979) also identifies maple and chestnut as potential tree forage crops for New Zealand, but the latter mostly due to the potential of sheep using the starch rich chestnuts, which is impractical in the context of a PRB. These species and other non-native broad-leaved tree species potentially suitable as tree fodder potential (e.g., walnut, hickory and beech *Fagus spp*.) grow substantially slower, and recover less vigorously from pollarding, than the typical pollard/coppice trees poplar, willow and mulberry (Table 1, Table 3). Therefore, any use of these species as tree fodder could only be justified in the context of other productive uses, such as high value timber production, etc. Due to their slow growth, these trees will remove less nutrients, and will be slower to provide stream shading and stream bank stabilisation than the much faster-growing tree species. Furthermore, most of these other tree species cannot be propagated from cuttings or poles. This means that establishment cost will be higher, due to more expensive seedling material and greater effort (weed control, etc.,) required during the longer establishment phase.

Table 4: Protein and *in vitro* digestibility of several non-native tree species with potential as fodder crops.

Common name	Scientific name	% protein	% *in vitro* digestibility
European ash	Fraxinus excelsior	14.5	75
Chestnut	Castanea sativa	11.8	68
Maple	Acer campestre	13.4	64
European elm	Ulmus minor	14.5	67

5.3.6 Native species

Little scientific literature on the use of New Zealand native plants as tree forage could be identified. Most New Zealand tree fodder options pertain to shrubby plants, rather than trees, and information is primarily based on practical field experience as well as scientific observation reports from the pioneering days of New Zealand agriculture, rather than quantitative experiments. The New Zealand native species most commonly mentioned in the literature include the shrubs:

- mahoe (whiteywood, cow leaf, *Melicytus ramiflorus*)
- kamahi (*Weinmannia racemosa*)
- kapuka (broadleaf, *Griselinia littoralis*)
- lacebark (houhere, *Hoheria spp*.)
- cabbage tree (*Cordyline australis*)
- *Coprosma* spp. (particularly karamu *Coprosma robusta*)
- marbleleaf (*Carpodetus serratus*)
- wineberry (*Aristotelia serrata*)
- ribbonwood (*Plagianthus regius*)
- kotukutuku (*Fuchsia excorticata*)
- five-finger (whauwhaupaku, *Pseudopanax arboreus*).

Manuka (*Leptospermum scoparium*) was systematically analysed as an alternative feed by Lambert et al. (1989) and dismissed as a stock feed due to its low palatability and digestibility. These are likely due to the high essential oil content of Manuka (up to 0.6% fresh matter; Essien 2019) containing high concentrations of components such as monoterpenes, sesquiterpenes, methyl cinnamate, and triketones (i.e., leptospermone) which are fragrant, bio-active and partially anti-nutritive (Essien 2019). Other New Zealand natives may be more palatable to ruminants, as indicated by the varying extent of browsing damage caused by red deer among New Zealand shrub and tree species on conservation land (Bee at al 2007).

Low growth rates, however, may limit the potential of New Zealand native shrubs to provide tree fodder in PRBs. Browsing damage experiments provide data on native species recovery rates. In a field study in Southland, Bee et al. (2007) simulated browsing damage (partial defoliation by clipping) to various native trees and shrubs, including (from the above list) kotukutuku, kapuka and kamahi, which are relatively palatable to deer. Analysing 12 native species Bee at al. (2007) observed that after 60% defoliation of the sapling, shoot recovery took almost 2 years on average, while diameter growth was almost completely arrested. The only notable exception was kotukutuku, which showed shoot recovery after 1 year and no complete halt of stem diameter growth. Comparing their findings to overseas data, Bee at al. (2007) note that mean light-saturated radial growth rate of New Zealand native saplings was generally only ⅕ of the average rate reported in nine recent studies from around the world, and only ½ of the next least productive example. This data appears to indicate that the slow recovery of New Zealand native shrubs may primarily be a result of their overall slow growth rate, rather than an inability to regrow.

New Zealand native foliage tends to have low nutritional content compared to exotic species. Dickinson et al. (2015) showed that nitrogen and phosphorus concentration in the foliage dry matter of 11 native shrubs was on average less than half that of ryegrass pasture. The nitrogen concentrations of the native foliage dry matter were relatively consistent between 1% and 2% N and between 0.1% and 0.2% P. Only kapuka (*Griselinia littoralis*) and wineberry/makomako (*Aristotelia serrata*) recorded P concentrations up to 0.3%. Furthermore, during fertilizer tests with biosolids only ribbonwood (*Plagianthus regius*) showed a strong elevation of foliage phosphorus concentrations (up to 1% P in DM), indicating a tendency towards luxury nutrient consumption.

In another study, the foliage dry matter concentration of kamahi, toro, rimu, hinau and mahoe from the Tararua mountain range was 0.9%, 1.1%, 0.9%, 1.0% and 2.0%, respectively, albeit with relatively large variations among individual plants of the same species (Windley et al. 2016). The same study determined in-vitro digestibility of foliage as 57% for kamahi, 45% for toro, 39% for rimu, 46% for hinau and 62% for mahoe – values which are low compared to pasture grasses and exotic fodder tree species (see sections 5.1, 5.3.2 to 5.3.4).

Nutrient removal by native shrubs in a PRB will be low, due to their slow growth and their relatively low foliar nutrient concentration. Feed value (digestibility) is not widely tested but indicated as generally low. Therefore, harvested native shrub biomass may be better utilised as wood chip substrate for composting barns or for bio-energy.

5.4 Timber

Advantages:

- Some products are suitable for on-farm uses, so no market development needed.
- Potential co-benefits include windbreaks and shade for stock.
- Maintenance and harvest technologies and practices are established.

Limitations:

- Established production forest species (Pinus radiata, Douglas fir) not suitable for PRB due to low wood quality (side branches grow unless pruned frequently).
- Harvest can be very damaging for the buffer and adjacent waterway.
- Native species have low rates of nutrient uptake.
- Most native species have very long rotation times.
- Small market for fence posts and poplar poles limits large-scale production.
- Other specialty timber uses are untested.

Conclusions: for general purpose timber, PRB are not as suitable as woodlots, as high edge:area ratio means high maintenance. Speciality timber (fence posts and poplar poles), suitable for on-

5.4.1 General purpose, building and export timber

Forest timber and wood products are a major part of the New Zealand economy. Representing 1.3% of the world's trade in forest products, the sector generates NZ$5 billion annual gross income, contributes 3% to New Zealand's GDP and employs around 20,000 people. However, the sector is poorly diversified. In 2017, out of a total 1.706 million ha net stocked forest area, 1.536 million ha (90%) were in Pinus Radiata and 0.104 million ha (6%) in Douglas fir (NEFD 2017). It is therefore not surprising that several organisations and special interest groups like, the Farm Forestry Association, the Poplar and Willow Trust, the Northland Totara Working Group, and various iwi interests are trying to diversify the forest industry in New Zealand by introducing more diverse tree species (including natives) and alternative forest management systems (including mixed culture and agroforestry). Timber production on PRBs (primarily Zone 2 & 3) could be one, albeit small, contribution towards diversification of timber species and production systems.

The dominant timber species, Pinus Radiata and Douglas fir, are not well suited for PRBs because the wet conditions often found along stream margins are not ideal for these species. Furthermore, grown in the open as single or double rows along a PRB, these species would require high maintenance (pruning) to maintain acceptable growth form.

Minor timber species Lawson cypress (*Chamaecyparis lawsoniana*), redwood (*Sequoia sempervirens*) and potentially some eucalypts are likely better suited to the growth environment of a PRB. However, these species would also require more pruning and maintenance than in a forest or closed woodlot setting to achieve acceptable timber qualities, while harvest cycles may be equal or slightly shorter than in a forest.

The general usefulness of poplar as a supply for fence and farm timber products like fence battens, fence posts, stays and yard rails have been confirmed by the practical trials and experience of Hawke's Bay farmer Tim Forde (Taylor 2016). While there is agreement that poplar sapwood will deteriorate quickly, the heart wood of trees older than 30 years appears as a suitable substitute for pine in these low-spec applications, provided the wood is treated to the same level with wood preservatives (Taylor 2016).

A range of native tree species may be considered for timber production in PRBs. According to Bergin and Gea (2007) the most productive and easy to manage native tree species would be totara (*Podocarpus totara*) and for northern areas kauri (*Agathis australis*). Slightly less favourable native trees for timber production on PRBs include tanekaha (*Phyllocladus trichomanoides*), kahikatea (*Dacrycarpus dacrydioides*) (although proximity to a stream will meet its need for high moisture), rewarewa (*Knightia excelsa*), puriri (*Vitex lucens*), kanuka (*Kunzea ericoides*) and red beech (*Nothofagus fusca*).

Native species require substantially longer rotations than most exotic timber species, which are typically harvested after 25 to 40 years. Under good growing conditions, harvest of native species can be expected after 60 years at the earliest, while good quality timber from the natives listed above may only be available after 100 years (Bergin and Gea 2007). These long crop rotations severely diminish the attractiveness of natives for timber in general. For natives on PRBs the slow growth additionally means reduced nutrient uptake, and a delay before significant stream shading is achieved. Combined with the higher maintenance effort (pruning) required, PRBs may therefore not be the ideal place for native timber production.

For both exotic and native timber species harvesting from a PRB needs to be planned carefully. Harvest of timber trees planted in zone 2 and 3 may damage productive crops on other zones of the buffer and may harm the riparian flora, fauna and environmental services. Field studies carried out by Chizinski et al. (2010) in northern Minnesota however show that careful harvesting of timber from riparian buffers, where some trees are left standing (8.7±1.6 m^2/ha basal area in the studies), does not necessarily cause serious harm to the stream ecosystem.

5.4.2 Speciality timber

Given the complexities, large maintenance effort, relatively low yield and long rotation times of classical timber production on PRBs, are there better prospects for the production of less conventional timber products? Several interesting options were identified in this literature review. However, it needs to be noted that, despite their technical advantages and conceptionally favourable financial performance, very few of the options listed below have been tested in the field. Furthermore, none have an established market in New Zealand today. The barriers for speciality timber products may therefore lie more in market development and the establishment of logistics chains, rather than in the production and harvest of the speciality timber product itself. Using specialty timbers on-farm avoids these barriers.

5.4.3 Fence posts

For farm internal use the production of durable fence posts is one option. The key species used overseas for fence posts, *Robinia spp*. (especially *Robinia pseudoacacia*) and she-oaks (*Casuarina spp.*), cannot be considered for PRBs because they fix nitrogen and potentially export it to the adjacent stream. This leaves totara (*Podocarpus totara*) and white mulberry (heart wood) (*Morus* *alba*) as the principle species suitable for durable fence posts. Both species could be established as dense double or triple rows on Zone 3 of a PRB, at high planting densities of 1,000 – 3,000 stems/ha.

Fence post harvest may commence in stages after 15 to 25 years, yielding posts of different sizes over time. Assuming a production equivalent to 1,500/ha durable No.1 round fence posts (115-140mm, 2,4m) over 25 years (Bergin 2003), gross earnings may be around New Zealand $900/ha/y ($22,500 over 25 years).

Both totara and mulberry can be considered as dual-use species. Totara can be used as a densely planted, high trimmed tree hedge (Bergin and Gea 2007). Achieving the desired stumped growth form requires ongoing maintenance (trimming, pruning), but the trimmings can be used for essential oil extraction or bioenergy. Mulberry trimmings can be used as tree fodder.

5.4.4 Poplar poles

Poplar poles represent another speciality timber application for use on-farm, or within the local community or region. Poplar poles could be produced from poplar coppice stands established on PRBs and used for erosion control plantings. Most regions (e.g., Hawke's Bay, Greater Wellington, Northland) have a sustained demand of several tens of thousands of poplar poles annually (Charlton et al. 2003). According to the Northland Regional Council land manager, the NRC region has for years produced only about 3% of the poplar (and willow) poles that are required for urgently needed erosion control plantings on council land (pers. com. Duncan Kirvell, 2018). In the context of PRBs, poplar pole production would be established from cuttings at high planting densities (>5,000/ha) on zone 2 or 3 of the productive riparian buffer as a "row crop" (Figure 6). The first harvest could be expected after 2-3 years, subsequent harvests (new shoots form root stock) also after about 2-3 years. Optimum planting densities and expected yields are strongly dependent on light and water availability, making PRBs almost ideal candidate sites. Barriers to for poplar pole production are low, but some maintenance effort for block thinning and shoot pruning are required for the production of high- quality poles. Smaller sites can be harvested manually with chain saws, while larger sites are harvested with tractor mounted cutters, and/or cut and collect technology. These are easy to use on the accessible zone 2 and 3 of the PRB. Should demand for poplar poles diminish temporarily, farmers would have the option to use the poplar pole material as tree fodder.

5.4.5 Mushroom growth media

Another potential speciality timber option for PRBs is production of wood mushroom growth media. According to Buchanan and Barnes (2001) New Zealand produces mainly button mushroom (*Agaricus bisporus*) grown on compost substrate, and imports mainly the high-value wood grown species 'shiitake', 'oyster mushroom', and 'enokitake'. Given New Zealand's growing Asian population, there is definite scope for domestic production of 'shiitake' and similar high value mushrooms, although Buchanan and Barnes (2001) warn that many small-scale operations were tried and failed throughout the 1980's.

The high-value wood grown mushrooms can be grown on a moderately wide variety of hard wood media. Potential PRB species include chestnut, walnut, maple, ash, beech, various oaks and potentially even native trees considering historic utilisation of 'wood ear fungus' (*Auricularia polytricha*) (Buchanan and Barners 2001). Large mushroom farms use chipped branch material in plastic bags, while high-end production is carried out on roughly 1 meter long, heartwood free logs of hardwood species, 100-150 mm diameter, cut green in spring (Frey 2014). The timber demand for the production of mushrooms is substantial, about 20 – 30 kg of green log fresh matter per kg of sellable mushroom, and secure long-term timber availability is the single biggest obstacle for small and medium scale 'shiitake' mushroom producers (Frey 2014). The most practical business model may therefore be a group of farmers with PRBs selling hardwood mushroom media to an external mushroom grower.

For speciality timber production on PRBs, mushroom wood substrate is interesting because it would provide a secondary use for hardwood trimmings and thinnings of hardwood species grown for other purposes such as export timber, tree fodder, etc. Alternatively, in a more intensive configuration, hardwood species could be grown on a much shorter rotation (10-25 years), potentially even as coppice, providing financial benefits sooner than almost all other hardwood utilisation pathways. This approach would also remove more nutrients from the riparian zone, though it would disrupt stream shading intermittently.

Figure 6: Conventional poplar pole production as a "double row crop" at the NRC nursery. (Source: Stephan Heubeck, NIWA).

5.4.6 Cork

A truly exotic, and so far only theoretical, speciality timber option for PRBs might be the production of cork. The cork oak (*Quercus suber*) is traditionally grown in agroforest systems in its main production region in Portugal and Spain. Large tracts of the North Island East Coast have a similar climate to Portugal and Spain, and *Quercus suber* has grown vigorously in New Zealand botanical gardens and arboreta for many decades. Cork oaks are very light demanding, requiring open environments, annual average temperatures between 13 and 17 °C and 500 to 700mm/y precipitation. They are drought tolerant and frost hardy to -5 to -10 °C.

The European cork industry produces 300,000 tonnes of cork a year, with a value of €1.5 billion of which wine corks represent 15% of cork usage by weight but 66% by revenue. While the demand for wine corks could be stagnating or diminishing due to the introduction of alternative bottle capping systems, alternative cork uses (e.g., as an insulation material or for flooring systems) are growing. In its main production region a cork oak sees an initial, low quality, harvest of cork once a diameter at breast height (DBH) of 20-30 cm is reached (15- 25 years). Subsequent high value cork harvests are then carried out once every 9 – 12 years. Cork yields of 10-20 kg/tree per harvest tend to increase with age, while the highest quality material is obtained from the second, third and fourth harvest.

Compared to other hardwood utilisation pathways the key advantage of cork is the earlier financial returns. Furthermore, the growth environment on a PRB (in the drier parts of New Zealand) should fit the requirements of *Quercus suber*, almost perfectly. Considering New Zealand's wine exports of 255 million litres in 2018, there should also be sustainability and branding advantages supporting the production of New Zealand grown wine corks.

5.5 Fibre

Advantages:

- Suitable for both on-farm use and sale to markets.
- High volume biomass removal means high nutrient removal from buffer zone.
- Many suitable species, various parts of the plant (stem-wood, trunks, leaves) are suitable for bedding material.
- Flax already used extensively in planted riparian buffers.
- Cultural as well as industrial uses.

Limitations:

- Default manual harvesting for flax complicates upscaling.
- Harvesting might be harmful to the riparian flora and fauna.
- Knowledge and technology gaps for high value uses (e.g., industrial textiles from flax).

Conclusions: Low-volume uses are low-risk but high-volume industrial uses involve greater uncertainty as markets are complex. If composting barns become a widespread farm management method, then on-farm demand for fibre may be very large.

Preferred species: flax (*Phormium tenax*), poplars, miscanthus. Also suitable: willows and natives.

5.5.1 On-farm fibre uses

Fibre from PRBs could be sourced from targeted cultivation of specific plants. Uses include functional and technical products as well as opportunistic use of mixed fibres for various on-farm uses.

Dairy farms have an existing demand for moderate amounts of fibre. Calf pens and sheds generally use dry sawdust or shavings as bedding material. In recent years the increasing use of stand-off pads with wood chip substrate has led to an increase in fibre demand by dairy farms, which has increased the cost of traditionally cheap wood by-products in some regions (i.e., Canterbury). According to Lou et al. (2013), 22% of all New Zealand dairy farms have stand-off pads, compared to 27% of farms with hard surface feed-pads and 2% with more intensive cow housing. The current fibre uses for calf bedding material and stand-off pads total several dozen cubic metres of chip material per farm per year. Wood chips may also be used in bioreactors designed to enhance denitrification (see Schipper et al. 2010).

The demand for fibre may rise due to the increasing use of composting barns as an environmentally friendly, more intensive wintering option for dairy cows. Composting barns may become mainstream on most New Zealand dairy farms as environmental regulations tighten, increasing future wood chip demand to as high as 3 m^3 (about 0.75 t DM) per dairy cow per year (Woodford et al. 2018). For the average New Zealand dairy farm milking 414 cows in 2018 this equates to a wood chip demand of 300 t DM/y. This amount could be grown annually on 15 ha stocked with highly productive coppice species. However, almost all woody shrub and tree species can provide chip material for composting barns and stand-off pads. The chip also does not have to be dry for most applications. The technology for fibre wood chip production from a PRB would be the same as for bio-energy wood chip production, and likely be managed through a contractor rather than by individual farms.

Miscanthus (*Miscanthus x giganteus*) may provide an alternative fibre product. As bedding material, miscanthus is softer than wood chip, but more durable than cereal straw (Merfield 2015) and could be a practical alternative for composting barns in particular.

5.5.2 Flax fibre

For the manufacture of functional and technical fibre products, New Zealand flax (harakeke *Phormium tenax*, wharariki *Phormium cookianum* and their hybrids) is an obvious candidate species for targeted cultivation on PRBs. Flax has for a long time been a key species for most environmental plantings on riparian margins. It is highly beneficial in this environment as *Phormium* sp. has one of the highest nutrient uptake capacities among 12 New Zealand native plants tested by Franklin et al. (2015a). Harakeke is significant to Māori (e.g., whakapapa, whakataukī, raranga) and was the basis of a major New Zealand export industry from 1860 until the late twentieth century.

From Victorian times to the 1980s New Zealand boasted a mechanized flax industry, specialising in the manufacture of coarse fibre products like baling twine, sacks and mats (McGruddy 2006). Since the decline of the original New Zealand flax industry, researchers, entrepreneurs, environmentalists, Māori entities, farmers and others have repeatedly tried to re-establish the manufacture of *Phormium* spp. products in New Zealand. Rather than the coarse products of the past, the key focus of these efforts has been industrial textiles, speciality pulp and paper products, high quality and functional clothing, bio-composite materials etc., as well as associated non-fibre flax products like flax seed oil. The quality and advantages of these novel New Zealand flax products have been proven in principle, and questions around manufacturing technology, while not trivial, appear to be solvable. However, harvesting methods, and associated modes of *Phormium* cultivation remain an area of debate. The default option for harvesting New Zealand flax is selective manual harvest, either annually or bi-annually. Mechanised whole crop harvest in the past has yielded poor quality material (up to 50% of harvested biomass being discarded as waste) and substantially hurt plant regrowth and long-term overall yields, while options for selective mechanical harvest don't exist, even theoretically (McGruddy 2006). Historic records show that flax cutters could harvest up to 1 ton/day of green material (about 100 kg fibre) from wild *Phormium*, and up to 4 ton/day (400 kg fibre) from managed plantations (McGruddy 2006). Hauling the cut flax leaf from the plant to the collection vehicle was identified as the hardest aspect of the harvesting job. These numbers illustrate that New Zealand flax products need to fetch high prices to justify the high labour cost during harvest.

Phormium spp. cultivation on PRBs could be facilitated as part of mixed native planting on the near water zone of the buffer (zone 1), provided flood risk is low, or in the understorey of zone 2. Alternatively, more intensively managed "row crop" cultures of New Zealand flax could be established on Zone 3 of the PRB. For manual harvesting the easy accessibility of New Zealand flax grown on any part of a PRB is a clear advantage.

5.6 Speciality honey crops

Advantages:

- Established industry.
- Established marketing pathways with known costs and prices.
- Harvest requires relatively little manual labour.
- Bees provide a secondary benefit as pollinators.
- Harvest is non-invasive, i.e., causes no damage to riparian buffers.

Limitations:

- Highest value honey (mono-floral manuka) cannot be produced from a riparian buffer.
- Lower value honeys (rata and kamahi) can be produced more cheaply on non-riparian bush blocks.

Conclusions: Can use PRB for honey but it will remain a niche rather than main use.

Preferred species: Rewarewa is the most promising novel species.

5.6.1 Manuka honey

Mono-floral manuka honey is a speciality honey valued for its health benefits, which are primarily associated with its non-peroxide antibacterial properties (Snow and Manley-Harris 2004). These were initially labelled as the Unique Manuka Factor (UMF), and it wasn't until the latter 2000's that it was identified that the UMF is primarily related to manuka honey's methylglyoxal (MGO) content, a component not usually found in honey from other plants (Stephens 2006). These properties, combined with other health benefits like anti-inflammatory properties as well as the pleasant taste and smell of Manuka honey, have led to the creation of what some observers label a “manuka honey gold rush” in New Zealand over the last decade. In 2015 manuka honey exports totalled NZ$285 million per year. Depending on UMF level, manuka honey is sold for NZ$16 to >$60/kg, with beekeepers offering 10 – 30% of honey income as royalties to land owners for good manuka honey collection sites (Saunders 2017).

However, it appears impossible to produce high UMF manuka honey from plantations on productive riparian buffers. Forest managers PF Olsen advise that the minimum size for a manuka plantation for high UMF honey production is 20 ha (PF Olsen 2016). Saunders (2017) reports that manuka honey plantations established in areas with high occurrence of gorse or bordering productive pastures with high clover cover (i.e., most intensive New Zealand pastures) require a minimum size of 40 – 50 ha in order to produce high UMF mono-floral manuka honey. Clearly such demands cannot be reconciled with the characteristics of productive riparian buffers in intensively farmed agricultural catchments. Therefore, it appears that manuka planted on productive riparian buffers cannot be considered for the production of high UMF manuka honey.

5.6.2 Rewarewa honey

Rewarewa honey is another mono-floral honey from a New Zealand native plant that already has established product lines. Most major New Zealand honey producers distribute mono-floral rewarewa honey domestically and are increasingly marketing rewarewa honey overseas. While there are reports of anti-microbial and anti-inflammatory properties of rewarewa honey (Wilkinson and Cavanagh 2005, Leong et al. 2011), so far most is marketed for culinary use only, and priced at NZ$8 - $15/kg, much lower than manuka honey.

Unlike manuka honey, rewarewa honey is currently not harvested from managed tree plantations. Rewarewa is a secondary pioneer species, and there are large recovering native bush areas and re-wilding lands throughout New Zealand’s North Island with a good proportion of rewarewa trees that are used by beekeepers for rewarewa honey production. This extensive management strategy is aided by the fact that during the season rewarewa is among the most preferred honey sources for bees, allowing for the production of a mono-floral honey even in areas where a diverse range of other nectar and pollen sources is available to honey bees. However, as regenerating native bush areas mature and the demand for rewarewa honey increases, demand for rewarewa plantations for mono-floral honey production may increase.

An initial trial of a rewarewa plantation for honey production was established in 2018 on the Walker farm in South Taranaki with support from Venture Taranaki, Callaghan Innovation and silviculture advice from senior New Zealand forestry consultant David Bergin. The project proponents project a rewarewa tree planting density of 250 to 350 stems per hectare and a ratio of 5 rewarewa trees per beehive, each capable of producing 25 to 35 kg mono-floral honey per season in what would become a high intensity honey production system (Groenestein 2018).

As a secondary pioneer species rewarewa would be well suited for incorporation into a PRB. It can cope with full sunlight, most soil types and climates typically found in the North Island. Only permanently wet/swampy sites and sites with extreme wind exposure may be unsuitable (pers. com. David Bergin). Rewarewa could therefore be incorporated as a premier native tree species on zone 2 of a PRB. Its tall, slender growth form and moderate growth rate (Crowe 1992, Bergin and Gea 2007) could provide stream shading soon after buffer establishment without limiting most productive uses on zone 3 of the productive riparian buffer, or negatively affecting species on zone 1 of the PRB.

5.6.3 Other mono-floral honey

Many other native tree species could be grown on PRBs for honey production. According to Butz-Huryn (1995) 23 New Zealand native plant species provide honey bees with surplus honey stores. Out of these, 9 native plants provide the basis for larger or smaller mono-floral (or special) honey product lines. Besides the above-mentioned manuka and rewarewa honey, these honeys are based on: rata (*Metrosideros perforate*, *Metrosideros robusta*, *Metrosideros umbellata*), pohutakawa (*Metrosideros excelsa*), kanuka (*Kunzea ericoides*), kamahi (*Weinmannia racemosa*) and tawari (*Ixerba brexioides*).

There are significant practical barriers for the economic production of high-quality mono-floral honey for some of these species:

- The flowering season of pohutukawa overlaps with manuka, creating a potential conflict with production of the higher-priced honey.
- Large established and underutilised native stands of rata and kamahi are located on the South Island's West Coast, and in other smaller locations around New Zealand. These may remain the cheaper alternative for mono-floral honey production, compared to managed stands such as PRBs, for a considerable time yet.
- As with manuka, production of high-quality mono-floral kanuka honey is only possible where there is a relative dominance of kanuka flowers compared to alternative sources of nectar, which may be impossible to achieve on a PRB in an intensively farmed catchment.
- Tawari has the advantage that, like rewarewa, it is a very much preferred honey source for bees. It should therefore be possible to produce a high-quality mono-floral honey even in the presence of alternative nectar and pollen sources for the bees. The price of mono-floral tawari honey falls between rewarewa and high UMF manuka honey. However, tawari is restricted to the upper half of the North Island, and appears to be very difficult to plant and raise outside its natural forest environment. An entry in the New Zealand Plant Conservation Network database (New Zealand PCN 2005), suggests that tawari may be mycorrhizal and that this can be overcome when co-planted with kapuka (*Griselinia littoralis*). However, this has so far not been proven at scale.

In conclusion, despite several promising options to produce high value mono-floral honey on PRBs, many challenges remain. Rewarewa honey production seems to be currently the most promising and is also well aligned with the overall environmental goals of the PRB concept, not least because of the advantageous growth form of the rewarewa tree providing early shading and the potential for future timber harvests as a co-product and insurance policy.

5.7 Fruits, nuts and other food products

Advantages:

- A wide range of species and varieties may be suitable.
- Harvest is non-invasive, causing little damage to riparian flora, fauna and environmental performance.
- Long, narrow shape of riparian buffers means fruit is accessible to mechanical harvesting equipment.
- Marketing pathways are well-established.

Limitations:

- Management in riparian zones may involve some special considerations in addition to typical orchard management.
- Little published information specific to growing in riparian areas.

Conclusions: high potential to add value to PRB.

Preferred species: Many. Varies by region.

A wide range of fruit and nut trees are potentially suitable riparian crops, and in contrast with forestry species, harvesting can usually be carried out non-invasively. There is little peer-reviewed literature available that is specific to the growing of fruit trees in riparian areas in New Zealand. Most available information is shared informally through media such as nursery information sheets, lifestyle magazines or organisations like the New Zealand Tree Crops Association and Tropical Fruit Growers Association.

One of the main challenges in planting a fruit crop is deciding what to plant, as appropriate species can vary greatly with factors such as climate (especially in relation to temperature and frost), soil type, and local pests and diseases. Southern Woods Nursery[1] recommends different varieties of selected fruit trees in different regions of New Zealand (Table 5).

In Northland, the Tropical Fruit Growers Association is promoting the planting of bananas, pineapples and other tropical fruits. They note that these species adapt well to Northland's climate and although they ripen more slowly than in the tropics, selling locally means that the fruits can ripen naturally and as a result be denser and more nutritious. They propose planting bananas on dairy farms, particularly around effluent ponds, noting that all parts of the plant are also edible for cattle[2].

Management of fruit tree species also varies by region, therefore local advice, particularly from local nurseries, is essential. However, management in riparian areas requires some special considerations in addition to typical orchard management, particularly in relation to the use of nutrients, pesticides

[1] https://www.southernwoods.co.nz/uploads/content/files/Info6-FruitTrees-RecommendedvarietiesbyRegion_000.pdf

[2] https://www.tropicalfruitgrowers.nz/

and herbicides. For example, multi-tiered buffers are generally recommended for riparian areas in order to maximise interception of nutrient (and other contaminant) flows. Herbicide and pesticide treatment may need to be minimised because of the proximity to waterways. For these reasons, the selection of pest and disease resistant options, and a diverse selection of fruit and/or nut trees may be particularly important in riparian zones, although this needs to be balanced with economic as well as practical harvesting requirements. Multiple use species are worth considering due to the additional value they could bring. Pine nuts and hazelnuts, for example, are both robust species with a high value crop, as well as useful wood.

Table 5: Recommended fruit tree varieties by New Zealand region. (Source: Southern Woods plant nursery).

Northern NZ *Climate characteristics:* Semi-subtropical. Humid & warm. Few frosts during winter. Low chill varieties.	**Mid NZ** *Climate characteristics:* Temperate. Frosts during winter. Warm summers.	**Southern NZ** *Climate characteristics:* Temperate. Regular frosts & possible snow during winter & spring. Warm summers. Cool autumns.
Apples Low chill varieties: 'Baujade', Egremont Russet', Freyberg', 'Fuji', 'Gala', 'Granny Smith', 'Initial', 'Kidd's Orange Red', 'Oratia Beauty', 'Peasgood Nonsuch', 'Tydeman's Late Orange', 'Winter Banana', 'Worcester Pearmain'	All varieties: Recommended Rezista varieties with natural disease resistance and heritage varieties. 'Initial', 'Baujade', 'Prima', 'Priscilla', 'Peasgood Nonsuch', 'Monty's Surprise'	
Apricots Low chill varieties: 'Katy Cot', 'Royal Rosa', 'Trevatt'	All varieties: Recommend: 'Moorpark', 'Trevatt', Royal Rosa'. Dwarf varieties: 'Aprigold', 'Golden Glow'	
Advocados All varieties: 'Hass', 'Reed'	All varieties: Protect from frosts.	Not suitable: (or frost-free micro-climate)
Cherries 'Lapins'	All varieties: Recommend: 'Stella', 'Lapins'	
Citrus All varieties	All varieties: but less hardy types like limes need to be protected from frost.	Hardier varieties like: Lemons 'Meyer'. Grapefruit 'Golden Special'. Mandarin 'Miho'. Grow others in pots to bring indoors.
Dwarf Stonefruit All varieties		All varieties: except 'Rose Chiffon'
Feijoas All varieties. Recommend: 'Anatoki', 'Kaiteri', 'Apollo', 'Wiki Tu'	All varieties. Recommend: 'Anatoki', 'Kaiteri', 'Apollo', 'Wiki Tu'	Early season varieties: 'Anatoki', 'Kaiteri', 'Unique', 'Pounamu'
Figs All varieties		Early figs: 'Brown Turkey', 'Brunswick'
Loquats All varieties: Recommend 'Wiki Gold'		
Medlars Medlar are suitable for all areas.		

Nashi All varieties. Recommend 'Hosui', 'Nijiseiki'		
Nectarines 'Fantasia', 'Snow Queen'	All varieties. Recommend 'Fantasia', 'Queen Giant', 'Red Gold', 'Theo Ching'	
Olives All varieties		Hardy varieties. 'Frantoio', 'Leccino'
Peaches 'Blackboy', 'Golden Queen', 'Redhaven', 'Wiggins'	All varieties. Recommend 'April White', 'Blackboy', 'Gordons Glory', 'Red Haven'	
Pears 'Winter Cole'	All varieties. Recommend 'Beurre Bosc', 'Packham's Triumph', 'Taylor's Gold'	
Persimmons All varieties. Recommend 'Fuyu'		
Plums Low chill varieties. 'Burbank', 'Damson', 'Duff's Early Jewel', 'Elephant Heart', 'Purple King', 'Santa Rosa', 'Satsuma', 'Torwick'	All varieties. Recommend 'Black Doris', 'Burbank', 'Elephant Heart', 'Omega', 'Santa Rosa'. Prune Plums: 'Italian', 'Stanley'	
Quinces All varieties. Recommend 'Smyrna', 'Van Deman'		
Sapote All varieties. Recommend 'Wiki Woo'		
Almonds Low chill varieties. 'All in One', 'Garden Prince' (dwarf)	All varieties. Recommend 'All in One', 'Garden Prince', (dwarf), 'Monovale'	Not recommended due to the high risk of very early spring flowers being frosted.
Chestnuts All varieties. Recommend '1002', '1005', '1015'		
Hazelnuts Not suitable in high humidity.	All varieties.	
Macadamias All varieties.	All varieties. Protect from frost.	Not suitable due to frost tenderness.
Pecans Not recommended due to high chilling requirements.	All varieties.	
Pinenuts Suitable for all areas. *(Pinus pinea)*		
Walnuts All varieties, though high humidity can cause disease problems.	All varieties.	

There may be niche applications for New Zealand native plants on PRBs cultivated as spices and beverages. These niches have growth potential, and a clear linkage with New Zealand's booming tourism industry.

- Kawakawa (*Piper excelsum*) is increasingly used in New Zealand both for the brewing of a leaf infusions (tea) as well as seasoning / flavouring agent for many foods and beverages (Butts et al. 2019).
- Dried horopito (bush pepper) leaf is already sold commercially at a small scale as a seasoning for red meat, as well as for the brewing of savoury teas.
- Purangi Estate on the Coromandel Peninsula has in the past exported a manuka leaf-based tea to Japan (RNZ 2012).
- Purangi Estate also considers a speculative potential for the production of a New Zealand grown coffee, based on the seeds of Karamu (*Coprosma spp*.) a plant botanically related to the Arabian coffee shrub (*Coffea arabica*).

Currently the small volumes of these products are either collected as wild foods or harvested opportunistically from existing resources. An expansion of production may require more systematic cultivation, and PRBs would be ideally suited to facilitate this, since PRBs could incorporate the target species with little effort or loss of functionality. As for most high value, low volume PRB configuration, while the economics may be favourable, the overall environmental benefits of cultivating these native food plants would be small, indicating that integration with other PRB uses would be favourable compared to mono-culture cultivation on any zone of the buffer.

5.8 Plants for fragrances, medical and speciality chemicals

Advantages:

- Sales diversify the farm business.
- For most products mechanised harvest is already possible or could be developed relatively easily.
- One of the few productive uses for native species.
- Manuka essential oil is potentially a high value product with a proven market.
- Long, narrow shape of riparian buffers means plants are accessible to mechanical harvesters.
- Bulk biomass harvest removes a lot of nutrients from the buffer.

Limitations:

- Apart from manuka essential oil, all other products have under-developed markets, or are in the basic research stage.
- Industry cooperation required for market development. Farmer cooperation required to achieve economies of scale.
- In most cases a monoculture would be required to make harvesting practical.
- The highest-value extract products are from species that are very slow-growing or are not suited to riparian buffers (e.g., mountain plants).

Conclusions: Manuka essential oil shows high potential. This product is well-suited to PRB because in a riparian strip plants are accessible to mechanical harvesters. However, much more research needed on the product itself, harvest methods, extraction methods, and market development.

Preferred species: Manuka. Kanuka may also be suitable.

5.8.1 Manuka essential oil extraction

Manuka essential oil is a generic term for the non-water miscible fraction of condensate extracted from manuka foliage via mild steam distillation. This non-uniform natural product has a wide range of beneficial properties and therefore uses, ranging from its use as a fragrance in room perfume and scented candles to beauty products including massage oils and hair shampoo to medical applications for the treatment of head lice and intestinal worms. Manuka essential oil quality and quantity varies widely between different growth locations and plant strains. The target essential oil is only found in green foliage (not in bark or stem material) and the best essential oil yields are obtained from plantations no taller than 3m and younger than 7 years, although regular trimming (harvesting) can extend the useful life of a manuka plantation for essential oil extraction (Saunders 2017). Well managed stands can be harvested every year or every second year, primarily during spring and early summer.

The manuka essential oil industry is much less developed and professionalized than the manuka honey industry so the economics are not certain and are subject to rapid change. Saunders (2017) estimates that (generally manual) harvesting of manuka foliage comprises about 50% of the total production cost for manuka essential oil (Figure 7). Small scale distillers are reported to pay NZ$500 – 600 per tonne of good quality harvested manuka foliage, which may yield 3 – 5 kg manuka essential oil. Essien et al. (2019) report that manuka essential oil yields vary throughout the season, being highest in April (0.6%) and lowest in October (0.2%).

After essential oil extraction, further use of manuka biomass is largely limited to uses as green manure or mulch. As the biomass is water-saturated after steam treatment, use as biomass fuel or as bedding material (composting barn) would require energy intensive and costly drying, while use as fodder for ruminants could only be considered as maintenance feed for drystock, because of manuka's low digestibility and palatability (Lambert et al. 1989b).

The biomass yields of manuka foliage for essential oil extraction, and the nutrient removal from the riparian buffer achieved through this harvest can be estimated from field studies. In studies of forage shrub production as a dry stock supplement at the Ballantrae Hill Country Research Station, Manawatu, Lambert et al. (1989a, 1989b) established experimental hedge rows of various forage shrub species over 2.5 years. At the start of the experimental period the manuka hedge row was trimmed to nominal dimensions of 62 cm height and 34 cm width. Forage shrub yields were compared to pasture growth yields determined in adjacent grazed paddocks using a trim technique and semi-mobile 0.5 m^2 exclosure frames. Lambert et al. (1989a) determined the hill country pasture growth as 8.4 t DM/ha/y and the productivity of manuka forage (leaf) from the hedge row as only a third of that (140±26 g/m row for manuka vs 422±33 g DM/m row equivalent for pasture), indicating a manuka foliage productivity of about 2.8 t DM/ha/y. However, manuka produced an additional 189±34 g DM/m row of stem material, equivalent to another about 3.8 t DM/ha/y stem biomass. It was observed that manuka DM yields were higher when manuka foliage was harvested only once per year instead of four times. Lambert et al. furthermore observed that >85% of annual total manuka growth occurred during the spring and summer quarters, while (unlike pasture) growth ceased completely over the winter quarter.

Lambert et al. (1989b) determined the total nitrogen and total phosphorus concentration of manuka leaves as 1.5% N and 0.10% P and manuka stems as 0.7% N and 0.05% P, respectively. These concentrations were confirmed by Reis (2015) who found manuka leaf concentrations of 1.2 - 1.6% N and 0.08 – 0.15% P, for manuka control plants grown in different soils. Fertilization with bio-solids increased leaf N and P concentrations by 25% to 100%. Extrapolating from these numbers, we estimate that an annual harvest of 6.6 t DM manuka, consisting of 2.8 t DM leaf and 3.8 t DM stem material would remove 69 kg N and 5 kg P per year from 1 ha productive riparian buffer planted in manuka. These values are substantial and indicate that regular manuka biomass harvest for essential oil extraction from a riparian buffer would effectively prevent a riparian buffer from becoming nutrient saturated. However, it appears that growth stops completely over the winter quarter

(Lambert et al. 1989a), which suggests limited nutrient absorption by manuka during this critical time of year.

Practical management of manuka for essential oil extraction on a PRB would be accommodated best in 3 to 8 m wide strips of manuka on Zone 3. Mechanical harvesting could be facilitated at fence post height with hedge cutters or mulchers on hydraulic booms, fitted with an air suction system to collect the harvested biomass in bin or trailer.

Figure 7: Manual harvest of manuka foliage from un-managed stands. (Source: Saunders 2017).

5.8.2 Other New Zealand natives essential oil extraction

Kanuka and many other species have potential for producing essential oil. Saunders (2017) speculates that kanuka can be cultivated for essential oil extraction analogous to manuka essential oil. However, while kanuka essential oil has slightly different properties that should make it more valuable, the market for kanuka essential oil is even less developed and knowledge gaps in regard to cultivation and harvesting, distillation and marketing are even larger than for manuka essential oil production. Essien et al. (2019) concur that research and market development in kanuka essential oil is underdeveloped relative to manuka, but note that commercialization of kanuka essential oil should be aided by its superiority in terms of anti-inflammatory properties, and higher essential oil yield per unit foliage compared to manuka. However, overall kanuka essential oil yield may be more variable from year to year.

Totara, due to its above-average growth rates and ability to be grown in a hedge configuration, which simplifies mechanized biomass harvest on a PRB (Bergin and Gea 2007). Alternatively, the prunings and thinnings of totara grown for timber or fence posts could be used for essential oil extraction. The extraction process would be the same as for manuka essential oil extraction (low pressure steam extraction) and existing equipment could be used for both species. However, no information on expected totara essential oil yield is available, and there is currently no established market for this product, which complicates valuing of the resultant totara essential oil product.

Pittosporum species, particularly lemonwood (*Pittosporum eugenioides*), have potential but yields are low. Weston (2004) analysed steam extracted essential oils from 7 *Pittosporum* species. He determined that New Zealand lemonwood has a unique essential oil composition among the group, as well as in comparison to other fragrance extracts, based on the major essential oil components of octyl acetate, terpinen-4-ol and decanol. Weston (2004) concludes that lemonwood essential oil could be considered as the basis for a potentially unique New Zealand fragrance due to its "lemon-like" aroma and significant cultural significance. Lemonwood foliage regenerates so readily, it is conceivable that it could be grown as a fragrance crop, however, the yields of the oils were considered too low to attract commercial interest (Weston 2004). Regarding riparian plantings of *Pittosporum eugenioides*, dense or mono-culture plantings of lemonwood very quickly shade out all understorey growth of grasses, herbs and other smaller cover plants, which can substantially increase the erosion risk from areas under lemonwood cover over relatively short periods of time (pers. com. Warren Coffey, Waikato Regional Council Catchment Management Officer, 2018).

Further New Zealand species with at least theoretical future potential for essential oil extraction include kauri (*Agathis australis*), karo (*Pittosporum crassifolium*), kawakawa (*Piper excelsum*), miro (*Pruminopitys ferruginea*), silver pine (*Manoao colensoi*), bog pine (*Halocarpus bidwillii*) and kawaka (*Libocedrus plumose*), however at present no information about essential oil yields of these species is available. In addition, cultivation on PRBs may be difficult due to climatic species restrictions (especially for kauri, silver pine), and very low growth rates (especially silver pine, bog pine, kawaka).

5.8.3 New Zealand flax extracts

Flax (*Phormium* spp.) have potential to produce fine chemical extracts for the lifestyle, health and beauty market. Flax gel and flax seed oil are two identified products.

Flax gel (pia harakeke) is an exudate found in the leaf butt, comprised mostly of sugars (polysaccharides), specifically acidic xylans with highly branched side-chains. Flax gel has been researched as a standardised thickener for cosmetics, and some high value, small volume natural beauty product lines have started to incorporate pia harakeke. Its utilisation in this regard is aided by the fact that the material can be air dried and preserved and re-constituted with water without loss of quality (McGruddy 2006).

Phormium spp. seed oil has potential applications as a high-grade culinary oil, or as a base oil in the cosmetics industry, similar to almond oil, with target values of tens of dollars per litre. New Zealand flax seeds contain 20 – 30% oil, making them suitable for cold press extraction with conventional equipment like auger screw presses. Flax seed yields may be as high as 1 t/ha/y, however McGruddy (2006) reports of very erratic and variable seed yields, including several years per decade with barely any yield at all.

Because of the unpredictability of flax seed oil yields, and the difficulty of realizing stable returns, McGruddy (2006) suggests that the most practical development pathway for both New Zealand flax seed oil and pia harakeke, would be to opportunistically extract both products at a central flax processing facility deriving its main income from flax fibre products. Other fine chemicals, such as musizin, aromatic glycosides, anti-fungal compounds, cucurbitans, polyphenolics, etc., may be extracted from *Phormium* spp. in the future (McGruddy 2006), however these undertakings may again be best aligned with a more general flax fibre processing chain providing a base income as well as logistics.

5.8.4 Wood extracts

High-value bio-products can be extracted from pink pine (*Halocarpus biformis*) and totara heartwood. Pink pine is a small endemic New Zealand forest tree of cooler and higher altitude climates, occurring sporadically from the NI Central Plateau to Stewart Island. It contains the compound manool which is a functional bio-product characterised by a strong scent and fixative properties. Manool can be converted to amberketals and other compounds highly valued in the perfume industry. The value of these fine chemicals is in excess of NZ$1,000/kg. Dunedin company Westchem Industries Ltd. uses a hexane extraction process to obtain manool from recovered pink pine heart wood logged on the SI West Coast shortly after World War 2 (Goldsmith 2017). Pink Pine has an extremely slow growth rate of only about 1cm/year and may require 100 years or more to reach maturity at which point the extraction potential for manool becomes realisable (Goldsmith 2017). Despite its attractive product value, pink pine would therefore not be an ideal fit for PRBs, since it's slow growth rate would provide few immediate environmental benefits and financial returns may not be realized for centuries.

A very close analogue to pink pine manool is a fine chemical extract from totara heart wood. Wairarapa company Mende Biotech Ltd. extracts a fine chemical from recycled totara heart wood, since termed "Totarol", which has antibacterial, anti-inflammatory and antioxidant properties. Totarol is currently used in lifestyle and beauty products and may have scope for future medical applications, i.e., for the treatment of skin diseases and antibiotic resistant germs (Mende Biotech Ltd. 2019). While the growth rate of totara is much higher than that of pink pine, the formation of large proportions of totara heart wood, worthy of extraction, would easily take 100 years or more (Bergin 2003), again limiting the scope for production of totara heart wood for chemical extraction on PRBs. Furthermore, since totara used to be an abundant native species throughout New Zealand, large stocks of recycled totara timber for Totarol extraction will be available for decades to come.

5.8.5 Medicinal plants

There is potential for species grown in riparian buffers to provide health benefits for both humans and animals. A range of plants have been shown to have potential phytotherapy benefits for animals, particularly in the treatment of parasites (see e.g., Davidović et al. 2012).

New Zealand native plants have a wide range of potential medicinal uses. Considerable knowledge of these uses has been passed down over many generations by Māori rongoā practitioners. Many of these medicinal plants are trees and shrubs which could be grown on a PRB.

The diversity of conditions (wet and dry, exposed and shaded) found in riparian areas allows for the simultaneous cultivation of a large range of plants, including the majority of the >40 plants described by Beresford (2012).

Cultivation of New Zealand native plants on PRBs for pharmaceuticals and Western medical cures is currently limited. However, it could represent a valuable industry in the future, not least due to the high endemism among New Zealand plants, and uniqueness of New Zealand native ecology. Some potential examples include:

- Falcarindiol, a highly potent antifungal agent, which has been isolated in high levels from the leaf of pate / seven-finger (*Schefflera digitate*; Muir et al. 1982).

- Polygodial, an anti-fungal agent, found in extracts of pepperwood / horopito (*Pseudowintera colorata*; Calder et al. 1986).
- Acyl-phloroglucinol derivatives (with anti-viral properties) and eudesmol (with anti-microbial properties), both found in kanuka essential oil (Essien et al. 2019).
- Piperine analogs and ligans, both extractable from kawakawa (*Piper excelsum*) have potential uses for regulating glucose metabolism and as an insecticide, respectively (Butts et al. 2019).
- The antifungal and anti-inflammatory substance musizin, as well as two cucurbitans with anti-leukaemia activity, found in hexane and ethanol extracts of *Phormium* spp. (McGruddy 2006).

Many of the New Zealand natives containing these products can easily be cultivated on a PRB and have already been mentioned in the context of other productive uses.

Safety/regulatory hurdles in the phyto-medical arena are very high (McGruddy 2006), so considerable expertise and financial resources may be required to take any of the active substances in the plants listed above through the long process of testing, accreditation and certification for commercial medicinal purposes.

5.9 Carbon farming

Advantages:

- Potentially provides an additional income stream from trees already planted for other purposes.
- Could be an enabler for other PRB uses, providing income while other products mature.
- No harvest so no new technology needed and no harvest damage to the buffer.

Limitations:

- Width rule excludes all but the very largest riparian buffers from generating carbon credits.
- Rules could change in future adding regulatory risk.
- Compliance cost and effort is high relative to prospective earnings.

Conclusions: Carbon farming is very risky and unsuitable for almost all PRB configurations.

Preferred species: Long-lived, fast-growing species, e.g., totara, kauri, maple, walnut, redwood.

Theoretically, it is possible for riparian buffers in New Zealand to earn "carbon credits" (NZU) under the Permanent Forest Sink Initiative (PFSI) (MPI 2015). However, it was announced on the 17th of December 2018 that the PFSI will be discontinued and replaced with a new post-1989 forest activity scheme.

The PFSI (and likely any replacement scheme) was not aimed at small scale "carbon credit" generation such as from riparian buffers, but clearly focused on large forested landholdings. In order for a block of afforested land to be eligible for the PFSI:

- The land must not have been in forest at 31 December 1989, and there must have been a change of land use from non-forest to eligible forest since 31 December 1989.
- Active steps such as planting, seeding or facilitating natural regeneration must have been taken.
- The minimum land area is at least one hectare that has, or will have at maturity, tree crown cover of more than 30 percent in each hectare, stocked with trees that have the potential to reach a minimum height of five metres at maturity.
- The trees must not be in forest or shelterbelts less than 30 metres wide on average, and forest which is less than 30 metres wide on average (MPI 2015).
- The land may have undergone partial harvest, provided 80% of the pre-harvest basal area is retained (MPI 2015).

While PRBs can fulfil the requirements regarding canopy cover, tree height, and total area, the requirement for 30 m width would exclude most current riparian buffers. For blocks less than 100 ha in size, carbon stocks will be estimated according to Table 2 of the Climate Change (Forestry Sector) Regulations 2008 (SR 2008/355). For indigenous forest the table gives a per ha carbon stock (CO_{2equi}) of 40.2 t at age 10, 158.7 t at age 20, 257.5 t at age 30 and 323.4 t at age 50. Assuming a carbon price of NZ$20/t CO_{2equi} earnings from carbon credits would be NZ$800 after 10 years, and NZ$3,200 after 20 years. Considering compliance costs of several thousand dollars for initial registration with the scheme and on-going compliance effort (MPI 2015), earning carbon credits is unlikely to be economical or feasible for even some of the widest PRBs.

6 Discussion and conclusions

Many products could potentially be harvested from a riparian buffer to yield a valuable resource or financial return for the farming system. These products, and the species that could yield them, are summarised in Appendix A. This report confirms that multiple productive and environmental benefits can be achieved through a combination of plant species. The best product or mix of products will be different for different farms, as financial return, practicality and environmental performance all vary with environmental factors, farming systems and proximity to markets. Most peer-reviewed research has focused on large scale commercial monoculture production, and small-scale multipurpose systems may have additional benefits that are not yet widely understood.

Productive riparian buffers can provide resilience to the farming system in a number of ways. A particular strength of the productive riparian buffer concept is that most of the species under consideration have multiple potential uses. Multiple uses not only provide multiple income or resource streams, but also help to mitigate risks. If the primary use fails or proves not to be economic (e.g., due to market dynamics or time to maturity), then another use or product can provide a "fall back". Products sold beyond the farm gate provide for diversification of the farm business. However, options that can be incorporated into existing farm system provide additional resources to the system itself, for example additional feed options. In many cases, farmers will already have knowledge of how to grow, maintain, harvest and use the product.

The values of riparian buffers extend beyond income generation and environmental/ecological benefits. Other values include enhancing the landscape qualities of a farm, providing culturally important species for Māori (such as flax for raranga/weaving and various plants for rongoā/medicine), improving recreational values of waterbodies, and providing opportunities for interaction with others in the local community.

The productive riparian buffers concept requires balancing productive harvest with environmental considerations. Some of the products involve environmental risk, either as harm to the riparian flora and fauna, or temporary reduction in the environmental benefits they provide to the adjacent waterbody. For example, harvest of products such as timber may involve disturbance to soil, stream shade and riparian habitat; cultivation of fruit may require herbicides or insecticides that could enter the water. Nutrient application and the growth of leguminous species should be avoided for riparian areas where environmental goals include nitrogen removal. However, extractive harvest can also provide some enhancement of environmental services. For example, products such as herbaceous feed, tree fodder, wood chip and timber that are harvested in high volumes can help remove nutrients from riparian zones and prevent nutrient saturation of soils. The ideal scenario is to harvest these products with as little disturbance to the PRB as possible.

For many PRB products, mechanical harvesting will be needed. A few products (such as herbaceous feed) can use existing harvesting technologies, and these can be incorporated into PRBs immediately. However, in many cases mechanical harvesting requires either adaptation of existing technologies or development of new technologies. In some cases, the main issue is choosing which technology to invest in.

There are large differences in the time to maturity (first and subsequent harvests) among different products. The most rapid returns are provided by herbaceous feed, which can be harvested multiple times per year. Harvest of tree fodder may begin after as little as three years, whereas harvest of native timber may require up to 100 years. Growth rates will affect not only financial returns but also environmental performance, as environmental services such as shading require trees to have reached a certain level of maturity.

In summary, we recommend that PRB design remain flexible, providing multiple benefits that are matched to the farming system, local environmental issues and local demand for products.

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8 References

Abernethy, B., Rutherfurd, I.D. (2000) The effect of riparian tree roots on the mass-stability of riverbanks. *Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group*, 25: 921-937.

Albrecht, G., Sartore, G-M., Connor, L., Higginbotham, N., Freeman, S., Kelly, B., Stain, H., Tonna, A., Pollarg, G. (2007) Solastalgia: the distress caused by environmental change. *Australasian Psychiatry*, 15: Suppl 1: S95-8.

Bee, J., Kunstler, G., Coomes, D. (2007) Resistance and resilience of New Zealand tree species to browsing. *Journal of Ecology*, 95: 1014–1026.

Beets, P., Pollock, D. (1987) Uptake and accumulation of nitrogen in pinus radiata stands as related to age and thinning. *New Zealand Journal of Forestry Science*, 17(2/3): 353-71.

Beresford, R. (2012) The Rongoa Maori Booklet: Medicinal Native Plants of New Zealand. *Otago University School of Pharmacy*, Dunedin, New Zealand. https://05c.blogtown.co.nz/wp-content/blogs.dir/866/files/2012/09/Rongoa-maori-bklet-Otago1.pdf

BERG (2018) Report of the Biological Emissions Reference Group. https://www.mpi.govt.nz/dmsdocument/32125/loggedIn

Bergin, D., Gea, L. (2007) Native Trees – Planting and early management for wood production. *New Zealand Indigenous Tree Bulletin,* No. 3, published by the New Zealand Forest Research Institute, Rotorua.

Bergin, D. (2003) Totara – Establishment, growth and management. *New Zealand Indigenous Tree Bulletin*, No. 1, published by the New Zealand Forest Research Institute, Rotorua.

Buchanan, P., Barnes, J. (2001) The Mushroom Industry in New Zealand. *Summary report compiled for the International Society of Mushroom Science.* http://www.isms.biz/articles/the-mushroom-industry-in-new-zealand/

Burrows, L., Wakelin, S., Quinn, J., Graham, E., Mackay, A. (2018) Carbon sequestration potential of non-ETS land on farms. *Landcare Report for Ministry of Primary Industries* LC3161: 75.

Butts, C., van Klink, J., Joyce, N., Paturi, G., Hedderley, D., Martell, S., Harvey, D. (2019) Composition and safety evaluation of tea from New Zealand kawakawa (Piper excelsum*). Journal of Ethnopharmacology*, Volume 232: 110-118.

Butz-Huryn, V. (1995) Use of native New Zealand plants by honey bees (Apis mellifera L.): A review. *New Zealand Journal of Botany*, 33: 4: 497-512.

Calder, V., Cole, A., Walker, J. (1986) Antibiotic compounds from New Zealand plants. III: a survey of some New Zealand plants for antibiotic substances. *Journal of the Royal Society of New Zealand,* Volume 16, Number 2: 169-181.

Charlton, J., Douglas, G., Wills, B., Prebble, J. (2003) Farmer experience with tree fodder. *Grassland Research and Practice Series,* No. 10.

Chizinski, C., Vondracek, B., Blinn, C., Newman, R., Atuke, D., Fredricks, D., Hemstad, N., Merten, E., Schlesser, N. (2010) The influence of partial timber harvesting in riparian buffers on macroinvertebrate and fish communities in small streams in Minnesota, USA. *Forest Ecology and Management*, Volume 259, Issue 10: 1946-1958.

Collier, K., Cooper, A., Davies-Colley, R., Rutherford, J., Smith, C., Williamson, R. (1995) Managing Riparian Zones: A contribution to protecting New Zealand's rivers and streams. Volume 1: *Concepts*. Department of Conservation. Wellington, New Zealand: 40.

Collier, K.J., Smith, B.J. (1995) Sticky trapping of adult mayflies, stoneflies and caddisflies alongside three contrasting streams near Hamilton, New Zealand. *New Zealand Natural Science,* 22: 1-9.

Collins, R.C., Donnison, A., Ross, C., McLeod, M. (2004) Attenuation of effluent-derived faecal microbes in grass buffer strips. *New Zealand Journal of Agricultural Research*, 47: 565–574.

Cooper, A.B. (1990) Nitrate depletion in the riparian zone and stream channel of a small headwater catchment. *Hydrobiologia*, 202: 13–26.

Cooper, A.B., Smith, C.M., Smith, M.J. (1995) Effects of riparian set-aside on soil characteristics in an agricultural landscape: Implications for nutrient transport and retention. *Agriculture, Ecosystems and Environment*, 55: 61–67.

Crowe, A. (1992) *Which Native Tree? A Simple Guide to the Identification of New Zealand Native Trees*. Penguin Books, New Zealand.

DairyNZ 40-062: Getting riparian planting right in the Waikato - Your step-by-step guide for successful riparian planting. *Dairy New Zealand Technical Paper,* 40-062, available online: https://www.dairynz.co.nz/media/660477/waikato_riparian_management.pdf

DairyNZ (2018) Pre-graze mowing. https://www.dairynz.co.nz/feed/pasture-management/pre-graze-mowing?_cldee=cy5oZXViZWNrQG5pd2EuY28ubno%3d&recipientid=contact-b80837a8679de11190de005056ba0008-f88f6b78f0034dfcb7c0854b3ae4fbf2&utm_source=ClickDimensions&utm_medium=email&utm_campaign=Regional+e-newsletter+-+Waikato&esid=224590f8-e0db-e811-a96d-000d3ae129d7

Dadson, S.J., Hall, J.W., Murgatroyd, A., Acreman, M., Bates, P., Beven, K., Heathwaite, L., Holden, J., Holman, I.P., Lane, S.N. (2017) A restatement of the natural science evidence concerning catchment-based ‘natural’ flood management in the UK. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 473: 20160706. http://dx.doi.org/10.1098/rspa.2016.0706

Davidović, V., Joksimović, M., Stojanović, B., Relić, R. (2012) Plant usage in protecting the farm animal health. *Biotechnology in Animal Husbandry*, 28(1): 87-98. DOI: 10.2298/BAH1201087D

Davies-Colley, R.J. (1997) Stream channels are narrower in pasture than in forest. *New Zealand Journal of Marine and Freshwater Research*, 31: 599-608.

Davies-Colley, R.J., Quinn, J.M. (1998) Stream lighting in five regions of North Island, New Zealand: control by channel size and riparian vegetation. *New Zealand Journal of Marine and Freshwater Research,* 32(4): 591-605.

Diaz-Rainey, I., Tulloch, D. (2016) Carbon pricing and system linking: Lessons from the New Zealand Emissions Trading Scheme. *Energy Economics*, 73, (2018): 66–79.

Dickinson, N., Marmiroli, M., Das, B., McLaughlin, D., Leung, D., Robinson, B. (2015) Endemic Plants as Browse Crops in Agricultural Landscapes of New Zealand*. Agroecology and Sustainable Food Systems*, 39: 224–242.

Dosskey, M.G., Vidon, P., Gurwick, N.P., Allan, C.J., Duval, T.P., Lowrance, R. (2010) The Role of Riparian Vegetation in Protecting and Improving Chemical Water Quality in Streams. *JAWRA Journal of the American Water Resources Association*, 46(2): 261-277.

Dosskey, M.G. (2001) Toward quantifying water pollution abatement in response to installing buffers on crop land. *Environmental Management,* 28: 577-598.

Douglas, G., McIvor, I. (2013) Poplar and willow as supplementary fodder sources. *New Zealand Tree Grower*, November 2010.

Duehr, J.P., Siepker, M.J., Pierce, C. L., Isenhart, T.M. (2006) Relation of Riparian Buffer Strips to In-Stream Habitat, Macroinvertebrates and Fish in a Small Iowa Stream. *Journal of Iowa Academy Sciences*, 113: 49–55.

Emile, J.C., Delagarde, R., Barre, P., Novak, S. (2016) Nutritive value and degradability of leaves from temperate woody resources for feeding ruminants in summer. *3rd European Agroforestry Conference.* INRA, Montpellier, 23-25 Mai 2016, France: 409-412. https://euraf.isa.utl.pt/files/pub/docs/silvopastoralism_52_emile.pdf

Environment Waikato (2002) *Trees on Farms: a guide with local experience of growing trees in the Waikato Region.* Retrieved 31-3-2019 from https://www.waikatoregion.govt.nz/Community/Your-community/For-Farmers/Waterways-and-wetland-management/Trees-on-farms

Essien, S., Baroutiana, S., Dell, K., Young, B. (2019) Value-added potential of New Zealand mānuka and kānuka products: A review. *Industrial Crops & Products,* 130:198–207.

Fisher, K., Jacinthe, P.A., Vidon, P., Liu, X., Baker, M.E. (2014) Nitrous oxide emission from cropland and adjacent riparian buffers in contrasting hydrogeomorphic settings*. Journal of Environmental Quality*, 43: 338–348.

Florsheim, J.L., Mount, J.F., Chin, A. (2008) Bank erosion as a desirable attribute of rivers. *BioScience*, 58: 519-529.

Fortier, J., Truax, B., Gagnon, D., Lambert, F. (2015) Biomass carbon, nitrogen and phosphorus stocks in hybrid poplar buffers, herbaceous buffers and natural woodlots in the riparian zone on agricultural land. *Journal of Environmental Management*, Volume 154, 1 May 2015: 333-345.

Franklin, H.M., Dickinson, N.M., Esnault, C.J., Robinson, B.H. (2015a) Native plants and nitrogen in agricultural landscapes of New Zealand. *Plant and Soil,* 394(1-2): 407-420.

Franklin, P., Smith, J., Baker, C., Bartels, B., Reeve K. (2015b) First observations on the timing and location of giant kokopu (Galaxias argenteus) spawning. *New Zealand Journal of Marine and Freshwater Research*, 49: 419–426.

Frey, G. (2014) The Basics of Hardwood-Log Shiitake Mushroom Production and Marketing. *Publication* ANR-102P, produced by Communications and Marketing, College of Agriculture and Life Sciences, Virginia Polytechnic Institute and State University. https://www.pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/ANR/ANR-102/ANR-102-pdf.pdf

Groenestein, C. (2018) Rewarewa being planted in South Taranaki for honey project*. Stuff newspaper article published 28th September 2018.* https://www.stuff.co.nz/taranaki-daily-news/news/107410412/rewarewa-being-planted-in-south-taranaki-for-honey-project.

Goldsmith, S. (2017) Pink Pine (Halocarpus biformis): A Commercial Opportunity for Ngāi Tahu. *Workshop presentation of a University of Canterbury MBA project,* 21 February 2017, Christchurch, New Zealand. Video recording: https://www.youtube.com/watch?v=dqpzAov_Okk

Hall, P., Gifford, J. (2008) Bioenergy options for New Zealand. *A situation analysis of biomass resources and conversion technologies prepared by Scion Research*, Rotorua, New Zealand.

Halliwell, G. (1979) A Guide to Tree Forage Crops. *Advisory Services Division, Ministry of Agriculture and Fisheries,* Gisborne.

Harmsworth, G.R., Young, R.G., Walker, D., Clapcott, J.E., James, T. (2011) Linkages between cultural and scientific indicators of river and stream health*. New Zealand Journal of Marine and Freshwater Research,* 45(3): 423-436.

Harris, W., Heenan, P. (1992) Domestication of the New Zealand flora - an alternative view. *New Zealand Journal of Crop and Horticultural Science,* 20: 257-271.

Harris, M., Wills, B. (2005) Poplar fodder trial. *New Zealand Tree Grower*, February 2005.

Hauk, S., Wittkopf, S., Knoke, T. (2014)Analysis of commercial short rotation coppices in Bavaria, Southern Germany. B*iomass and Bioenergy*, Volume 67: 401-412.

Hawke's Bay Regional Council (1996) Conservation Trees – Fodder willows for Hawke's Bay. *Environment Topics : Land Management, Info brochure June 1996*, published by Hawke's Bay Regional Council.

Hefting, M.M., Bobbink, R., de Caluwe, H. (2003) Nitrous Oxide Emission and Denitrification in Chronically Nitrate-Loaded Riparian Buffer Zones. *Journal of Environmental Quality*, 32: 1194–1203.

Hejcmanová, P., Stejskalová, M., Hejcman, M. (2014) Forage quality of leaf-fodder from the main broad-leaved woody species and its possible consequences for the Holocene development of forest vegetation in Central Europe. *Vegetation History and Archaeobotany*, Volume 23, Issue 5: 607–613.

Hickford, M.J.H., Schiel, D.R. (2011) Synergistic Interactions within Disturbed Habitats between Temperature, Relative Humidity and UVB Radiation on Egg Survival in a Diadromous Fish. *PLoS One* 6, e24318.

Hobbie, S.E. (1992) Effects of plant species on nutrient cycling. *Trends in Ecology & Evolution*, 7(10): 336-339.

Jones, T., McIvor, I. (2013) Willows and poplars for drought mitigation. *New Zealand Tree Grower*.

Karssies, L., Prosser, I. (1999) Guidelines for riparian filter strips for Queensland irrigators. *Technical Report,* 32/99, CSIRO Land and Water, Canberra.

Karssies, L., Prosser, I.P. (1999) Sediment storage capacity of grass buffer strips. *Proceedings of the second Australian Stream Management Conference: The challenge of rehabilitating Australia's streams*, Adelaide, Cooperative Research Centre for Catchment Hydrology.

Kemp, P., Mackay, A., Matheson, L., Timmins, M. (2001) The forage value of poplars and willows. *Proceedings of the New Zealand Grassland Association*, 63: 115–119.

Kemp, P., Barry, T., Douglas, G. (2003) Edible forage yield and nutritive value of poplar and willow. *Grassland Research and Practice Series*, No 10: 53-63.

Keniger, L., Gaston, K., Irvine, K., Fuller, R. (2013) What are the benefits of Interacting with nature? *International Journal of Environmental Research and Public Health*, 10: 913–935.

Kennen, K., Kirkwood, N. (2015) Principles and resources for site remediation and landscape design. *Phyto.*: Figure 3.1: 63. Routledge.

Kerckhoffs, H., Trolove, S., Heubeck, S., Renquist, R. (2014) Methane production from biofuel crops grown in New Zealand. *Agronomy New Zealand*, 44: 49–60.

Kirchgeßner, M. (1997) Tierernährung: Leitfaden für Studium, Beratung und Praxis. Edition 10, DLG Verlag: 582.

Krejcek, S. (2009) Riparian management in Taranaki – a success for native biodiversity? *Honours thesis.* Carl von Ossietzky University Oldenburg Department of Biology and Environmental Sciences.

Lambert, M.G., Jung, G.A., Harpster H.W., Lee, J. (1989) Forage shrubs in North Island hill country – 4. Chemical composition and conclusions". *New Zealand Journal of Agricultural Research*, Vol. 32: 499-506.

Lambert, M.G., Jung, G.A., Costall, D.A. (1989) Forage shrubs in North Island hill country – 1. Forage production. *New Zealand Journal of Agricultural Research*, Vol. 32: 477-483.

Leong, A., Herst, P., Harper, J. (2011) Indigenous New Zealand honeys exhibit multiple anti-inflammatory activities. *Innate Immunity*, 18(3): 459–466.

Luo, J., Longhurst, B., Ledgard, S., Woodward, B., Saggar, S., Van der Weerden, T., Lindsey, S., Zonderland-Thomassen, M., Olubode-Awosola, F., Turner, J., Boyes, M., Pinares, C. (2013) Review of greenhouse gas emissions from housing/stand-off pad systems. *MPI Technical Paper*, No: 2013/XX, prepared by AgResearch Ltd for the Ministry for Primary Industries, Wellington, New Zealand.

Luske, B., van Eekeren, N., Vonk, M., Altinalmazis-Kondylis, A., Roelen, S. (2017) Agroforestry for ruminants in the Netherlands - Lessons learned from innovations related to agroforestry for livestock. *Research report of the AGFORWARD program* (Grant Agreement N° 613520), prepared for the European Commission.

Marden, M., Lambie, S., Phillips, C. (2018) Biomass and root attributes of eight of New Zealand's most common indigenous evergreen conifer and broadleaved forest species during the first 5 years of establishment. *New Zealand Journal of Forestry Science*, 48(1): 9. https://doi.org/10.1186/s40490-018-0113-y

Mayer, P.M., Reynolds, S.K., McCutchen, M.D., Canfield, T.J. (2007) Meta-analysis of nitrogen removal in riparian buffers. *Journal of Environmental Quality*, 36(4): 1172-1180.

Maseyk, F.J., Dominati, E.J., White, T., Mackay, A.D. (2017) Farmer perspectives of the on-farm and off-farm pros and cons of planted multifunctional riparian margins. *Land Use Policy,* 61: 160–170.

Maseyk, F.J., Dominati, E.J., Mackay, A.D. (2018) Change in ecosystem service provision within a lowland dairy landscape under different riparian margin scenarios. *International Journal of Biodiversity Science, Ecosystem Services & Management*: 14(1): 17-31.

Matheson, F., Quinn, J., Haidekker, S., Madarasz-Smith, A., Wilding, T., Clapcott, J., Harding J., Wilcock, B., Young, R., Baker, M., Clode, G., Heath, N., Hicks, A., Rutherford, K. (2017) Ecosystem health in disturbed lowland catchments: Karamū catchment, Hawkes Bay. *NIWA Client Report for Ministry for Business, Innovation and Employment Envirolink Fund:* 50.

Mathews, J., Pepper, J. (1978) Steam treatment of Aspen poplar to increase digestibility for ruminants. *Can. J. Anim. Sci.,* 58: 521-523.

McCabe, S., Barry, T. (1988) Nutritive value of willow (Salix sp.) for sheep, goats and deer. J. *Agric. Sci.*, Cambridge, 111: 1-9.

McGruddy, E. (2006) Integrating New Zealand Flax into Land Management Systems. *Final report of the New Zealand sustainable farming fund project 03/153*, Sustainable Farming Fund, Wellington, New Zealand.

McIvor, I. (2013) Willows for the farm. *Willows No.1 Info brochure published by the New Zealand Poplar & Willow Research Trust,* Palmerston North, New Zealand.

McKergow, L.A., Matheson, F.E., Quinn, J.M. (2016) Riparian management: A restoration tool for New Zealand streams. *Ecological Management and Restoration*, 17: 218-1127.

McKergow, L.A., Taylor, A., Stace, C., Costley, K.J., Timpany, G.C., Paterson, J. (2008) Contour grass filter strips - hydrology and water quality. Carbon and nutrient management in agriculture. Addressing the hard questions. *Fertilizer and Lime Research Centre Workshop*, Palmerston North, 13-14 February 2008.

McWilliam, E., Barry, T., Lopez-Villalobos, N. (2005) Organic matter digestibility of poplar (Populus) and willow (Salix) forage trees and its in vitro prediction. *J. Sci. Food. Agric.*, 85: 1098–1104.

Mende Biotech Ltd (2019) Online company and product information, available on: www.totarol.com

Merfield, C. (2015) Miscanthus - a new tool for New Zealand Ag and Hort? *The FFC Bulletin*, Vol. 1. http://www.bhu.org.nz/future-farming-centre/information/bulletin/2015-v1/miscanthus-a-new-tool-for-nz-ag-and-hort.

Ministry for the Environment (2017) National Policy Statement for Freshwater Management 2014. Updated August 2017 to incorporate amendments from the National Policy Statement for Freshwater Amendment Order 2017.

Morgan, J.A., Martin, J.F., Bouchard, V. (2008) Identifying plant species with root associated bacteria that promote nitrification and denitrification in ecological treatment systems. *Wetlands*, 28(1): 220-231.

MPI (2015) Guide to the Permanent Forest Sink Initiative. *Ministry for Primary Industries,* Pastoral House, 25 The Terrace, PO Box 2526, Wellington.

Muir, A., Cole, A., Walker J. (1982) Antibiotic compounds from New Zealand plants. *Journal of Medicinal Plant Research*, Vol. 44: 129-133.

Naiman, R., Decamps, H., Pollock, M. (1993) The Role of Riparian Corridors in Maintaining Regional Biodiversity. *Ecological Applications*, 3(2): 209-212.

NEFD (2017) National Exotic Forest Description as of 1st of April 2017*. Published by the Ministry for Primary Industries*, Pastoral House, 25 The Terrace, PO Box 2526, Wellington 6140, New Zealand.

Newman, S. (1997) Poplar agroforestry in India. *Forest Ecology and Management,* 90: 13-17.

Novak, S., Liagre, F., Emile, J. (2016) Integrating agroforestry into an innovative mixed crop-dairy system 3. *European Agroforestry Conference (EURAF 2016)*, Montpellier, France. CIRAD Editions: 468.

New Zealand PCN (2005) New Zealand Plant Conservation Network web archive entry for Tawari. https://web.archive.org/web/20071215105517/http://www.nzpcn.org.nz/nz_threatenedplants/detail.asp?PlantID=1419

Noble, M., Duncan, P., Perry, D., Prosper, K., Rose, D., Schnierer, S., Tipa, G., Williams, E., Woods, R., Pittock, J. (2016) Culturally significant fisheries: keystones for management of freshwater social-ecological systems.

Olsen, P.F. (2016) Press release Manuka Establishment Basis https://nz.pfolsen.com/market-info-news/wood-matters/2016/april/manuka-establishment-basics/

Oppong, S., Kemp, P., Douglas, G., Foote, A. (2001) Browse yield and nutritive value of two Salix species and Dorycnium rectum in New Zealand. *Agroforestry Systems,* 51: 11–21. MME, contract 8001 -CT90-0030, for the European Commission.

Papanastasis, V., Tsiouvaras, C., Dini-Papanastasi, O., Vaitsis, T., Stringi, l., Ceret, C., Dupraz, C., Armand, D., Meuret, M., Olea, L. (1995) Selection and Utilization of Cultivated Fodder Trees and Shrubs in the Mediterranean Region. *Research report carried out within the CAMAR* EC*/DG.VI Progra.*

Parkyn, S., Shaw, W., Eades, P. (2000) Review of information on riparian buffer widths necessary to support sustainable vegetation and meet aquatic functions. *NIWA Client Report*: ARC00262, prepared for Auckland Regional Council Technical Publication, No. 350.

Parkyn, S. (2004) Review of Riparian Buffer Zone Effectiveness. *MAF Technical Paper,* No: 2004/05, Ministry of Agriculture and Forestry, Wellington, New Zealand.

Parkyn, S., Davies-Colley, R.J., Cooper, A.B., Stroud, M.J. (2005) Predictions of stream nutrient and sediment yield changes following restoration of forested riparian buffers*. Ecological Engineering*, 24: 551-558.

Parkyn, S.M., Meleason, M.A., Davies-Colley, R.J. (2009) Wood enhances crayfish (Paranephrops planifrons) habitat in a forested stream. *New Zealand Journal of Marine and Freshwater Research*, 43: 689–700.

Parminter, T. (2008) An examination of the use of a human behaviour model for natural resource policy design and implementation by government (central and regional) agencies. *PhD thesis,* The University of Waikato, Hamilton.

Phillips, C.J., Marden, M., Lambie, S.M. (2015) Observations of "coarse" root development in young trees of nine exotic species from a New Zealand plot trial*. New Zealand Journal of Forestry Science,* 45(1): 13.

Quinn, J. (2009) Riparian management classification reference manual. *NIWA Client Report* HAM2009-072: 57.

Quinn, J.M., Hickey, C.W. (1990) Characterisation and classification of benthic invertebrate communities in 88 New Zealand rivers in relation to environmental factors. *New Zealand Journal of Marine and Freshwater Research,* 24: 387–409.

Quinn, J.M., Brown, P.M., Boyce, W., Mackay, S., Taylor, A., Fenton, T. (2001) Riparian zone classification for management of stream water quality and ecosystem health. *JAWRA Journal of the American Water Resources Association*, 37(6): 1509-1515.

Quinn, J.M., Boothroyd, I.K., Smith, B.J. (2004) Riparian buffers mitigate effects of pine plantation logging on New Zealand streams: 2. Invertebrate Communities. *Forest Ecology and Management,* 191: 129–146.

Quinn, J.M., Wilcock, R.J., Monaghan, R.M., McDowell, R.W., Journeaux, P. (2009) Grassland farming and water quality in New Zealand. *Tearmann: Irish Journal of Agricultural-Environmental Research*, 7: 69-88.

Radcliffe, J. (1983) Fodder trees an option for dry hill country. *Proceedings of the 1983 Hill and High Country Seminar*, Centre for Resource Management, Lincoln College, 10-11 May 1983: 49-57.

Reeves, P., Meleason, M., Matheson, F. (2006) Sustainable riparian plantings in urban and rural landscapes. Page 1. *National Institute for Water and Atmosphere (NIWA).*

Reis, F. (2015) The response of manuka (Leptospermum scoparium) to homogeneous and heterogeneous distribution of biosolids in soil. *A Dissertation submitted in partial fulfilment of the requirements for the Degree of Bachelor of Science with Honours at Lincoln University*.

Rheinhardt, R.D., Brinson, M.M., Meyer, G.F., Miller, K.H. (2012) Carbon storage of headwater riparian zones in an agricultural landscape. *Carbon Balance and Management,* 7: 4.

Radio New Zealand (2012) While there's tea, there's hope. *Radio interview with Robert Evans of Purangi Estate*. Initial broadcast during “Country Life,” 20 April 2012 9:30. https://www.radionz.co.nz/national/programmes/countrylife/audio/2516437/while-there's-tea,-there's-hope

Robertson, J., Beacom, S., Shiels, R. (1971) Feeding Value of Poplar Silage in rations for Yearling Steers. *Can. J. Anim. Sci*., 51: 243-246.

Sabo, J.L., Sponseller, R., Dixon, M., Gade, K., Harms, T., Heffernan, J., Jani, A., Katz, G., Soykan, C., Watts, J., Welter, J. (2005) Riparian zones increase regional species richness by harbouring different, not more, species. *Ecology*, 86: 56–62.

Sánchez, M. (2000) Mulberry: an exceptional forage available almost worldwide! *Animal Production and Health Division*. FAO, Rome. http://www.fao.org/livestock/agap/frg/mulberry/Papers/HTML/Mulbwar2.htm

Saunders, I. (2017) The Mānuka & Kānuka Plantation Guide. *Info report compiled by Boffa Miskell Limited*, available online at: http://www.gw.govt.nz/assets/Manuka-plantation-guide-landcare-April2017.pdf

Schipper, L.A., Robertson, W.D., Gold, A.J., Jaynes, D.B., Cameron, S.C. (2010) Denitrifying bioreactors - An approach for reducing nitrate loads to receiving waters. *Ecological Engineering*, 36(11): 1532-1543.

Schweier, J., Becker, G. (2012) Harvesting of short rotation coppice – harvesting trials with a cut and storage system in Germany, *Silva Fennica*, 46(2): 287–299.

SDWA (2013) The Sustainable Dairying: Water Accord: A Commitment to New Zealand by the Dairy Sector. https://www.dairynz.co.nz/environment/in-your-region/sustainable-dairying-water-accord/

Simon, A., Collison, A.J. (2002) Quantifying the mechanical and hydrologic effects of riparian vegetation on streambank stability. *Earth Surface Processes and Landforms*, 27(5): 527-546.

Smith, C.M. (1989) Riparian pasture retirement effects on sediment, phosphorus, and nitrogen in channelised surface run-off from pastures*. New Zealand Journal of Marine and Freshwater Research*, 23: 139–146.

Snow, M.J., Manley-Harris, M. (2004) On the nature of non-peroxide antibacterial activity in New Zealand manuka honey. *Food Chemistry,* 84(1): 145-147.

Speldewinde, P., Cook, A., Davies, P., Weinstein, P. (2009) A relationship between environmental degradation and mental health in rural Western Australia. *Health & Place*, 15(3): 880–887.

Spinelli, R., Magagnotti, N., Picchi, G., Lombardini, C., Nati, C. (2011) Upsized Harvesting Technology for Coping with the New Trends in Short-Rotation Coppice. *Applied Engineering in Agriculture*, 27(4): 551-557.

Stantiall, J. (2008) Cost-benefit analysis of tree fodder. *New Zealand Tree Grower.*

Stephens, J. (2006) The factors responsible for the varying levels of UMF® in mānuka (Leptospermum scoparium) honey. *Unpublished Ph.D. thesis*, University of Waikato, Hamilton, New Zealand. URL: http:// www.umf.org.nz/wp-content/uploads/2013/10/Dr-Stephens-The-factors-responsible-for-UMF-in-Manukahoney.pdf

Sweeney, B.W., Newbold, J.D. (2014) Streamside Forest Buffer Width Needed to Protect Stream Water Quality, Habitat, and Organisms: A Literature Review. *Journal of the American Water Resources Association,* 50: 560-584.

SR 2008/355 (2008) Climate Change (Forestry Sector) Regulations 2008*. Order in Council at Wellington this 29th day of September 2008.* Published under the authority of the New Zealand Government. http://www.legislation.govt.nz/regulation/public/2008/0355/latest/DLM1633733.html

Talamucci, P., Pardini, A., Argenti, G. (2000) Effects of grazing animals and cutting on the production and intake of a mulberry-subterranean clover association" In: Mulberry for animal production. *Proceedings of an electronic conference carried out between May and August 2000,* Editor, M.D. Sanchez, Food and Agricultural Organisations of the UN, Rome, 2002: 223-229.

Taylor, K. (2016) A profitable passion for poplars. *Stuff newspaper article published 1st July 2016*. https://www.stuff.co.nz/business/farming/81654092/a-profitable-passion-for-poplars

Temel, S., Pehluvan, M. (2015) Evaluating orchard and poplar leaves during autumn as an alternative fodder source for livestock feeding. *Cien. Inv. Agr.,* 42(1): 27-33.

Thomas, M.B., Spurway, M.I. (2002) Kowhai (Sophora species) and other nitrogen-fixing plants of New Zealand. In: *The International Plant Propagators' Society Combined Proceedings*, Vol. 51, No. 2001: 94-97.

Tipa, G., Teirney, L.D. (2006) A cultural health index for streams and waterways: a tool for nationwide use: 1-58. Wellington: *Ministry for the Environment.*

Tullus, A., Mandre, M., Soo, T., Tullus, H. (2010) Relationships between cellulose, lignin and nutrients in the Stemwood of Hybrid Aspen in Estonian plantations. *Cellulose Chem. Technol*., 44(4-6): 101-109.

Van Kraayenoord, C., Slui, B., Knowles, F. (1995) Introduced forest trees in New Zealand, recognition, role, and seed source - The willows (*Salix spp.*), *FRI Bulletin (1995)* No. 124: 15–32, Water and Soil Division, Ministry of Works and Development, Aokautere, Palmerston North, New Zealand.

Vidon, P., Serchan, S. (2016) Landscape geomorphic characteristic impacts on greenhouse gas fluxes in exposed stream and riparian sediments. *Environmental Science: Processes & Impacts,* 18: 844.

Weston, R. (2004) Composition of Essential Oils from the Leaves of Seven New Zealand Species of Pittosporum (Pittosporaceae). *Journal of Essential Oil Research*, Vol. 16: 453-458.

Wilkinson, J., Cavanagh, H. (2005) Antibacterial Activity of 13 Honeys Against Escherichia coli and Pseudomonas aeruginosa. *Journal of Medicinal Food*, Vol. 8, Issue 1.

Williamson, R.B., Smith, R.K., Quinn, J.M. (1992) Effects of riparian grazing and channelization on streams in Southland, New Zealand. 1. Channel form and stability. *New Zealand Journal of Marine and Freshwater Research*, 26: 241–258.

Windley, H., Barron, M., Holland, E., Starrs, D., Ruscoe, W., Foley, W. (2016) Foliar Nutritional Quality Explains Patchy Browsing Damage Caused by an Invasive Mammal. *PLoS ONE*: 11(5): e0155216. doi:10.1371/journal.pone.0155216.

Woodford, K., Roberts, A., Manning., M. (2018) Dairy composting barns can improve productivity, enhance cow welfare and reduce environmental footprint: A synthesis of current knowledge and research needs. In: *Farm environmental planning – Science, policy and practice*. (Eds. L.D. Currie and C.L. Christensen). http:flrc.massey.ac.nz/publications.html. Occasional Report No. 31. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand: 6.

Zhang, X., Liu, X., Zhang, M., Dahlgren, R., Eitzel, M. (2010) A Review of Vegetated Buffers and a Meta-analysis of their Mitigation Efficacy in Reducing Nonpoint Source Pollution. *J. Environ. Qual.,* 39:76–84.

Appendix A Summary of plant species with potential uses in productive riparian buffers

Type of plant	Examples	Bank zones	Productive uses	Likely Environmental benefits	Likely Social/cultural benefits	Risks	Further information
Exotic trees - forage	Poplars and willows	2,3	Fodder, (timber, biofuel)	N, P Shading Erosion control (Sediment)	Aesthetic value	Avoid nitrogen fixers If not managed trees can overgrow Harvest can disturb PRB	http://www.poplarandwillow.org.nz/
Exotic trees - fruit	Avocado, Pear, Banana, Pecan, Mulberry	3	Fruit, fibre (timber, fuel)	N, P Shading Erosion control (Sediment)	Aesthetic value Community benefits (Local food)	May attract pests Pesticide use near water and natives needs to be managed	https://www.tropicalfruitgrowers.nz/ https://treecrops.org.nz/
Exotic trees - timber	Redwood, Walnut, Maple	2,3	Timber (Fodder)	N, P Shading Erosion control (Sediment)	Aesthetic value	Lots of maintenance required to produce quality product on PRB	http://www.nzffa.org.nz/ http://www.nzffa.org.nz/farm-forestry-model/why-farm-forestry/trees-for-riparian-plantings/
Exotic grasses	Diverse pastures, no legumes	3	Feed, silage	Sediment, N, P			https://www.landcareresearch.co.nz/publications/innovation-stories/2016-stories/discovering-prosperity-by-planting-diverse-pastures
Native trees - timber	Totara Rewarewa Kanuka	2,3	Timber (Honey, essential oils)	Biodiversity Erosion control (Sediment)	Aesthetic value	Lots of maintenance required to produce quality product on PRB	http://www.nzffa.org.nz/ https://www.tanestrees.org.nz/

Type of plant	Examples	Bank zones	Productive uses	Likely Environmental benefits	Likely Social/cultural benefits	Risks	Further information
Native trees – honey/oils	Manuka, Kanuka, various shrubs	1,2,3	Essential oils, (Rongoā Māori)	Biodiversity Sediment	Māori health and wellbeing, tourism, Rural industry development	High value products mostly have underdeveloped markets – long term vision needed	http://www.nzffa.org.nz/farm-forestry-model/why-farm-forestry/trees-for-erosion-controlsoil-conservation/report-trees-for-steep-slopes/tree-species/manuka/
Native trees and shrubs-fodder	Mahoe, five finger, Coprosma, Griselinia, NZ flax	1, 2,3	Fodder, (animal health)	Biodiversity Sediment, N,P		Very low growth rates lead to low nutrient removal and delays till stream shading	http://www.nzpcn.org.nz/
Native sedges, monocots	Flax, carex, raupo	1,2,3	Fibre, Rongoā Māori, (Fodder)	N,P, Biodiversity Sediment	Māori health and wellbeing, Rural industry development	Technical barriers to upscaling	http://www.nzpcn.org.nz/publications/Harakeke-Report06.pdf
Native species - medicinal	Kawakawa Manuka, Horopito	1,2	Rongoā Māori (food / fodder)	Biodiversity Sediment, N,P	Māori health and wellbeing, aesthetic value		https://maoriplantuse.landcareresearch.co.nz